1. Executive Summary

The United States Federal Government has a legal mandate for stewardship of basic research in nuclear physics, mainly through the Office of Science in the Department of Energy and through the National Science Foundation. It also has a clear interest in ensuring the Nation that all of its programs are effective and efficient. The Government Performance and Results Act of 1993 (GRPA) and *The President's Management Agenda*, dated Fiscal Year 2002 and issued by the Executive Office of the President, Office of Management and Budget (OMB), require the setting of goals for each program and the measurement of program performance against these goals to assess and monitor its effectiveness. This report is an assessment of the effectiveness of the nation's nuclear physics program by reviewing progress towards the goals and Milestones established in 2003.

These goals, described in a report which can be found on the Office of Science website at http://www.sc.doe.gov/np/nsac/docs/nsac_report_performance_measures.pdf, include detailed Performance Measures in the four major subject areas of Nuclear Physics and some 41 Milestones that address specific areas of the overall program. These goals and Milestones were recommended by NSAC in 2003, following their development by the 2003 Subcommittee on Performance Measures. Assessments of progress towards meeting the goals established by this report were to be made every five years. NSAC was subsequently charged July 17, 2006, as part of a broader charge to produce a new Long Range Plan, to review progress towards the above Performance Measures. This Subcommittee was established for that purpose.

The Performance Measures were developed to gauge performance by the field in addressing opportunities and open questions in the major areas of nuclear physics. They were developed in the context of the then-existing state of knowledge, the state of the art in theoretical and experimental practice, and existing facilities. The measures took into account those facilities under preparation or planned for implementation within the 12-year time window considered. The Performance Measures represent attainment of new knowledge, advances in understanding or interpretation of existing data and theory, and realization of new capabilities for the field. Risk is implied in their very definition. Definite efforts must be made; appropriate experiments must be conceived, designed, executed and analyzed. Results must be interpreted in the context of existing theory and the theoretical framework must itself be extended via new concepts, models, and mathematical and/or numerical tools. Additional risk is inherent from the uncertainties of funding support for this research. The original Milestones and Performance Measures were developed in the context of the funding levels anticipated at the time of the 2002 NSAC Long Range Plan. However, funding for the program must be managed by the agencies in the context of actual Congressional appropriations, which have been less than levels anticipated in 2002. Therefore not all goals will be possible due to the constraints arising from the enacted levels of funding.

We started with a detailed evaluation of work done in the specific areas of the Milestones, since each of these can be tied to specific experiments, theoretical efforts, and publications. We then used the results of this evaluation to analyze progress towards the more broadly defined

Performance Measures and to establish an overall grade for progress on each Measure. Each of the 41 Milestones set forth by the 2003 subcommittee were reviewed to identify documented achievements, key work still in progress, and any issues that have developed since 2003, with particular attention to referencing work published in the peer-reviewed scientific literature. We established a grading scale for evaluation of progress towards the broad Performance Measures and another for the more specific Milestones.

This report is the first examination of the original set of Milestones, whose due dates range from 2005 to 2014. It was expected, and indeed found, that most are still works in progress, but a number of them are complete. Where appropriate, we propose revised Milestones and the reasons for them, in some cases changing the scientific focus and in others changing only the date. A number of new Milestones are recommended to reflect progress made and knowledge gained as well as new opportunities that have arisen. Many of these are taken from the 2007 Long Range Plan. Due dates for these new and revised Milestones are proposed. We extend these in some cases to 2020 to reflect the expected timeline for realizing new opportunities and bringing online new facilities described in the 2007 Long Range Plan. The very fact that new Milestones make sense reflects positively on the health and dynamic nature of the field. Details of the Milestone evaluations are given in Appendices 3-9.

We then analyzed progress towards the Performance Measures themselves using the Milestone analysis as key input. A second grading scale was established for this evaluation; it is described in Section 5. Given the dynamic nature of scientific research, new opportunities have arisen that expand the reach of the program supported by DOE SC Nuclear Physics. These are to a significant extent captured in the new and revised Milestones as noted above, but in a few cases warranted revisions to the broader Performance Measures themselves.

Each of the Performance Measures for Nuclear Physics that were set down by the 2003 NSAC Subcommittee on Performance Measures has a completion date of 2015. Not surprisingly, only a fraction of the research that must be carried out to achieve these Performance Measures fully has been completed. Therefore, we took our main task to be the evaluation of progress toward the achievement of the Performance Measures, using the expectations and Milestones established by the 2003 Subcommittee report as the yardstick.

The Performance Measures were laid out in such a way that sustained high effort would be required to achieve them by 2015. Both the goals and pace for achieving them were meant to be demanding. This effort has many aspects, including: focused research addressing specific experimental and theoretical questions, thoughtful deployment of resources, sustained research funding support, a planned program of investments in new capabilities, and pursuit of new scientific opportunities revealed by ongoing research. The assumption of a constant level of effort that formed the basis for the 2002 NSAC Long Range Plan was used by the 2003 Subcommittee to establish the goals, the Milestones, and the timeline for achieving them. In view of the actual budgets in the intervening period, it would be truly remarkable if we were to have achieved excellent progress. Indeed, delays in progress toward a number of the Milestones are directly attributable to the reduced levels of funding actually received.

We determine that progress towards accomplishing the goals in the Performance Measure for Hadronic Physics is Good, meaning that if support of activities underway can be maintained at FY07 levels or better, these activities could reach their planned conclusions to the Good level by 2015. However, the timescale will be a challenge, and the sub-field is not likely to accomplish the goals under the Performance Measure to the Excellent level. The Good rating must be understood in the context of the actual funding levels over the period being evaluated (2003-2007). If expectations for progress are recalibrated to what would have been reasonable with the actual level of funding received (rather than the constant effort budget that was the basis for the expectations), then the timescale for the Performance Measures and Milestones would have been stretched, and the progress achieved would have been evaluated as Excellent, rather than Good. Sustained funding and effort at recent (FY07) levels should allow the rating of Good progress to be preserved through 2015.

We determine that progress towards accomplishing the goals in the Performance Measure for Physics of High Temperature and High Density Hadronic Matter is Excellent, with significant additional, related research on the topic completed. This research has led to the conclusion that a true surprise has been found: a new type of strongly-coupled matter with a ratio of viscosity to entropy density lower than any heretofore known. Attempts to understand this property have led to completely unanticipated connections to theories of quantum gravity and to a postulated fundamental quantum limit on the ratio of viscosity to entropy density. Progress in this field has benefited from operation of RHIC, the first ever heavy-ion collider, which has the advantage of exploring a completely new area with the attendant possibility of unexpected new behavior, which was indeed found. Despite these accomplishments, recent funding has meant markedly reduced RHIC running time in the past three years. The result is that data needed to achieve upcoming Milestones are only partly in hand and that only preliminary studies have been carried out preparatory to taking data needed for later Milestones. The result is that several near-term deadlines are in jeopardy, and future progress towards the Performance Measures may only be possible at the Good level.

We determine that progress towards accomplishing the goals in the Performance Measure for Nuclear Structure and Astrophysics is Good or somewhat better. We note that sustained Good or better progress in this area does require access to new beams and improved beam intensities, because much of the pressing new subject matter involves studies of nuclei located well away from the valley of stability and, ultimately, reaching nuclei at the limits of particle stability. Sustained funding and effort at present levels should allow the rating of Good progress to be preserved when a final evaluation in the target year of 2015 is performed, with an Excellent rating remaining a strong possibility.

We determine that progress towards accomplishing the goals in the Performance Measure for Neutrinos, Neutrino Astrophysics and Fundamental Interactions is Good. In contrast to the situation for the three other major subfields, progress here towards the Performance Measures has been uneven, with significantly more progress in some areas than others. This area of Nuclear Physics depends on purpose-built experiments more so than other areas, with a potential large payoff on focused questions. Much of the physics depends on weak interactions with their associated quite small probabilities and attendant need for large-volume detectors and/or very long experiment durations. This means that the pace of capital investment more directly affects whether a given area can make progress. In this area targeted new support, as described in the 2007 Long Range Plan, will enable Good (or better) progress in the future on the Performance Measures for this subfield that have lagged.

We stress that sustained funding is key to being able to pursue the range of activities yet to be accomplished in the specific Milestone areas. If funding can be increased to the growth path of the ACI and America COMPETES act (the scenario that provided the planning basis for the 2007 NSAC Long Range Plan), and sustained as envisioned therein, then one could reasonably expect that an Excellent rating by 2015 is possible for most Performance Measures. We remain concerned that continued stringencies in funding will in particular lead in particular to reduced operation of experimental and computational facilities, making the achievement of Good performance by 2015 difficult; it simply would not be possible to do the work in time if the funding patterns of the past 5 years are continued. The potential for loss to the field from missed scientific opportunities is significant.

In the areas of Performance Measures for Hadronic Physics and for Nuclear Structure and Astrophysics, we find that the current Performance Measures still serve to capture the present and near future focus of these efforts. For High Temperature and High Density Hadronic Matter a new research direction stems from the discovery that a strongly-coupled fluid with a remarkably low ratio of viscosity to entropy density is formed in relativistic heavy-ion collisions at RHIC. Understanding this has led to conjectured links to theories of gravity, a remarkable deduction if proven. The new scope of the needed experimental and theoretical work can be captured by one added Performance Measure, which addresses the low shear viscosity of this fluid. For Neutrinos, Neutrino Astrophysics and Fundamental Interactions major new opportunities have developed since the last report on Performance Measures to NSAC. We propose to return the setting of improved limits on the neutron EDM to the Performance Measure set now that a definite plan for that effort is established (thus addressing a specific concern of the previous report). We further propose two new Performance Measures in this area to capture the effort on precision electroweak measurements by the field.

The revised Performance Measures and the updated table of Milestones should again be reviewed at an appropriate interval, for example five years hence. This future evaluation will be in a different situation: inasmuch as this was the first evaluation against a new set of Performance Measures and Milestones, the next review will need to evaluate progress against a set of Performance Measures whose due dates will be arriving soon. It would be appropriate then to establish a new set of Performance Measures, building on the current set, to encapsulate what will undoubtedly be a new set of program goals that reflect progress to date and new opportunities yet to be defined. We would expect this next review to propose modified Performance Measures and associated Milestones. Their execution will then depend on facilities that will be by the time of this next review being readied for operation, but are at the present time in early project stages. The FRIB recommended in the 2007 Long Range Plan with completion late in the next decade, and the 12 GeV Upgrade of CEBAF at Jefferson Lab (now approaching CD-3), are examples. These several steps will ensure that the Performance Measures remain fresh and continue to set demanding goals.

In a step toward this evolution we have proposed several new Milestones, with due dates out to 2020. They capture current concrete plans and anticipate in part the expected change in focus of those future Performance Measures. We would expect the next evaluation also to reflect progress towards the plan set forth in the 2007 Long Range Plan, which is the most recent in a series which have served Nuclear Physics well these past 30 years.

2. Introduction

The United States Federal Government has a legal mandate for stewardship of basic research in nuclear physics, mainly through the Office of Science in the Department of Energy and through the National Science Foundation. It also has a clear interest in ensuring the Nation that all of its programs are effective and efficient. The Government Performance and Results Act of 1993 (GRPA) and *The President's Management Agenda,* dated Fiscal Year 2002 and issued by the Executive Office of the President, Office of Management and Budget (OMB), require the setting of goals for each program and the measurement of program performance against these goals to assess and monitor its effectiveness. This report is an assessment of the effectiveness of the nation's nuclear physics program by reviewing progress toward the goals and Milestones established in 2003.

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On September 13, 2003, the Nuclear Science Advisory Committee (NSAC) was charged by the Department of Energy (DOE) and the National Science Foundation (NSF) to recommend Performance Measures for the Nuclear Physics program to the DOE Office of Science. OMB guidance and proposed Nuclear Physics Performance Measures were provided to NSAC. OMB also requested appropriate Milestones that could be used to judge the quality of the progress that had been made towards the Performance Measures. NSAC was requested to submit a report on the appropriateness of the proposed measures, herein referred to as "Performance Measures", to comment on whether the Performance Measures were suitably ambitious and encompassed the DOE Nuclear Physics program, and to make recommendations for appropriate Milestones for each of the Performance Measures.

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A subcommittee was formed to report on this activity and it returned its report on November 18, 2003 to NSAC, which accepted it and transmitted it to the DOE and NSF. This report, which can be found on the Office of Science website at http://www.sc.doe.gov/np/nsac/docs/nsac_report_performance_measures.pdf, established more detailed Performance Measures in four major subject areas of Nuclear Physics, and some 41 Milestones were set down as a means of judging quality of progress by examining quite specific areas of the overall program. The 2003 Report forms the starting point for this report. The process for periodic assessment of progress in the Nuclear Physics program towards these goals was identified as part of the 2003 charge to NSAC in 2003; assessments of progress towards meeting the goals established by that report were to be made every five years. NSAC was subsequently charged July 17, 2006, as part of a broader charge to produce a new Long Range Plan, to review progress towards the above Performance Measures. The specific paragraph from that charge letter reads:

"Activities across the federal government are being evaluated against established performance goals. In FY2003, utilizing input from NSAC, the long-term goals for the DOE SC Nuclear Physics program and the metrics for evaluations of the program activities were established. It is timely during this long range planning exercise to gauge the progress towards these goals, and to recommend revised long-term goals and metrics for the DOE SC Nuclear Physics program, in the context of the new LRP, if appropriate, The findings and recommendations of this evaluation should be a separate report."

The current subcommittee was given this charge; the charge letter and subcommittee membership are given in Appendices 1 and 2. At the time we began our work, a revised version of the Performance Measures had been submitted by DOE SC Nuclear Physics that left the basic Performance Measures intact but changed the scoring from the original two-level scheme established by OMB in 2003 to a more nuanced four-level scoring scheme.

The methodology used to carry out the evaluation is detailed in Section 3 below. The four Performance Measures, together with the recently modified assessment scoring scheme and the reasoning underlying their choice by the 2003 Subcommittee, are given in the Section 4. Much of our task was to assess progress towards these Measures using an analysis of work done in the specific areas covered by the Milestones associated with each of the Performance Measures. The methodology used to carry out that assessment is presented in Section 5. The Milestone results are summarized in our evaluation of the Performance Measures in Section 6. This Milestone summary is also given in Appendix 3, before a description of new and continuing Milestones in Appendix 4 and the detailed Milestone evaluations in Appendices 5-9. Our analysis determines that these Performance Measures do still capture essential elements of the program, but that new opportunities noted in the recently-completed 2007 Long Range Plan coupled with scientific progress since 2003 require that these Milestones be supplemented with over a dozen new ones to capture the full breadth of the program, and that four additions be made to the broader Performance Measures themselves to reflect evolving program focus. The new Performance Measures are presented in Section 7 and a revised set of Milestones, including both new and continuing ones, that is appropriate for the next assessment is given in Appendix 4. We make some concluding remarks in Section 8.

3. Methodology

We started with a detailed evaluation of work done in the specific areas of the Milestones, since each of these can be tied to specific experiments, theoretical efforts, and publications. We then used the results of this evaluation to analyze progress towards the more broadly defined Performance Measures per se and establish an overall grade for progress on each Measure. Each of the 41 Milestones set forth by the 2003 subcommittee were reviewed to identify documented achievements, key work still in progress, and any issues that have developed since 2003, with particular attention to referencing work published in the peer-reviewed scientific literature. We established a grading scale for evaluation, which is given below in Section 5 on Milestones, and used it to evaluate progress for each Milestone. The detailed results of the Milestone evaluations are given in Appendix 3 in summary tables and Appendices 5-9 in detail. The summary together with the evaluations of progress towards the Performance Measures are given in Section 6. Milestone status was noted as complete or not.

This report is the first examination of the original set of Milestones, whose due dates range from 2005 to 2014. It was expected, and indeed found, that most are still works in progress, but a number of them are complete. Where appropriate, we propose revised Milestones and the reasons for them, in some cases changing the scientific focus and in others changing only the date. A number of new Milestones are recommended to reflect progress made and knowledge gained as well as new opportunities that have arisen. Many of these are taken from in the 2007 Long Range Plan. Due dates for these new and revised Milestones are proposed. We extend these in some cases to 2020 to reflect the expected timeline for realizing new opportunities and bringing online new facilities described in the 2007 Long Range Plan. The very fact that new Milestones make sense reflects positively on the health and dynamic nature of the field. The Milestone status and evaluation plus the revised list of Milestones including new and revised ones, are given in summary tabular form in Appendices 3 and 4. The detailed evaluations of individual Milestones and supporting references from the scientific literature are given in Appendices 5 through 9.

We then analyzed progress towards the Performance Measures themselves using the Milestone analysis as key input. Another grading scale was established for this evaluation, which is given in Section 5. Given the dynamic nature of scientific research, new opportunities have arisen which expand the reach of the program supported by DOE SC Nuclear Physics. These are to a significant extent captured in the new and revised Milestones as noted above, but in a few cases warranted revisions to the broader Performance Measures themselves. These proposed additions are given after the discussion and summary of progress towards the Measures in Section 7.

These evaluations and proposed new Milestones and Performance measures were discussed with representative members of the field. This resulted in valuable feedback on how well the state of the field was captured, on the feasibility of new Milestones and/or due dates, on the importance of capturing work in certain areas that have benefitted in recent years from investments made by DOE, both in DOE SC Nuclear Physics facilities as well as in , e.g., large-scale computing facilities. We have benefitted from this feedback in preparing this report.

Before proceeding to the evaluations, we comment on the funding of the field, in particular on the assumptions made in the 2002 and 2007 Long Range Plans and in the 2003 Performance Measures report. Unfortunately recent funding history differs significantly from those planning assumptions. We believe this approach is useful to provide context for some of the evaluations in the following. The 2002 LRP, which formed the basis for budget assumptions in the 2003 report on Performance Measures, was written under the assumption of a constant level of effort based on the FY03 appropriation, i.e., a budget that would follow inflation. The 12-GeV upgrade at TJNAF was to be pursued from the base program; the suggestion for a new facility for rare isotope beams was deemed to require an addition of funds outside this constant level of effort. The actual budget history of the field is (*** here are the numbers, FY03/04/05/06/07/08 is #,#,#,#,#,#, all given in FY08 dollars ***). There have been Omnibus Appropriations and budget rescissions in several years and a particular sharp reduction in funding, by 8.5% (???) in FY06. This has necessarily reduced operating time at all four accelerator-based user facilities operated by DOE SC Nuclear Physics, and at the National Superconducting Cyclotron Laboratory, operated by the NSF. It has also necessitated adjusting timelines if not the scope of new projects, and has meant that not all efforts foreseen in 2002-2003 could be undertaken on the timelines envisioned at that time.

The current FY08 funding supports operations at all accelerator-based user facilities, at levels well short of full utilization. It also supports a broad program of investments in new capabilities at current facilities: construction of both the 12-GeV upgrade at TJNAF and the injector upgrades at RHIC, and certain new efforts particularly in the area of neutrino science and fundamental interactions. The 2007 LRP was written with the assumption of the growth budgets foreseen in the American Competitiveness Initiative and the America COMPETES Act. This level of funding would provide for near full utilization of existing accelerator-based user facilities and further new initiatives, similar to the 12-GeV upgrade at TJNAF, a new capability in low-energy Nuclear Physics called the Facility for Rare Ion Beams (FRIB), a new suite of targeted experiments searching for anticipated physics beyond the Standard Model, and the RHIC-II upgrade. There are cases noted below where progress towards goals could have been improved with the benefit of more stable or predictable funding levels, and others where it is noted that the funding levels envisioned under COMPETES would be needed to reach an excellent level of performance.

4. Performance Measures

The Performance Measures listed later in this section were developed to gauge performance by the field in addressing opportunities and open questions in the major areas of nuclear physics. They were developed in the context of the then-existing state of knowledge, the state of the art in theoretical and experimental practice, and existing facilities. The measures took into account those facilities under preparation or planned for implementation within the 12-year time window considered. The Performance Measures represent attainment of new knowledge, advances in understanding or interpretation of existing data and theory, and realization of new capabilities for the field. Risk is implied in their very definition. Definite efforts must be made; appropriate experiments must be conceived, designed, executed and analyzed. Results must be interpreted in the context of existing theory and the theoretical framework must itself be extended via new concepts, models, and mathematical and/or numerical tools. Some risk is inherent to the probability of funding support; the agencies have managed to program in the context of Congressional appropriations, but not all goals may be possible due to the constraints arising from the enacted levels of funding.

The Performance Measures for DOE SC Nuclear Physics and proposed rating scale, as established by DOE, are given here. The Measures are organized into four groups corresponding to major program areas.

4.A Performance Measures for Hadronic Physics

- By 2015, make precision measurements of fundamental properties of the proton, neutron and simple nuclei for comparison with theoretical calculations to provide a quantitative understanding of their quark substructure.
    - What does this measure mean? - The broad goals of research in hadronic physics include linking the physics of nuclei to the fundamental theory of strong interactions, namely, Quantum Chromodynamics (QCD), understanding the structure of protons and neutrons that make up nuclei in terms of quarks and gluons because the latter are the fundamental ingredients of QCD, and understanding the structure of light nuclei both in terms of nucleons at low energy and in terms of quarks and gluons at high energy.
    - Why is this measure important? - These goals require probing nuclei and their constituents with electron and photon beams that are capable of high spatial resolution and high energy so as to be able to produce the excited mesonic and baryonic states of QCD. Form factors determine how the particles are distributed inside nucleons and light nuclei. Structure functions and generalized parton distributions, the latter being a new tool in the field, determine how the quarks and gluons are distributed in nucleons and how the spin of the proton is built up from the quarks and gluons. High-energy proton-proton collisions provide a complementary window into how the quarks and gluons build up the nucleons. Lattice QCD calculations are expected to provide the best theoretical means to compare experiments directly with QCD, however, a variety of theoretical tools are used to model and understand the observed phenomena. Ab initio many-body calculations based on two-nucleon interactions with the addition of modest three-nucleon interactions provide the best theoretical means to understand the low-energy aspects of the structure and interactions of nuclei. The Milestones for Hadronic Physics include representative examples of progress in each of these aspects without being inclusive of all relevant work.
    - Definition of “Excellent” – 1) Research leads to quark flavor dependence of nucleon form factors and structure functions being measured; 2) hadron states described with QCD over wide ranges of distance and energy; 3) two-body and three-body nucleon-nucleon interactions expressed in a QCD basis; 4) precision measurements of composition of nucleon spin performed.
    - Definition of “Good” – 1) Research leads to quark and gluon contributions to the nucleon’s spatial structure and spin being measured; 2) theoretical tools for hadron structure being developed and tested; 3) data show how simple nuclei can be described at a nucleon or quark-substructure level for different spatial resolution of the data.
    - Definition of “Fair” – Supported research leads to modest outputs in only two of the three goals described in the “Good” rating.
    - Definition of “Poor” – Supported research leads to modest outputs in only one of the three goals described in the “Good” rating.
    - How will progress be measured? – *Expert Review every five years will rate progress as “Excellent”, “Good”, “Fair” or “Poor”.*

4.B Performance Measures for High Temperature, High Density Hadronic Matter

- By 2015, recreate brief, tiny samples of hot, dense nuclear matter to search for the quark-gluon plasma and characterize its properties.
  - What does this measure mean? - The goal is to create for the first time in the laboratory hot (2×10^{12} K), dense (≥ 30 times normal nuclear density) matter that is predicted to have existed a few microseconds after the beginning of the Universe by colliding heavy nuclei at center of mass energies up to 200 GeV per nucleon pair. These studies will seek to establish properties of this new state (such as initial temperature, pressure, and entropy) and the time evolution of the collision process.
  - Why is this measure important? - These studies will measure collective phenomena (such as the flow of specific particles) and establish theoretically the dynamics of the process creating these phenomena. The study of penetrating probes such as fast quarks and gluons will provide information on the processes of color and energy transport. Perturbative QCD (pQCD) gives a description of such processes and together with experimental results will shed light on the nature of this strongly interacting matter. We seek to establish whether the temperatures are sufficiently high that the matter consists of weakly interacting quarks and gluons (deconfinement) rather than strongly interacting hadrons, to the extent that the strong color force is sufficiently screened so as to suppress production of bound states of charm and anti-charm quarks (known as the J/ψ family). This research will either verify or nullify the prediction by the Standard Model using QCD on the lattice that a deconfined state of matter, the quark-gluon plasma, exists at high temperatures and densities.
  - Definition of "Excellent" – 1) The existence of a deconfined, thermalized medium is determined; 2) its properties such as temperature history, equation of state, energy and color transport (via jets), and screening (via heavy quark production) are characterized.
  - Definition of "Good" – 1) The existence of hot, high-density matter is established; 2) some of its properties (e.g., its initial temperature via the photon spectrum) measured; 3) confinement properties, and energy transport (via jets) are explored.
  - Definition of "Fair" – Supported research leads to modest outputs in only two of the three goals described in the "Good" rating.
  - Definition of "Poor" – Supported research leads to modest outputs in only one of the three goals described in the "Good" rating.
  - How will progress be measured? – *Expert Review every five years will rate progress as "Excellent", "Good", "Fair" or "Poor".*

4.C Performance Measures for Nuclear Structure and Nuclear Astrophysics

- By 2015, investigate new regions of nuclear structure, study interactions in nuclear matter like those occurring in neutron stars, and determine the reactions that created the nuclei of atomic elements inside stars and supernovae.

- What does this measure mean? - Our understanding of nuclear structure is poised at a new threshold. Detailed studies of rare isotopes will dramatically expand our understanding of the nucleus and nuclear matter and will provide new insights into the nuclear forces by allowing study of particular nuclei and reactions that isolate and amplify specific nucleonic interactions.

  Nuclear processes play a central role in understanding the evolution of the stars, their violent explosions and the synthesis of the elements in these explosions. This chain of events produces the elements of life itself. A rich and multi-faceted research program in nuclear astrophysics is required to decipher the universe in which we live.

- Why is this measure important? - In the area of nuclear structure, we will study the limits of nuclear existence and the evolution of structure between these limits. An ultimate goal is a unified microscopic understanding of the nuclear many-body system in all its manifestations, as well as of the remarkable simplicities and collective behaviors that these nucleonic systems display. Complementary studies near stability and the quest to make the heaviest elements form a coherent long-term research program. To achieve these goals across the broad expanse of the nuclear landscape, the program carries out research at a number of smaller facilities, typically in short-term experiments (one to few weeks in nature), whose outcome influences follow-up studies. The character of this research makes it especially difficult for a few, short Milestones to broadly capture what is needed to achieve the performance measures. The Milestones represent important examples of the significant progress that will be made. The foci of this work are to identify the evolution of nuclear structure with mass and charge and improve theoretical models to gain a more complete understanding of the nucleus, and to explore nuclei at the limits of existence to establish their properties and test the models of nuclear structure and reactions in currently unmeasured regimes of nucleonic matter.

  In the area of nuclear astrophysics, we will study the physics of core collapse supernovae, hypernovae, and their connection with gamma-ray bursts. These are the most energetic explosions in our universe and factories for formation of a significant fraction of the elements. We will also study the properties of neutron star remnants left behind by these explosions, which serve as cosmic laboratories for high-density nuclear physics inaccessible in terrestrial experiments. We will investigate type Ia supernovae, the standard candles through which extraordinary facts about our universe and its fate have been illuminated. We will also investigate the evolution of stars and other cataclysmic stellar explosions including novae and X-ray bursts. A unifying theme for these focus areas is to precisely understand how a variety of microscopic nuclear physics phenomena come together to guide spectacular macroscopic phenomena such as the evolution and explosion of stars and their production of the elements.

- Definition of “Excellent” - 1) Extensive measurements on stable and exotic nuclei and the drip lines are performed; 2) their structure is established and the isospin dependence of effective interactions studied; 3) new nuclei with neutron skins are observed and studied; 4) reactions for several astrophysical processes, including some r-process nuclei, are measured.
- Definition of “Good” - 1) Properties of nuclei and reactions near and far from stability are measured allowing study of effective interactions, collective behavior, and structural evolution; 2) new weakly bound nuclei are observed and the limits of binding explored; 3) some reactions of stellar interest are measured.
- Definition of “Fair” – Supported research leads to modest outputs in only two of the three goals described in the “Good” rating.
- Definition of “Poor” – Supported research leads to modest outputs in only one of the three goals described in the “Good” rating.
- How will progress be measured? – *Expert Review every five years will rate progress as “Excellent”, “Good”, “Fair” or “Poor”.*

4.D Performance Measures for Neutrinos, Neutrino Astrophysics, and Fundamental Interactions

- By 2015, measure fundamental properties of neutrinos and fundamental symmetries by using neutrinos from the sun and nuclear reactors and by using radioactive decay measurements.
    - What does this measure mean? The goals of neutrino physics include a complete characterization of the properties of neutrinos and an improved understanding of solar neutrinos. Direct observation of charged- and neutral-current channels is essential to determine the solar neutrino flux of all active flavors. Precise determination of various components of this flux provides stringent limits on neutrino properties (masses and mixings) as well as the theory of the main-sequence stellar evolution. Direct neutrino mass measurements are sensitive to the absolute neutrino mass scale with few, if any, assumptions about neutrino properties.

      The goal of investigating fundamental interactions at low energies is to provide an independent window on new physics beyond our current understanding of the interactions of elementary particles. Precision measurements of the beta decays can give strong signatures of new physics beyond the Standard Model (e.g. supersymmetry).

    - Why is this measure important? Research in neutrino physics will address key issues in understanding the scale of the new physics beyond the Standard Model, provide potential insight into the origin of fermion masses, impact cosmology (hot dark matter, large scale structure formation and anisotropies of cosmic microwave background radiation) and astrophysics (core-collapse supernovae, r-process nucleosynthesis, and the origin of elements). Direct neutrino mass measurements, combined with observables from oscillation and neutrinoless double beta decay experiments, can potentially measure the CP-violating phases in the lepton sector and yield understanding of hierarchy and ordering of neutrino masses.

The neutrino mass scale that is inferred from the solar and atmospheric neutrino experiments implies the possibility of seeing neutrinoless double beta decay with experiments sensitive to masses of about 50 meV. Observation of the zero neutrino mode would establish the Majorana nature of neutrinos (i.e. that neutrinos are their own antiparticles) and may provide clues to the existence of the CP-violating phases.

When the next Galactic supernova occurs a significant number of neutrino events can be detected at neutrino observatories such as the SuperKamiokande, SNOLAB, or KamLAND experiments. Such a measurement will provide important clues to the astrophysics of supernovae as well as to neutrino properties.

In the area of fundamental interactions, the precise predictions of the standard model at the level of quarks and leptons take on additional, still poorly understood, aspects when the weak interactions between nucleons are considered. There is reason to expect that these aspects may be explained in the framework of a more complete theoretical treatment based on the symmetries of QCD.

The violation of CP (Charge-Conjugation times Parity) symmetry for elementary particles during the Big Bang is believed to be responsible for the apparent excess of matter compared to anti-matter that we observe in the universe. While new sources of CP violation are possible in the neutrino sector there could also be larger violations for nucleons due to new physics beyond the standard model. New precise searches for both the neutron and atomic electric dipole moment measurements (EDM) coupled with improvements in the theory could signal a new source of CP violation and better quantify the role of nucleon CP violation in understanding the matter-antimatter asymmetry.

Precise investigation of fundamental symmetries for the neutron can be performed with new sources of Cold and Ultra-Cold neutrons (Cold neutrons have wavelengths of 0.5 - 10 nm and Ultra-Cold neutrons have wavelengths > 50 nm). A cold neutron beamline for fundamental physics studies is under development at the Spallation Neutron Source (SNS), operated by Basic Energy Sciences in DOE. Additional funding (beyond constant effort) would likely be needed to develop and complete measurements of the neutron electric dipole moment with Ultra-Cold neutrons to improve the sensitivity by at least an order of magnitude.

- Definition of "Excellent" - 1) Double beta-decay lifetime limits are extended 10-fold or more; 2) R&D completed demonstrating if precision pp solar experiment is possible; 3) played key roles in low-energy neutrino experiments and beta-decay probing cosmologically interesting neutrino masses.

- Definition of "Good" - 1) Double beta-decay lifetime limits extended; 2) participated in low-energy neutrino experiments and beta-decay probing cosmologically relevant neutrino masses; 3) parameters for quark mixing for nuclear beta-decay quantified.
- Definition of "Fair" – Supported research leads to modest outputs in only two of the three goals described in the "Good" rating.
- Definition of "Poor" – Supported research leads to modest outputs in only one of the three goals described in the "Good" rating.
- How will progress be measured? – *Expert Review every three years will rate progress as "Excellent", "Good", "Fair" or "Poor".*

5. Performance Measure Evaluation Approach

Each of the Performance Measures for Nuclear Physics that were set down by the 2003 NSAC Subcommittee on Performance Measures has a completion date of 2015. Not surprisingly, only a fraction of the research that must be carried out to achieve these Performance Measures fully has been completed. Therefore, we took our main task to be the evaluation of progress toward the achievement of the Performance Measures, using the expectations and Milestones established by the 2003 Subcommittee report as the yardstick.

The Performance Measures were laid out in such a way that sustained high effort would be required to achieve them by 2015. Both the goals and pace for them were meant to be demanding. This effort has many aspects, including: focused research addressing specific experimental and theoretical questions, thoughtful deployment of resources, sustained research funding support, a planned program of investments in new capabilities, and pursuit of new scientific opportunities revealed by ongoing research. The assumption of a constant level of effort that formed the basis for the 2002 NSAC Long Range Plan was used by the 2003 Subcommittee to establish the goals, the Milestones, and the timeline for achieving them. In view of the actual budgets in the intervening period, it would be truly remarkable if we were to have achieved excellent progress. Indeed, delays in progress toward a number of the Milestones are directly attributable to the reduced levels of funding actually received.

Our overall evaluation of progress as defined by the Performance Measures was done using the grading scale defined here. The top grade is reserved to performance in that major area that goes beyond mere achievement of certain pre-defined goals and instead represents a qualitative advance in understanding of that area, the type of advancement that can point to new avenues of study:

Table 1: Performance Measure Grading Scale

Excellent: On track to achieve the Performance Measure fully, either earlier than anticipated or with additional, related research

on the topic completed, or with progress (and/or incremental studies planned that can be completed in time) such that we are confident that the issues will be regarded as definitively settled.
Good: On track to achieve Performance Measure as anticipated.
Fair: Achieving the Performance Measure to the "good" level on the timescale planned is at risk without an increased effort (Note: if the scientific results themselves rule out achieving a Milestone – e.g. new examples of X were not found because Nature does not have any, then we consider the Performance Measure 'achieved', assuming the experiments/calculations were done.)
Poor: Achieving the Performance Measure to the "good" level on the timescale planned is not likely without substantially increased effort.

The Performance Measures, as established, were foreseen to cover a dozen years, i.e., to 2015 and to address what could be accomplished in that time frame. In a sense therefore our report is a mid-term report card, noting what is accomplished, what is underway, what remains, and proposing a few mid-course corrections or added ports of call as science reveals nature and new opportunities are noted.

In order to provide a framework for evaluating progress toward the Performance Measures, the 2003 Subcommittee identified a series of Milestones (forty one in all) that are representative of broader efforts in the whole of Nuclear Physics. These Milestones each connect to one or more of the focus areas identified in the Performance Measures. It was anticipated in 2003 that seven of the forty one Milestones would have been completed by the start of 2008, and that substantial progress would have been made on the other thirty four. These Milestones permit connection to specific research projects, which can be expected to lead to published research results in the peer-reviewed literature and/or to completed specific projects.

Our evaluation of progress began with a detailed evaluation of the status of these Milestones (see Appendices 5-9). In cases where the Milestone date has passed, we asked if the results had been obtained on the timescale (and with the information content) anticipated. For Milestones due in the future, we evaluated actual progress against the anticipated progress that should have been made toward the Milestones. We also asked, in particular, if adequate progress has been made developing the tools, techniques, data, and/or calculations needed for the next steps. New Milestones and revised Milestones are proposed, in particular to capture new directions indicated by recent results and new opportunities for the field noted in the 2007 Long Range Plan.

In evaluating the individual Milestones, we used a grading system directly analogous to the one used for the Performance Measures. For Milestones whose due date had already passed, the grading scale was as follows:

Table 2: Milestone Grading Scale

Exceeded: the Milestone was fully achieved, either earlier than

anticipated or with additional, related research on the topic completed, and the issues are regarded as definitively settled.
Achieved: the Milestone was completed as anticipated.
Not Fully Achieved: the Milestone was not completed on the timescale planned, but significant progress was made. (Note: if the scientific results themselves rule out achieving a Milestone – e.g. new examples of X were not found because Nature does not have any, then we consider the Milestone as 'achieved', assuming the experiments/calculations were done.)
Unlikely: the Milestone was not completed on the timescale planned and is not likely to be achieved soon without substantially increased effort.

For Milestones that are not yet formally due, our evaluation focused on progress toward the Milestones. The grading scale used was:

Table 3: Milestone Grading Scale for Milestones not yet Due

Expect to Exceed: On track to achieve Milestone fully, either earlier than anticipated or with additional, related research on the topic completed, or with progress (and/or incremental studies planned that can be completed in time) such that we are confident that the issues will be regarded as definitively settled.
Expect to Achieve: On track to achieve Milestone as anticipated.
Expect to Not Achieve Fully: Achieving the Milestone on the timescale planned is at risk without an increased effort (Note: if the scientific results themselves rule out achieving a Milestone – e.g. new examples of X were not found because Nature does not have any, then we consider the Milestone as 'achieved', assuming the experiments/calculations were done.)
Unlikely: Achieving the Milestone on the timescale planned is not likely without substantially increased effort.

We note here that while no Milestone was rated Unlikely, some were rated Not Fully Achieved/Expect to Not Achieve Fully due to the actual rate of funding, arising in turn from limitations imposed from outside Nuclear Physics and indeed outside the Department of Energy and NSF.

Our evaluation of each of these Milestones was then mapped, or sorted onto the specific topics in the Performance Measures, both to evaluate the status of each Performance Measure as of today and to evaluate its expected status in 2015. Some of the Milestones map on to more than one

Performance Measure. Our evaluations were shared with knowledgeable members of the community active in the relevant sub-field, both to provide a peer review of our process and to solicit the thoughts of the larger community on both the overall health of the sub-field and on possible revisions and additions to the Milestones relevant for future activities.

A rough measure of the health and activity in each of the subfields represented by the Performance Measures can be obtained by averaging over the relevant Milestones and equating the grading scales for the Milestones and the Performance Measures in the order listed. A more thoughtful evaluation of each subfield, which included a review of progress in areas not explicitly identified in the (representative) Milestones, was also carried out; it yielded overall evaluations consistent with the averages over the Milestones.

In the next section, we present our evaluation of the Performance Measures for the four main areas of activity in Nuclear physics, as set down in the 2003 report. We identify the mapping of the Milestones to Performance Measures, and provide an evaluation of progress to date and prospects for further progress.

The status of the Milestones and our proposed revisions and additions, which take note of progress in the subfields, important developments, and new directions identified by the 2007 NSAC Long Range Plan, are then discussed. It is important to note that these new Milestones reflect the assumptions made in the 2007 Long Range Plan about targeted increases in funding. They also serve to reflect the health and dynamic aspects of the field; several new specific opportunities have presented themselves in the last five years. The new Milestones vary in due dates between 2015 and 2020.

In Section 7 we present an updated version of two of the four Performance Measures, those for High Temperature, High Density Hadronic Matter and those for Neutrinos, Neutrino Astrophysics and Fundamental Interactions. We found that in two of the sub-fields the present Performance Measures are still appropriate as summaries of their goals, and that new directions for the research effort are adequately captured within updated sets of Milestones. However, the level of change in the other two sub-fields is such that an updated overall Performance Measure is appropriate as well. The revised set of Performance Measures would be expected to be achieved after the current ones, with a reasonable due date being 2020.

6. Evaluation of the Performance Measures for Nuclear Physics

In this section we identify the mapping of the Milestones to Performance measures, provide an evaluation of progress to date and prospects for the future, and offer summary comments. (For compactness in quoting ratings assigned, we refer e.g. to both "Achieved" for past Milestones and "Expect to Achieve" for future ones as "Achieved".)

Deleted: present the Performance Measures for the four main areas of activity in Nuclear Physics, as set down in the 2003 report. We then

6.A Hadronic Physics

The Performance Measure for Hadronic Physics is stated in Section 4.A. The summary ratings for the associated Milestones are given here.

Table *: Milestone Progress in Hadronic Physics**

Year	Milestone	Complete?	Status Assessment
2008 HP1	Make measurements of spin carried by the glue in the proton with polarized proton-proton collisions at center of mass energy, $\sqrt{s_{NN}}$ = 200 GeV.	Yes	Achieved
2008 HP2	Extract accurate information on generalized parton distributions for parton momentum fractions, x, of 0.1 - 0.4 , and squared momentum change, –t, less than 0.5 GeV^2 in measurements of deeply virtual Compton scattering.	No	Not Fully Achieved
2009 HP3	Complete the combined analysis of available data on single π, η, and K photo-production of nucleon resonances and incorporate the analysis of two-pion final states into the coupled-channel analysis of resonances.	No	Expect to Not Achieve Fully
2010 HP4	Determine the four electromagnetic form factors of the nucleons to a momentum-transfer squared, Q^2, of 3.5 GeV^2 and separate the electroweak form factors into contributions from the u, d and s-quarks for $Q^2 < 1$ GeV^2 .	No	Expect to Exceed
2010 HP5	Characterize high-momentum components induced by correlations in the few-body nuclear wave functions via (e,e'N) and (e,e'NN) knock-out processes in nuclei and compare free proton and bound proton properties via measurement of polarization transfer in the $^4He(\vec{e},e\vec{p})$ reaction.	No	Expect to Achieve
2011 HP6	Measure the lowest moments of the unpolarized nucleon structure functions (both longitudinal and transverse) to 4 GeV^2 for the proton, and the neutron, and the deep inelastic scattering polarized structure functions $g_1(x,Q^2)$ and $g_2(x,Q^2)$ for x=0.2-0.6, and $1 < Q^2 <$ 5 GeV^2 for both protons and neutrons.	No	Expect to Exceed

Year	Milestone	Complete?	Status Assessment
2012 HP7	Measure the electromagnetic excitations of low-lying baryon states (<2 GeV) and their transition form factors over the range $Q^2 = 0.1 – 7\ GeV^2$ and measure the electro- and photo-production of final states with one and two pseudoscalar mesons.	No	Expect to Achieve
2013 HP8	Measure flavor-identified q and $\bar{q}$ contributions to the spin of the proton via the longitudinal-spin asymmetry of W production.	No	Expect to Achieve
2014 HP9	Perform lattice calculations in full QCD of nucleon form factors, low moments of nucleon structure functions and low moments of generalized parton distributions including flavor and spin dependence.	No	Expect to Exceed
2014 HP10	Carry out ab initio microscopic studies of the structure and dynamics of light nuclei based on two-nucleon and many-nucleon forces and lattice QCD calculations of hadron interaction mechanisms relevant to the origin of the nucleon-nucleon interaction.	No	Expect to Achieve

To evaluate progress toward this Performance Measure we began by mapping the four goals given in the Performance Measures' definition of Excellent performance in this area to the individual Milestones in Hadronic Physics as follows:

1. Quark flavor dependence of the nucleon form factors and structure functions measured; see Milestones HP2, HP4, HP8, HP9. No Milestone is yet past, nor is any yet complete. HP4 and HP9 were both rated as 'exceeding' the Milestone goals, with HP8 rated as 'achieved'.
2. Hadron states described with QCD over wide ranges of distance and energy; see Milestones HP5, HP6, HP7, HP10. No Milestone is yet past nor is any yet complete. HP6 was rated as 'exceeding' with the other three rated 'achieved'.
3. The nucleon-nucleon interaction mechanisms determined from QCD; see Milestones HP3, HP7, HP9, HP10. No Milestone is yet past nor is any yet complete. HP9 was rated 'exceeding' and HP7 and HP10 were rated as 'achieved'.
4. Precise measurements of quark and gluon contributions to nucleon spin performed; see Milestones HP1, HP8. No Milestone is yet past; HP1 is complete. Both Milestones were rated as 'achieved'.

We note that there have been no roadblocks uncovered to completing the work in any area, no focus areas that have been neglected, and no efforts that failed to produce scientific results. There have been some setbacks arising from budgets below what was anticipated in 2003 (notably in FY2006), and there have been some schedule delays due to external factors, such as Hurricane Isabel, which required rescheduling some planned experiments relevant to HP2, 5, and

6. In the two cases where ratings of 'not fully achieved' were given, only a delay in schedule for completion is foreseen; the anticipated scientific results should still be obtained, and indeed substantial progress has been made, with the required experiments either taking data or anticipating doing so in the immediate future, and the relevant theoretical efforts fully underway and publishing key results.

We determine that the progress towards accomplishing the goals in the Performance Measure for Hadronic Physics is Good, meaning that if support of activities underway can be maintained at FY07 levels or better, these activities could reach their planned conclusions to the Good level by 2015. However, the timescale will be a challenge, and the sub-field is not likely to accomplish the goals under the Performance Measure to the Excellent level. This rating is supported by a calculation of the average for the evaluations of the Milestones, which is somewhat better than Achieved, reflecting Good progress on a broad range of activities in Hadronic Physics. This summary was also found to be consistent with our overall evaluation of the progress in hadronic physics when other major efforts that are not specifically attached to Milestones are included. The details of the Milestone evaluation are presented in the section below.

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The Good rating must be understood in the context of the actual funding levels over the period being evaluated (2003-2007). If expectations for progress are recalibrated to what would have been reasonable with the actual level of funding received (rather than the constant effort budget that was the basis for the expectations), then the timescale for the Performance Measures and Milestones would have been stretched, and the progress achieved would have been evaluated as Excellent, rather than Good. Sustained funding and effort at recent (FY07) levels should allow the rating of Good progress to be preserved through 2015. Future surprises may lead to a re-evaluation, but none are yet apparent. We stress that sustained funding is key to being able to pursue the range of activities yet to be accomplished in the specific Milestone areas. If funding can be increased to the growth path of the ACI and America COMPETES act (the scenario that provided the planning basis for the 2007 NSAC Long Range Plan), then one could expect to achieve a rating of Excellent for this Performance Measure, including new Milestones proposed specifically for early experiments from the JLab 12 GeV Upgrade, by 2020. We remain concerned that continued stringencies in funding will in particular lead to reduced operation of experimental and computational facilities, making the achievement of Good performance by 2015 difficult and the achievement of Excellent performance by 2020 improbable: it simply would not be possible to do the work in time if the funding patterns of the past 5 years are continued. The potential for loss to the field from missed scientific opportunities is significant.

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6.B High Temperature and High Density Hadronic Matter

The Performance Measure for Physics of High Temperature and High Density Hadronic Matter is stated in Section 4.B. The summary ratings for the associated Milestones are given here.

Table *: Milestone Progress in High Temperature/High Density Hadronic Matter**

Year	Milestone	Complete?	Status Assessment
2005 DM1	Measure J/Ψ production in Au + Au at $\sqrt{s_{NN}}$ = 200 GeV.	Yes	Achieved
2005 DM2	Measure flow and spectra of multiply-strange baryons in Au + Au at $\sqrt{s_{NN}}$ = 200 GeV.	Yes	Exceeded
2007 DM3	Measure high transverse momentum jet systematics vs. $\sqrt{s_{NN}}$ up to 200 GeV and vs. system size up to Au + Au.	Yes	Exceeded
2009 DM4	Perform realistic three-dimensional numerical simulations to describe the medium and the conditions required by the collective flow measured at RHIC.	No	Expect to Achieve
2010 DM5	Measure the energy and system size dependence of J/Ψ production over the range of ions and energies available at RHIC.	No	Expect to Achieve
2010 DM6	Measure e^+e^- production in the mass range 500 ≤ m_{e+e-} ≤ 1000 MeV/c2 in $\sqrt{s_{NN}}$ = 200 GeV collisions.	No	Expect to Achieve
2010 DM7	Complete realistic calculations of jet production in a high density medium for comparison with experiment.	No	Expect to Achieve
2012 DM8	Determine gluon densities at low x in cold nuclei via p + Au or d + Au collisions.	No	Expect to Exceed

To evaluate progress toward this Performance Measure we began by mapping the goals given in the Performance Measures' definition of Excellent performance in this area to the individual Milestones in Physics of High Temperature and High Density Hadronic Matter as follows:

1. The existence of a deconfined, thermalized medium is determined; see Milestones DM1, DM2, DM4, DM5. Two Milestones are past; both are complete. DM2 was rated as 'exceeding' the Milestone goals, with DM1, DM4 and DM5 rated as 'achieved'.
2. Its properties such as temperature history, equation of state, energy and color transport (via jets), and screening (via heavy quark production) are characterized; see Milestones

DM3, DM6, DM7, DM8. We note the four proposed new Milestones, DM10, DM11, DM12 and DM13, also bear on this aspect of the evaluation. Results from these areas would have to be considered in a future evaluation of progress. One Milestone is past and is complete. DM3 and DM8 were rated as 'exceeding' with the other two rated 'achieved'.

We note that there have been no roadblocks uncovered to completing the work in any area, no focus areas that have been neglected, and there were no efforts that failed to produce scientific results. Indeed, there have been a few scientific discoveries, notably that the system produced is strongly and not weakly coupled as had been assumed for many years. This does not invalidate scientifically any existing Performance Measure, but does present new opportunities captured in the proposed new Milestones for this area. It may well pose a challenge to demonstrating the Performance Measure on deconfinement, but this is the sort of challenge that inspires scientists to new understanding.

We determine that the current progress towards accomplishing the goals in the Performance Measure for Physics of High Temperature and High Density Hadronic Matter is Excellent, with significant additional, related research on the topic completed. Indeed, as noted in the Milestone evaluations in Appendix 3, results extending the effort laid out in Milestones DM2 and DM3 have already been reported, and the theoretical effort for DM4 has led to the conclusion that a true surprise has been found, a new type of strongly-coupled matter with a ratio of viscosity to entropy density lower than any heretofore known. Attempts to understand this property have led to completely unanticipated connections to theories of quantum gravity and to a postulated fundamental quantum limit on the ratio of viscosity to entropy density. This unforeseen development implies that “viscosity” should be added as a particularly important property to be quantified. In the following we propose both a specific new Milestone as well as an extension of the “Excellent” Performance Measure for this subfield.

We remark that progress in this field has benefitted from operation of RHIC, the first ever heavy-ion collider, which has the advantage of exploring a completely new area with the attendant possibility of unexpected new behavior. Unanticipated behavior has indeed been found, despite the less than optimal facility utilization allowed by funding levels below those anticipated in the 2002 Long Range Plan.

The rating of Excellent is supported by a calculation of the average for the evaluations of the Milestones, which is midway between Achieved and Exceeded, reflecting progress between Good and Excellent on a broad range of activity in Physics of High Temperature and High Density Hadronic Matter. This summary was found to be consistent with our overall evaluation of the progress in high temperature and high density hadronic matter physics when other major efforts that are not specifically attached to Milestones are also included. The details of the Milestone evaluation are presented in the Appendix below.

The field is now in its eighth year meaning base questions are mature and more detailed ones are needed; this is reflected in the proposed new Milestones. However, despite these accomplishments, recent funding has meant markedly reduced RHIC running time in the past three years. The result is that data needed to achieve upcoming Milestones are only partly in hand and that only preliminary studies have been carried out preparatory to taking data needed for DM5. The experiments for DM6 will only be done next year, leaving little time for analysis. New investments for detection capability for DM8 are only now being made. The result is that several near-term deadlines are in jeopardy, and near-term progress towards the Performance Measures may only be possible at the Good level. Future surprises may lead to a re-evaluation, but none are yet apparent. We stress that sustained funding is key to being able to pursue the range of activities yet to be accomplished in the specific Milestone areas.

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6.C Nuclear Structure and Astrophysics

The Performance Measure for Nuclear Structure and Astrophysics is stated in Section 4.C. The summary ratings for the two sets of associated Milestones are given here.

Table *: Milestone Progress in Nuclear Structure**

Year	Milestone	Complete?	Status Assessment
2006 NS1	Measure changes in shell structure and collective modes as a function of neutron and proton number from the proton drip line to moderately neutron-rich nuclei.	Yes	Exceeded
2007 NS2	Measure properties of the heaviest elements above Z=100 to constrain and improve theoretical predictions for superheavy elements	Yes	Achieved
2009 NS3	Extend spectroscopic information to regions of crucial doubly magic nuclei such as Ni-78	No	Expect to Exceed
2009 NS4	Extend the determination of the neutron drip line up to Z of 11.	No	Expect to Achieve

2010 NS5	Complete initial measurements with the high resolving power tracking array, GRETINA, for sensitive studies of structural evolution and collective modes in nuclei (Modified due date proposed)	No	Expect to Not Achieve Fully
2013 NS6	Carry out microscopic calculations of medium mass nuclei with realistic interactions, develop a realistic nuclear energy density functional for heavy nuclei, and explore the description of many-body symmetries and collective modes, and their relationship to effective forces	No	Expect to Exceed

Table *: Milestone Progress in Nuclear Astrophysics**

Year	Milestone	Complete?	Status Assessment
2007 NA1	Measure transfer reactions on r-process nuclei near the N=50 and N=82 closed shells	Yes	Achieved
2009 NA2	Measure properties of and reactions on selected proton-rich nuclei in the rp-process to determine radionuclide production in novae and the light output and neutron star crust composition synthesized in X-ray bursts	Yes	Exceeded
2009 NA3	Perform three-dimensional studies of flame propagation in white dwarfs during Type Ia supernova	No	Expect to Exceed
2010 NA4	Reduce uncertainties of the most crucial stellar evolution nuclear reactions (e.g. 12C(α,γ)16-O) by a factor of two, and others (e.g. the MgAl cycle) to limits imposed by accelerators and detectors	No	Expect to Achieve

2011 NA5	Measure neutron capture reactions, including radioactive s-process branch-point nuclei, to constrain s-process isotopic abundances	No	Expect to Achieve
2012 NA6	Measure masses, lifetimes, spectroscopic strengths, and decay properties of selected neutron-rich nuclei in the supernova r-process, and reactions to predict radionuclide production in supernovae	No	Expect to Exceed
2013 NA7	Perform realistic multidimensional simulations of core collapse supernovae	No	Expect to Achieve
2013 NA8	Perform simulations of neutron star structure and evolution using benchmark microphysical calculations of the composition, equation of state, and bulk properties of dense matter	No	Expect to Achieve

To evaluate progress toward this Performance Measure we began by mapping the four goals given in the Performance Measures' definition of Excellent performance in this area to the individual Milestones in Nuclear Structure and Astrophysics as follows:

1. Extensive measurements on stable and exotic nuclei and the drip lines are performed; see Milestones NS1, NS2, NS3, NS4, NS5, NA1, NA2, NA5 and NA6. Four Milestones are past and all of these are complete. NS1, NS3, NA2 and NA6 were rated as 'exceeding' the Milestone goals, with NS2, NS4, NA1, and NA5 rated as 'achieved'. NS5 was rated as ‘not fully achieved’.
2. Their structure is established and the isospin dependence of effective interactions studied; see Milestones NS1, NS3, NS5, NS6, NA1 and NA6. Two Milestones are past and both are complete. NS1, NS3, NS6, and NA6 were rated as 'exceeding' with NA1 rated as 'achieved'.
3. New nuclei with neutron skins are observed and studied - Milestone NS4. This Milestone is not yet past and is not complete. Substantial progress towards realizing the Milestone has been made and NS4 was rated as ‘achieved’.
4. Reactions for several astrophysical processes, including some r-process nuclei, are measured; see Milestones NS3, NA1, NA2, NA4, NA5 and NA6. Two Milestones are past and both are complete. NS3, NA2, and NA6 were rated as ‘exceeded’, and the others were rated as 'achieved'.

There are three other Milestones listed in the original set, all under Nuclear Astrophysics, NA3, NA7 and NA8, which do not map simply to the four Performance Measures under Nuclear Structure and Astrophysics. These all deal with application of our knowledge of nuclear physics to describe the physics of exploding stars, specifically Type 1a supernovae (NA3, rated Expect to Exceed) and Type II core collapse supernovae (NA7, rated Expect to Achieve) , and the structure of neutron stars (NA8, rated Expect to Achieve). Work on these Milestones makes extensive use also of large-scale computing facilities provided elsewhere in the Department of Energy. Although not directly tied to specific Performance Measures here, we find them useful indicators of the overall health and progress of the field as well as indicators of the links between nuclear physics and astrophysics on the one hand and large-scale computing on the other.

We note that there have been no roadblocks uncovered to prevent completion of the work in any area, although experiments to meet the Milestone on determining the neutron drip line up to Z=11 (NS4) have shown that the drip line is farther from stability than previously anticipated, and the computational complexity of modeling supernovae in three dimensions may require additional time (NA7). There have been additional, unexpected setbacks arising from funding levels below what was anticipated in 2003, with the principal impact on the Milestones being for NS5. Indeed, the timeline associated with the funding profile for the relevant new hardware device, GRETINA, extends beyond what was anticipated in 2003 and the original completion date of 2010 is out of reach. In total, no focus areas have been neglected, and there were no efforts that failed to produce scientific results. Further progress on the Milestones and achievement of the performance measures will benefit from new and upgraded accelerator facilities, both inside and outside of the US that will provide access to key new rare isotopes. These new rare isotope capabilities in the US are the HRIBF high power target upgrade, the CARIBU project at ATLAS, and the reacceleration project at the NSCL. With these new capabilities and the progress achieved so far, we do not at this time advocate any change in this Performance Measure.

We determine that the current progress towards accomplishing the goals in the Performance Measure for Nuclear Structure and Astrophysics is Good or somewhat better. The rating of Good is supported by a calculation of the average for the evaluations of the Milestones, which is somewhat better than Achieved, reflecting Good progress on a broad range of activities in Nuclear Structure and Astrophysics. As was the case for the other subfields above, progress was hampered by funding lower that envisioned at the time the original Milestones and Performance Measures were written. This rating of Good was found to be consistent with our overall evaluation of the progress in Nuclear Structure and Astrophysics when other major efforts that are not specifically attached to Milestones are also included. The details of the Milestone evaluation are presented in the section below.

We note that sustained Good or better progress in this area does require access to new beams and improved beam intensities, because much of the pressing new subject matter involves studies of nuclei located well away from the valley of stability and requires progressing to the limits of particle stability. This is particularly the case for Milestone NA7 on the stellar r-process. The ‘exhaustive studies’ noted in the first Performance Measure in particular require examining a large range of different nuclei in order that patterns may be established to contrast with and challenge prevailing theoretical predictions. This in turn requires extensive experimentation at several different accelerator facilities and the sustained support for operations and new beam development this implies. Sustained funding and effort at present levels should allow the rating of Good progress to be preserved when a final evaluation in the target year of 2015 is performed, with an Excellent rating remaining a strong possibility. Future surprises may lead to a re-evaluation, but none are yet apparent. We stress that sustained adequate funding is key to being able to pursue the full range of activities yet to be accomplished in the specific Milestone areas.

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6.D Neutrinos, Neutrino Astrophysics and Fundamental Interactions

The Performance Measure for Neutrinos, Neutrino Astrophysics and Fundamental Interactions is staed in Section 4.D. The summary ratings for the associated Milestones are given here.

Table *: Milestone Progress in Neutrinos, Neutrino Astrophysics and Fundamental Interactions**

Year	Milestone	Complete?	Status Assessment
2007 FI1	Measure solar boron-8 neutrinos with neutral current detectors	Yes	Exceeded
2008 FI2	Collect first data in an experiment which has the potential to observe beryllium-7 solar neutrinos	Yes	Exceeded
2008 FI3	Initiate an experimental program at the SNS fundamental physics beam line	No	Expect to Achieve
2010 FI4	Make factor of 5 improvements in measurements of neutron and nuclear beta-decay to constrain physics beyond the standard model	No	Expect to Not Achieve Fully
2010 FI5	Make factor of 5 improvement in theoretical uncertainties for testing the Standard Model via low energy electroweak observables	No	Expect to Exceed
2011 FI6	Improve the sensitivity of the direct neutrino mass measurements to 0.35 eV	No	Expect to Achieve

2012 FI7	Extend the sensitivity of searches for neutrinoless double-beta decay in selected nuclei by a factor of ten in lifetime	No	Expect to Not Achieve Fully
2012 FI8	Perform independent measurements of parity violation in few-body systems to constrain the non-leptonic weak interaction	No	Expect to Achieve
2012 FI9	Obtain results from new high-sensitivity searches for atomic electric dipole moments	No	Expect to Achieve

To evaluate progress toward this Performance Measure we began by mapping the three goals given in the Performance Measures' definition of Excellent performance in this area to the individual Milestones in Neutrinos, Neutrino Astrophysics and Fundamental Interactions. The fourth goal is the third from the Performance Measures' definition of Good and is qualitatively different from those listed under Excellent, thus is included specifically in what follows:

1. Double beta-decay lifetime limits are extended 10-fold or more; see Milestone FI7. This Milestone is not yet past, nor is it complete. FI7 was rated 'Not Fully Achieved'. An experiment is in preparation and R&D has started, but the improved precision by the stated deadline is not likely.
2. R&D completed demonstrating if precision pp solar experiment is possible; Milestones FI1 and FI2 bear on the Measure, but not directly. R&D efforts are started for a variety of approaches as noted below, but the effort as yet lacks continuing support and an explicit plan.
3. Played key roles in low-energy neutrino experiments and beta-decay probing cosmologically interesting neutrino masses; see Milestone FI1, FI2 and FI6, with aspects of FI5. Two of these Milestones are past and both are complete. FI1,FI2 and FI5 were rated 'exceeding' and FI6 was rated as ' achieved'.
4. Parameters for quark mixing for nuclear beta-decay quantified; see Milestones FI3, FI4, FI5, and FI8. No Milestone is yet past, nor is any yet complete. FI5 was rated as 'exceeded', and FI3 and FI8 were rated as 'achieved'.

There have been some slower starts arising from budgets below what was anticipated in 2003, with the principal effect on Milestones being for FI7, since the requirements for a successful program in double-beta-decay are more demanding than what was anticipated in 2003. This required careful consideration by a joint HEPAP-NSAC sub-committee, the Neutrino Science Assessment Group (NuSAG), to determine the appropriate technical direction and investment goal for a program that could actually address the Performance Measure. In the case of the Performance Measure on R&D for a precision solar pp experiment, to date only institutional R&D efforts have been pursued on a variety of techniques, both for experiments based on neutral-current and charged-current neutrino interaction approaches. A formal program in this area was recommended by the APS Multi-Divisional Study on Neutrino Physics (*** needs proper reference and date ***). Actual funding levels for this area of Nuclear Physics have meant that to date, however, only R&D efforts using institutional funds could be pursued. The results of these initial R&D programs are promising, with the elapsed time required to reach the current state of the art suggesting that a focused program could indeed be carried out by the overall deadline of 2015 for the Performance Measure. Thus, we do not at this time advocate any change in this Performance Measure.

We determine that the current progress towards accomplishing the goals in the Performance Measure for Neutrinos, Neutrino Astrophysics and Fundamental Interactions is Good. This rating is supported by a calculation of the average for the evaluations of the Milestones, which is somewhat better than Achieved, reflecting Good progress on a broad range of activities in Neutrinos, Neutrino Astrophysics and Fundamental Interactions. This summary was found to be consistent with our overall evaluation of the progress in the fields of Neutrinos, Neutrino Astrophysics and Fundamental Interactions when other major efforts that are not specifically attached to Milestones are also included. The details of the Milestone evaluation are presented in the section below.

In contrast to the situation for the three other major subfields, progress here towards the Performance Measures has been uneven, with significantly more progress on the third and fourth Performance Measures compared to that on the first two. A new apparatus to enable efforts in the fourth area will come online soon, and initial construction in support of the first has begun. This area of Nuclear Physics depends on purpose-built experiments more so than other areas, with a potential large payoff on focused questions. Much of the physics depends on weak interactions with their associated quite small probabilities and attendant need for large-volume detectors and/or very long experiment durations. This means that the pace of capital investment more directly affects whether a given area can make progress. In this area targeted new support, as described in the 2007 Long Range Plan, will enable Good (or better) progress in the future on the first two Performance Measures. In the absence of focused new investment, real scientific opportunities with important discovery potential may be missed.

The first Performance Measure, on double-beta-decay, will be very challenging to meet in time, and the second, on R&D for a precision pp solar experiment, still requires a definite plan for its execution. An increased level of funding beyond immediate past levels should allow the progress rating of Good progress to be preserved when a final evaluation in the target year of 2015 is performed. Future surprises may lead to a re-evaluation, but none are yet apparent.

7. New Performance Measures

In the areas of Performance Measures for Hadronic Physics and for Nuclear Structure and Astrophysics, we find that the current Performance Measures still serve to capture the present and near future focus of these efforts.

For High Temperature and High Density Hadronic Matter a new research direction stems from the discovery that a strongly-coupled fluid with a remarkably low ratio of viscosity to entropy density is formed in relativistic heavy-ion collisions at RHIC. Understanding this has led to conjectured links to theories of gravity, a remarkable deduction if proven. The new scope of the needed experimental and theoretical work can be captured by one added Performance Measure, which addresses the low shear viscosity of this fluid. The revised set of Performance Measures for High Temperature, High Density Hadronic Matter is :

Recreate brief, tiny samples of hot, dense nuclear matter to search for the quark-gluon plasma and characterize its properties

- Timeframe – By 2015
- Expert Review every five years rates progress as "Excellent", "Good", Fair" or "Poor"
- <u>Excellent</u> - 1) The existence of a deconfined, thermalized medium is determined; 2) its properties such as temperature history, equation of state, energy and color transport (via jets), and screening (via heavy quark production) are characterized; 3) viscosity of this medium is determined.
- <u>Good</u> – 1) The existence of hot, high-density matter is established; 2) some of its properties (e.g., its initial temperature via the photon spectrum) are measured; 3) confinement properties, and energy transport (via jets) are explored and limits are placed on viscosity of the medium.
- <u>Fair</u> – Supported research leads to modest outputs in only two of the three goals described in the "Good" rating.
- <u>Poor</u> - Supported research leads to modest outputs in only one of the three goals described in the "Good" rating.

We note that the revised Measure, together with several new Milestones in this area proposed below, requires an intense source of high energy heavy-ion collisions at a luminosity as much as an order of magnitude greater than presently available at RHIC, as will be provided by the RHIC-II upgrade discussed in the 2007 Long Range Plan. We note here recent developments in stochastic cooling of bunched beams at RHIC make it highly likely the overall timescale for RHIC-II will be substantially shortened from that foreseen in the 2007 Long Range Plan, in time to meet the 2015 timeframe for the Performance Measure above.

For Neutrinos, Neutrino Astrophysics and Fundamental Interactions major new opportunities have developed since the last report on Performance Measures to NSAC. We propose to return the setting of improved limits on the neutron EDM to the Performance Measure set now that a definite plan for that effort is established (thus addressing a specific concern of the previous report). We further propose two new Performance Measures in this area to capture the effort on precision electroweak measurements by the field. These will now capture the scope of this subfield. The revised set of Performance Measures is given here.

- Measure fundamental properties of neutrinos and fundamental symmetries by using neutrinos from the sun and nuclear reactors and by using radioactive decay measurements
- Timeframe – By 2015
- Expert Review every five years rates progress as "Excellent", "Good", "Fair", or "Poor"
- Excellent – 1) Double beta-decay lifetime limits are extended 10-fold or more; 2) R&D completed demonstrating if a direct, precision measurement of the rate of solar p-p fusion is possible; 3) played key roles in low-energy neutrino experiments and beta-decay probing cosmologically interesting neutrino masses; 4) precision experiments probing electroweak model parameters are completed, for example in beta-decay correlations of the neutron, parity-violating electron scattering, and g-factor measurements of elementary particles; 5) limits improved a factor of ten for the electric dipole moment of the neutron.
- Good – 1) Double beta-decay lifetime limits extended; 2) participated in low-energy neutrino experiments and beta-decay probing cosmologically relevant neutrino masses; 3) parameters for quark mixing for nuclear beta-decay quantified and the limit on neutron electric dipole moment improved.
- Fair – Supported research leads to modest outputs in only two of the three goals described in the "Good" rating.
- Poor – Supported research leads to modest outputs in only one of the three goals described in the "Good" rating.

8. Closing Remarks

The Performance Measures progress evaluations and associated Milestone status assessments reported here show that the field of Nuclear Physics has sustained considerable progress over the past 5 years since the original Performance Measures and Milestones were set down. In addition numerous new opportunities have been identified. Pursuit of these new opportunities together with those addressed by the Milestones still in progress and with related research opportunities will ensure a healthy and dynamic field that exhibits continued good progress. We caution that this generally positive outlook must be tempered by concern about funding outlook. In a sense this is positive – many good ideas are competing for available funds. Yet sustained good or excellent progress requires sustained program support to perform the needed research. The program roadmap laid out in the 2007 Long Range Plan shows the potential for further broad advances on scientific questions.

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The revised Performance Measures and the updated table of Milestones should be reviewed again at an appropriate interval, about five years hence. This future evaluation will be in a different situation. This was the first evaluation against the initially formulated set of Performance Measures and Milestones, with the timescale for the reseach to be carried out and evaluated being twelve years. The next review will be evaluating progress against a set of Performance Measures whose due date will be only a few years away. It would seem appropriate to establish at that time a new set of Performance Measures, building on the current set, to encapsulate what will undoubtedly be a new set of program goals that reflect progress to date and new opportunities yet to be defined. We would expect this next review to propose modified Performance Measures and associated Milestones. Their execution will then depend on facilities

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that will be by the time of this next review being readied for operation, but are at the present time in early project stages. The FRIB recommended in the 2007 Long Range Plan with completion late in the next decade, and the 12 GeV Upgrade of CEBAF at Jefferson Lab (now approaching CD-3) are examples. These several steps will ensure that the Performance Measures remain fresh and continue to set demanding goals.

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To anticipate this situation we have proposed here several new Milestones, with due dates out to 2020. They capture current concrete plans and anticipate in part the expected change in focus of those future Performance Measures. We would expect the next evaluation also to reflect progress towards the plan set forth in the 2007 Long Range Plan, which is the most recent in a series which have served Nuclear Physics well these past 30 years.

Appendix 1: Subcommittee Charge

Appendix 2: Subcommittee Membership

Appendix 3: Milestone Evaluation Summary

We present here in tabular form our summary assessment of progress towards the Milestones for each of the five subject areas. Note that Nuclear Structure and Nuclear Astrophysics are kept separate for Milestones but were joined above in the Performance Measure. In evaluating the individual Milestones we used a grading system directly analogous to the one used for the Performance Measures, but focused on progress toward the Milestones, as most are not yet due. It is presented in Section 5 of this report. This summary is followed in Appendix 4 by a rationale for and list of proposed new Milestones to be added for each of the five areas, immediately followed with the proposed new table of Milestones for that area. These new tables, which include a mix of continuing and proposed new Milestones, would form the Milestones which would be evaluated at the next review.

Hadronic Physics Milestones Evaluation Summary

Our evaluation of the ten Milestones for Hadronic Physics is presented in detail in Appendix 5. The table below summarizes that evaluation.

Table *: Milestone Progress in Hadronic Physics**

Year	Milestone	Complete?	Status Assessment

Year	Milestone	Complete?	Status Assessment
2008 HP1	Make measurements of spin carried by the glue in the proton with polarized proton-proton collisions at center of mass energy, $\sqrt{s_{NN}}$ = 200 GeV.	Yes	Achieved
2008 HP2	Extract accurate information on generalized parton distributions for parton momentum fractions, x, of 0.1 - 0.4 , and squared momentum change, –t, less than 0.5 GeV^2 in measurements of deeply virtual Compton scattering.	No	Not Fully Achieved
2009 HP3	Complete the combined analysis of available data on single π, η, and K photo-production of nucleon resonances and incorporate the analysis of two-pion final states into the coupled-channel analysis of resonances.	No	Expect to Not Achieve Fully
2010 HP4	Determine the four electromagnetic form factors of the nucleons to a momentum-transfer squared, Q^2, of 3.5 GeV^2 and separate the electroweak form factors into contributions from the u, d and s-quarks for $Q^2 < 1$ GeV^2 .	No	Expect to Exceed
2010 HP5	Characterize high-momentum components induced by correlations in the few-body nuclear wave functions via (e,e'N) and (e,e'NN) knock-out processes in nuclei and compare free proton and bound proton properties via measurement of polarization transfer in the $^4He(\vec{e},e\vec{p})$ reaction.	No	Expect to Achieve
2011 HP6	Measure the lowest moments of the unpolarized nucleon structure functions (both longitudinal and transverse) to 4 GeV^2 for the proton, and the neutron, and the deep inelastic scattering polarized structure functions $g_1(x,Q^2)$ and $g_2(x,Q^2)$ for x=0.2-0.6, and $1 < Q^2 <$ 5 GeV^2 for both protons and neutrons.	No	Expect to Exceed
2012 HP7	Measure the electromagnetic excitations of low-lying baryon states (<2 GeV) and their transition form factors over the range Q^2 = 0.1 – 7 GeV^2 and measure the electro- and photo-production of final states with one and two pseudoscalar mesons.	No	Expect to Achieve

Year	Milestone	Complete?	Status Assessment
2013 HP8	Measure flavor-identified q and $\bar{q}$ contributions to the spin of the proton via the longitudinal-spin asymmetry of W production.	No	Expect to Achieve
2014 HP9	Perform lattice calculations in full QCD of nucleon form factors, low moments of nucleon structure functions and low moments of generalized parton distributions including flavor and spin dependence.	No	Expect to Exceed
2014 HP10	Carry out ab initio microscopic studies of the structure and dynamics of light nuclei based on two-nucleon and many-nucleon forces and lattice QCD calculations of hadron interaction mechanisms relevant to the origin of the nucleon-nucleon interaction.	No	Expect to Achieve

High Temperature/High Density Hadronic Matter Milestones Evaluation Summary

Our evaluation of the eight Milestones for High Temperature/High Density Hadronic Matter is presented in detail in Appendix 6. The table below summarizes that evaluation.

Table *: Milestone Progress in High Temperature/High Density Hadronic Matter**

Year	Milestone	Complete?	Status Assessment
2005 DM1	Measure J/Ψ production in Au + Au at $\sqrt{s_{NN}}$ = 200 GeV.	Yes	Achieved
2005 DM2	Measure flow and spectra of multiply-strange baryons in Au + Au at $\sqrt{s_{NN}}$ = 200 GeV.	Yes	Exceeded
2007 DM3	Measure high transverse momentum jet systematics vs. $\sqrt{s_{NN}}$ up to 200 GeV and vs. system size up to Au + Au.	Yes	Exceeded

2009 DM4	Perform realistic three-dimensional numerical simulations to describe the medium and the conditions required by the collective flow measured at RHIC.	No	Expect to Achieve
2010 DM5	Measure the energy and system size dependence of J/Ψ production over the range of ions and energies available at RHIC.	No	Expect to Achieve
2010 DM6	Measure e^+e^- production in the mass range $500 \leq m_{e+e-} \leq 1000$ MeV/c2 in $\sqrt{s_{NN}} = 200$ GeV collisions.	No	Expect to Achieve
2010 DM7	Complete realistic calculations of jet production in a high density medium for comparison with experiment.	No	Expect to Achieve
2012 DM8	Determine gluon densities at low x in cold nuclei via p + Au or d + Au collisions.	No	Expect to Exceed

Nuclear Structure Milestones Evaluation Summary

Our evaluation of the six Milestones for Nuclear Structure is presented in detail in Appendix 7. The table below summarizes that evaluation.

Table *: Milestone Progress in Nuclear Structure**

Year	Milestone	Complete?	Status Assessment
2006 NS1	Measure changes in shell structure and collective modes as a function of neutron and proton number from the proton drip line to moderately neutron-rich nuclei.	Yes	Exceeded

2007 NS2	Measure properties of the heaviest elements above Z=100 to constrain and improve theoretical predictions for superheavy elements	Yes	Achieved
2009 NS3	Extend spectroscopic information to regions of crucial doubly magic nuclei such as Ni-78	No	Expect to Exceed
2009 NS4	Extend the determination of the neutron drip line up to Z of 11.	No	Expect to Achieve
2010 NS5	Complete initial measurements with the high resolving power tracking array, GRETINA, for sensitive studies of structural evolution and collective modes in nuclei (Modified due date proposed)	No	Expect to Not Fully Achieve
2013 NS6	Carry out microscopic calculations of medium mass nuclei with realistic interactions, develop a realistic nuclear energy density functional for heavy nuclei, and explore the description of many-body symmetries and collective modes, and their relationship to effective forces	No	Expect to Exceed

Nuclear Astrophysics Milestones Evaluation Summary

Our evaluation of the eight Milestones for Nuclear Astrophysics is presented in detail in Appendix 8. The table below summarizes that evaluation.

Table *: Milestone Progress in Nuclear Astrophysics**

Year	Milestone	Complete?	Status Assessment

2007 NA1	Measure transfer reactions on r-process nuclei near the N=50 and N=82 closed shells	Yes	Achieved
2009 NA2	Measure properties of and reactions on selected proton-rich nuclei in the rp-process to determine radionuclide production in novae and the light output and neutron star crust composition synthesized in X-ray bursts	Yes	Exceeded
2009 NA3	Perform three-dimensional studies of flame propagation in white dwarfs during Type Ia supernova	No	Expect to Exceed
2010 NA4	Reduce uncertainties of the most crucial stellar evolution nuclear reactions (e.g. 12C(α,γ)16-O) by a factor of two, and others (e.g. the MgAl cycle) to limits imposed by accelerators and detectors	No	Expect to Achieve
2011 NA5	Measure neutron capture reactions, including radioactive s-process branch-point nuclei, to constrain s-process isotopic abundances	No	Expect to Achieve
2012 NA6	Measure masses, lifetimes, spectroscopic strengths, and decay properties of selected neutron-rich nuclei in the supernova r-process, and reactions to predict radionuclide production in supernovae	No	Expect to Exceed
2013 NA7	Perform realistic multidimensional simulations of core collapse supernovae	No	Expect to Achieve
2013 NA8	Perform simulations of neutron star structure and evolution using benchmark microphysical calculations of the composition, equation of state, and bulk properties of dense matter	No	Expect to Achieve

Neutrinos, Neutrino Astrophysics and Fundamental Interactions Milestones Evaluation Summary

Our evaluation of the eight Milestones for Neutrinos, Neutrino Astrophysics and Fundamental Interactions is presented in detail in Appendix 9. The table below summarizes that evaluation.

Table *: Milestone Progress in Neutrinos, Neutrino Astrophysics and Fundamental Interactions**

Year	Milestone	Complete?	Status Assessment
2007 FI1	Measure solar boron-8 neutrinos with neutral current detectors	Yes	Exceeded
2008 FI2	Collect first data in an experiment which has the potential to observe beryllium-7 solar neutrinos	Yes	Exceeded
2008 FI3	Initiate an experimental program at the SNS fundamental physics beam line	No	Expect to Achieve
2010 FI4	Make factor of 5 improvements in measurements of neutron and nuclear beta-decay to constrain physics beyond the standard model	No	Expect to Not Fully Achieve
2010 FI5	Make factor of 5 improvement in theoretical uncertainties for testing the Standard Model via low energy electroweak observables	No	Expect to Exceed
2011 FI6	Improve the sensitivity of the direct neutrino mass measurements to 0.35 eV	No	Expect to Achieve
2012 FI7	Extend the sensitivity of searches for neutrinoless double-beta decay in selected nuclei by a factor of ten in lifetime	No	Expect to Not Achieve Fully

2012 FI8	Perform independent measurements of parity violation in few-body systems to constrain the non-leptonic weak interaction	No	Expect to Achieve
2012 FI9	Obtain results from new high-sensitivity searches for atomic electric dipole moments	No	Expect to Achieve

Appendix 4: New, Updated, and Continuing Milestones

New and updated Milestones are needed to reflect progress to date, new discoveries, and the redirection of effort that is necessary as we learn what Nature actually does and adapt our science program to reflect this. They also serve to keep the field “on point”. The programmatic direction laid out in the 2007 Long Range Plan makes the case for targeted new investments in all four subfields. New Milestones serve also to capture this, with the proviso that their achievement in many cases depends on the underlying budgetary assumptions.

We give for each of the five subject areas the proposed new table of Milestones. Existing ones that continue are kept with their present number. Revised ones are listed with their new dates and number. Discussion of the revised Milestones depends on the details of the evaluation of the existing Milestone and is given in the corresponding Appendix. Proposed new ones with due dates are given, together with a short explanation after the table stating why they reflect appropriate goals for this subject area.

New, Updated and Continuing Milestones for Hadronic Physics

Year	#	Milestone
2009	HP3	Complete the combined analysis of available data on single π, η, and K photo-production of nucleon resonances and incorporate the analysis of two-pion final states into the coupled-channel analysis of resonances.
2010	HP4	Determine the four electromagnetic form factors of the nucleons to a momentum-transfer squared, Q^2, of 3.5 GeV^2 and separate the electroweak form factors into contributions from the u, d and s-quarks for $Q^2 < 1$ GeV^2.
2010	HP5	Characterize high-momentum components induced by correlations in the few-body nuclear wave functions via (e,e'N) and (e,e'NN) knock-out processes in nuclei and compare free proton and bound proton properties via measurement of polarization transfer in the $^4He(\vec{e},e\vec{p})$ reaction.
2011	HP6	Measure the lowest moments of the unpolarized nucleon structure functions (both longitudinal and transverse) to 4 GeV^2 for the proton, and the neutron, and the deep inelastic scattering polarized structure functions $g_1(x,Q^2)$ and $g_2(x,Q^2)$ for x=0.2-0.6, and $1 < Q^2 < 5$ GeV^2 for both protons and neutrons.
2012	HP7	Measure the electromagnetic excitations of low-lying baryon states (<2 GeV) and their transition form factors over the range $Q^2 = 0.1$ – 7 GeV^2 and measure the electro- and photo-production of final states with one and two pseudoscalar mesons.

2012	HP11 (update of HP2)	Measure Deeply Virtual Compton Scattering (DVCS) off the proton and the neutron in order to extract accurate information on generalized parton distributions for parton momentum fractions, x, of 0.1 – 0.4, and squared momentum transfer, t, less than 0.5 GeV^2.
2013	HP8	Measure flavor-identified q and $\bar{q}$ contributions to the spin of the proton via the longitudinal-spin asymmetry of W production.
2013	HP12 (update of HP1)	Utilize polarized proton collisions at center of mass energies of 200 and 500 GeV, in combination with global QCD analyses, to determine if gluons have appreciable polarization over any range of momentum fraction between 1 and 30% of the momentum of a polarized proton.
2014	HP9	Perform lattice calculations in full QCD of nucleon form factors, low moments of nucleon structure functions and low moments of generalized parton distributions including flavor and spin dependence.
2014	HP10	Carry out ab initio microscopic studies of the structure and dynamics of light nuclei based on two-nucleon and many-nucleon forces and lattice QCD calculations of hadron interaction mechanisms relevant to the origin of the nucleon-nucleon interaction.
2015	HP13 (new)	Test unique QCD predictions for relations between single-transverse spin phenomena in p-p scattering and those observed in deep-inelastic lepton scattering
2018	HP14 (new)	Extract accurate information on spin-dependent and spin-averaged valence quark distributions to momentum fractions x above 60% of the full nucleon momentum
2018	HP15 (new)	The first results on the search for exotic mesons using photon beams will be completed.

New Milestone HP13 reflects the intense activity and theoretical breakthroughs of recent years in understanding the parton distribution functions accessed in spin asymmetries for hard-scattering reactions involving a transversely polarized proton. This leads to new experimental opportunities to test all our concepts for analyzing hard scattering with perturbative QCD. New Milestone HP14 and HP15 reflect improved opportunities which will become available upon completion of the 12-GeV upgrade at Jefferson Lab. New Milestone HP14 reflects work with upgraded high-resolution spectrometers in the existing complex, while HP15 reflects the first of many new opportunities in the new Hall D with a specially prepared beam of multi-GeV photons, which is a new capability provided by the 12-GeV upgrade.

New, Updated and Continuing Milestones for High Temperature/High Density Hadronic Matter

Year	#	Milestone
2009	DM4	Perform realistic three-dimensional numerical simulations to describe the medium and the conditions required by the collective flow measured at RHIC.
2010	DM5	Measure the energy and system size dependence of J/Ψ production over the range of ions and energies available at RHIC.
2010	DM6	Measure e^+e^- production in the mass range $500 \leq m_{e+e-} \leq 1000$ MeV/c2 in $\sqrt{s_{NN}} = 200$ GeV collisions.
2010	DM7	Complete realistic calculations of jet production in a high density medium for comparison with experiment.
2012	DM8	Determine gluon densities at low x in cold nuclei via p + Au or d + Au collisions.
2014	DM9 (new)	Perform calculations including viscous hydrodynamics to quantify, or place an upper limit on, the viscosity of the nearly perfect fluid discovered at RHIC.
2014	DM10 (new)	Measure jet and photon production and their correlations in A≈200 ion+ion collisions at energies from $\sqrt{s_{NN}} = 30$ GeV up to 5.5 TeV.
2015	DM11 (new)	Measure bulk properties, particle spectra, correlations and fluctuations in Au + Au collisions at $\sqrt{s_{NN}}$ between 5 and 60 GeV to search for evidence of a critical point in the QCD matter phase diagram.
2016	DM12 (new)	Measure production rates, high pT spectra, and correlations in heavy-ion collisions at $\sqrt{s_{NN}} = 200$ GeV for identified hadrons with heavy flavor valence quarks to constrain the mechanism for parton energy loss in the quark-gluon plasma.
2018	DM13 (new)	Measure real and virtual thermal photon production in p + p, d + Au and Au + Au collisions at energies up to $\sqrt{s_{NN}} = 200$ GeV.

Four new milestones are proposed. DM9 reflects the commencing intensive search for an expected critical point in the QCD phase diagram and will require operating RHIC at low energies and possibly a new effort at the CERN SPS. DM10 notes the effort to develop a theory of viscous hydrodynamics useful for describing observed flow at RHIC. DM11 captures efforts to measure jet correlations over a span of energies at RHIC and a new program using the CERN Large Hadron Collider and its ALICE, ATLAS and CMS detectors. DM12 uses the increase in RHIC luminosity that is part of the RHIC-II upgrade and associated detector upgrades to study rare particles with charm quarks, and possibly particles with bottom quarks, as a demanding way to learn how matter flow and energy loss are established in the partonic phase at RHIC. DM13 spans real and virtual photons and captures work with both low-mass lepton pairs and photons emitted as blackbody radiation from the collisions at RHIC.

New, Updated and Continuing Milestones for Nuclear Structure

Year	#	Milestone
2009	NS3	Extend spectroscopic information to regions of crucial doubly magic nuclei such as Ni-78
2009	NS4	Extend the determination of the neutron drip line up to Z of 11.
2013	NS6	Carry out microscopic calculations of medium mass nuclei with realistic interactions, develop a realistic nuclear energy density functional for heavy nuclei, and explore the description of many-body symmetries and collective modes, and their relationship to effective forces
2013	NS7 (Update of NS5)	Complete initial measurements with the high resolving power tracking array, GRETINA, for sensitive studies of structural evolution and collective modes in nuclei
2015	NS8 (new)	Measure properties and production mechanisms of the elements above Z~102 to understand the nature and behavior of these nuclei, and to assist theoretical predictions for the stability, structure and production of superheavy elements.

2018	NS9 (new)	Measure changes in shell structure and collective modes, from the most proton-rich to the most neutron-rich nuclei accessible, in order to improve our understanding of the nucleus, and to guide theory in every region of the theoretical roadmap (i.e., the light-element region where ab-initio calculations can be performed, the medium-mass region where effective interactions are used, and the region of heavy nuclei, the domain of density functional theory).

New milestone NS9 is proposed to replace the completed original Milestone NS1 from the 2003 set to reflect in particular recent progress in formulating and adapting theory to the various regions of nuclear masses and for the extremes of neutron-to-proton ratio. New Milestone NS8 is proposed to replace the completed original Milestone NS2 from the 2003 set; to capture future progress in this area, with a due date of 2015. The following activities would be expected in pursuing this Milestone: (1) provide further constraints on the location of the single-particle orbitals thought to play a decisive role in the stability of superheavy elements; (2) improve experimental knowledge about the various reaction mechanisms proposed for the production of superheavy nuclei (such as cold and hot fusion, fusion with neutron-rich beams, and collisions between very heavy nuclei); and (3) improve theoretical predictions for structure and production of superheavy elements. Revised Milestone NS7 changes the delivery date of original 2003 Milestone NS5 to take into account actual funding profiles for the GRETINA project.

New, Updated and Continuing Milestones for Nuclear Astrophysics

Year	#	Milestone
2009	NA3	Perform three-dimensional studies of flame propagation in white dwarfs during Type Ia supernova
2010	NA4	Reduce uncertainties of the most crucial stellar evolution nuclear reactions (e.g. 12C(α,γ)16-O) by a factor of two, and others (e.g. the MgAl cycle) to limits imposed by accelerators and detectors
2011	NA5	Measure neutron capture reactions, including radioactive s-process branch-point nuclei, to constrain s-process isotopic abundances
2012	NA6	Measure masses, lifetimes, spectroscopic strengths, and decay properties of selected neutron-rich nuclei in the supernova r-process, and reactions to predict radionuclide production in supernovae

2013	NA7	Perform realistic multidimensional simulations of core collapse supernovae
2013	NA8	Perform simulations of neutron star structure and evolution using benchmark microphysical calculations of the composition, equation of state, and bulk properties of dense matter
2014	NA9 (new)	Perform mass measurements and nuclear reaction studies to infer weak interaction rates in nuclei in order to constrain models of supernovae and stellar evolution.
2014	NA10 (new)	Measure or constrain key nuclear reaction rates to improve accuracy of astrophysical models of novae and X-ray bursts and allow astronomical data to be used to infer novae and neutron star properties

New Milestone NA9 is proposed to replace the completed original Milestone NA1 from the 2003 set to recognize the importance of weak interactions in astrophysical environments. The results of such measurements of masses and weak decay rates enter dominant terms in determining the isotope abundances created in stellar nucleosynthesis. New Milestone NA10 is proposed to replace the completed original Milestone NA2 from the 2003 set to reflect expected future work in the area of proton-rich nuclei in the rp-process of nucleosynthesis. The accumulated data would be used together with current theoretical models to determine in particular information on the astrophysical site of this nucleosynthesis.

New, Updated and Continuing Milestones for Neutrinos, Neutrino Astrophysics, and Fundamental Interactions

Year	#	Milestone
2008	FI3	Initiate an experimental program at the SNS fundamental physics beam line

2010	FI4	Make factor of 5 improvements in measurements of neutron and nuclear beta-decay to constrain physics beyond the standard model
2010	FI5	Make factor of 5 improvement in theoretical uncertainties for testing the Standard Model via low energy electroweak observables
2011	FI6	Improve the sensitivity of the direct neutrino mass measurements to 0.35 eV
2012	FI8	Perform independent measurements of parity violation in few-body systems to constrain the non-leptonic weak interaction
2013	FI9	Obtain results from new high-sensitivity searches for atomic electric dipole moments
2015	FI10	Complete R&D demonstrating if a direct, precision measurement of the solar p-p fusion rate is possible
2017	FI11 (Revised FI7)	Extend the sensitivity of searches for neutrinoless double-beta decay in selected nuclei by a factor of ten in lifetime
2020	FI12 (new)	Obtain initial results from an experiment to extend the limit on the electric dipole moment of the neutron by two orders of magnitude

New Milestone FI12 captures an effort just being established to use the ultra-cold neutron beamline being built at the SNS (see FI3) to improve the limit on the neutron's electric dipole moment by two orders of magnitude or better using a novel experimental technique. This project is still obtaining needed Critical Decisions but is projected to have significant results by 2020. The revised deadline for Milestone FI11 reflects the pace at which it has been possible to identify funding to carry out needed R&D as well as commence building the first of the two experiments recommended by NuSAG in this area. R&D results have been most encouraging, with efforts now moving to full system tests. New Milestone FI10 addresses the rate of the primary reaction powering the Sun, p-p fusion. One may look for either the p-p or p-e-p neutrinos, which require distinct experimental techniques. The neutrinos may be detected by charged or neutral current scattering, which place different demands on an experiment.