LONG RANGE PLAN

FOR

NUCLEAR SCIENCE

Interim Report

April, 1995

DOE/NSF NUCLEAR SCIENCE

ADVISORY COMMITTEE

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The goal of nuclear physics research is understanding, at a fundamental level, the structure and dynamics of strongly interacting matter, its properties under a wide variety of conditions in the laboratory and in the cosmos, and the forces that govern its behavior. Pursuit of this goal entails development of new technologies and advanced facilities; education of young scientists and training of a technical workforce in the science and technology of nuclear research; and significant contribution to the broader science and technology enterprise through the many intersections of nuclear physics with other disciplines. The knowledge, technology and well-trained young scientists that result from nuclear physics research will continue to yield a rich harvest of future applications and benefits for both science and society.

Strongly interacting matter (protons, neutrons, atomic nuclei and the states they reach under extreme conditions) makes up virtually the entire visible mass of the universe, as well as of the world about us. Nuclear physicists answer questions about how this matter has formed, how it is held together, how it is structured, how it interacts in collision, and how it is transformed in stellar interiors. As with any science, the answers are rooted in observation and measurement, requiring leading edge tools matched to the inquiries at hand. Some of the required facilities and instrumentation emphasize precision, yielding ever greater accuracy on physical observables until nature yields her secrets and thereby stimulates understanding at a deeper level. Examples include the use of electron beams to elucidate the structure of matter with increasingly fine spatial resolution, or discovery of new collective behavior through novel spectroscopies, or the search for all of this input into the Long Range Plan for Nuclear Science. We benefited from the participation of representatives from nuclear science advisory committees in Europe and Japan. This document is the result of that effort. It represents a consensus of the nuclear science community's aspirations, priorities and recommendations at this time. We are confident that its recommendations, consistent with the charge, frame an outstanding scientific program reaching into the next century with substantial contribution to the national interest.

SCIENCE

The full Long Range Plan , due in the summer of 1995,will contain an extensive discussion of major scientific accomplishments since the 1989 LRP and of major opportunities for the future. The latter can be grouped into four broad scientific thrusts.

1. **Nuclear Structure and Dynamics: Pushing at the Limits.**
Building upon the foundation of greatly increased understanding of nuclear structure and reactions earned over the last decades, the science is pushing at new frontiers of spin, of temperature, and of nuclear stability. For example, the study of highly deformed shapes and the discovery of new nuclei provide stringent tests to advance our microscopic understanding of nuclear structure. New experiments with beams of short-lived radioactive nuclei will have a significant impact both on nuclear physics and on numerous important astrophysical issues, such as creation of the elements.

2. **To the Quark Structure of Matter.**
Quantum chromodynamics (QCD) describes the interactions of quarks and gluons, the underlying constituents of strongly interacting matter. However, the way in which quarks and gluons are confined into the nuclear constituents, protons and neutrons, and the way in which they

RECOMMENDATIONS

The last several years have seen substantial development of the tools needed for these major scientific thrusts. Indeed, as stated in the charge requesting this Long Range Plan , "Nuclear science has made impressive progress since the 1989 Long Range Plan was submitted to the agencies. Significant new capabilities have been realized or are near completion at CEBAF, MIT/Bates, MSU/NSCL, IUCF, BNL, ORNL/RIB, Argonne, LBL and elsewhere. RHIC is under construction and scheduled for completion in 1999. Major new detectors such as SNO, Gammasphere, Hermes, Borexino, and others will open new horizons in nuclear physics. Also, a vigorous new National Theory Institute has been established." Recently developed instumentation and upgrades at university facilities have also been realized in response to forefront scientific opportunities. These substantial investments in people, ideas, instrumentation and facilities will yield significant advances if exploited effectively in the coming years, both through adequate facility utilization and through commensurate support of the scientist and student users.

1. **The highest priority for US nuclear science is vigorous pursuit of the scientific opportunities provided by the nation's recent investments in forefront instrumentation and facilities. This will greatly advance our understanding, at a fundamental level, of the structure and dynamics of strongly interacting matter, of its properties under a wide variety of conditions in the laboratory and in the cosmos, and of the forces that govern its behavior. Scientific, technological and educational returns commensurate with these investments will require resources consistent with the charge requesting this Long Range Plan.**

The assignment of highest priority to utilization of the array of new tools and facilities is consistent with maximizing return on the investments already made and is clearly important in this time of great pressure on federal the science opportunity. We note with pleasure that CEBAF's development of superconducting cavity technology has proceeded so well that energies even higher than the design goal of 4 GeV are anticipated in the near term. The community looks forward to further evolutionary increase of the CEBAF energy in the longer term, opening up additional scientific opportunities.

The highest priority for new construction in the 1989 Plan was the Relativistic Heavy Ion Collider (RHIC). Its principal goal is to study, in the laboratory, matter at the highest achievable energy densities, as it existed in the early universe. The transition to deconfined matter, that is, matter in which the quark and gluon constituents of protons, neutrons, and other hadrons are able to propagate over significant distances, is a fundamental prediction of QCD. Establishing this transition will represent a major step in scientific exploration of the world about us. RHIC construction is now well advanced and is on schedule for a 1999 completion date. The unique opportunities to discover and study new phenomena at RHIC have led to the formation of vigorous international collaborations whose members have invested major efforts in the design and construction of advanced detectors suited to RHIC's unexplored regime of ultrarelativistic heavy ion collisions.

2. **RHIC remains our highest construction priority. Its timely completion and operation are of utmost importance for discovery of the quark-gluon plasma and for study of this new form of matter.**

To characterize fully the properties and behavior of the quark-gluon plasma, measurement of a large number of complementary signatures is essential. Selected additions to the large RHIC detectors will substantially enhance their capability and should be implemented in a timely fashion.

INITIATIVES

they drive different facets of the science. The MSU upgrade can be accomplished on a relatively short time-scale. Construction of a major ISOL-type facility is estimated to cost somewhat more than a hundred million dollars and thus, within the constraints of our charge, must wait several years, until RHIC construction is substantially completed , for the bulk of its funding .

Proton beams, and the secondary beams of neutrons, mesons and leptons provided by intense primary beams, are a major part of the arsenal for nuclear science. The community has experienced significant loss of opportunity in this regard with the imminent closure of LAMPF as a nuclear physics user facility and with the Canadian decision not to proceed with construction of the proposed large facility, KAON. On the positive side, significant new capabilities with electromagnetic probes will address related physics , selected experiments with intermediate energy pion and lepton beams will be possible, the technology for polarizing protons in storage rings has been developed and utilized effectively , and the intensity of kaon beams at the Brookhaven AGS has been increased significantly. These developments lead to important scientific opportunities with hadronic beams building on existing facilities and experience and, specifically, a new direction.

4. **Multi-GeV proton beams are an essential tool for forefront studies aimed at elucidating the quark structure of nucleons and nuclei.**

   - **We strongly recommend funding for LISS as a major research equipment initiative. This facility will build on IUCF's leadership in stored, cooled, polarized proton beam technology to enable innovative experiments addressing the short-range behavior of nuclear forces.**

INSTRUMENTATION

While the last three recommendations have focused on facilities, there are substantive infrastructure issues that must be addressed in order to pursue our first priority, that of capitalizing scientifically on the investment in frontier opportunities. Instrumentation initiatives of modest scale are at the core of forefront scientific investigation and of student education. A varied menu of important opportunities already exists, with many scientists strongly committed to their realization. These span the major scientific thrust areas described above. Some are ready for implementation, others require more development and design. For example, the cost-effective use of high energy accelerators (such as Fermilab and SLAC) by nuclear physicists for experiments probing the quark structure of matter often requires new instrumentation. Large acceptance detectors would yield a unique internal target program and new parity-violating scattering experiments with intermediate energy electrons. At low energies , a novel approach to coincidence detection of multiple gamma rays could significantly advance nuclear structure studies with highly deformed nuclei. The potential exists for a world-leading ultra-cold neutron source for precision tests of the Standard Model. Novel techniques for trapping ions and neutral atoms for studies of fundamental interactions are being advanced at low-energy accelerator facilities, in both university and national laboratory environments. These and other innovative instrumentation proposals are coming forward regularly to capitalize on scientific, technical and facility progress. It is essential to allow flexibility to respond to the most important proposals through the peer review process. This is an important component of our first recommendation concerning vigorous pursuit of scientific opportunity.

5. **We recommend that capital equipment funding be increased. Innovative projects, of moderate cost but addressing key issues in all of the major**

commensurate with the scientific challenges should be evaluated on the same basis as experimental instrumentation proposals.

INTERNATIONAL COLLABORATION

International cooperation in nuclear physics has become and will continue to be extremely lively and productive at the scientist-to-scientist level. With the increased scale of major facilities, a number of more formal cooperative agreements have been pursued to open up scientific opportunities for the international community at unique facilities. In turn, these facilities have been able to extend their scientific reach through instrumentation development by the international partners. Current examples include, among many others, the important detector contributions by European and Japanese scientists to CEBAF and RHIC in the US, and US participation in the Sudbury Neutrino Observatory (SNO) in Canada and in the HERMES program at the DESY/HERA facility in Germany.

To further this process and to help lay the groundwork for extended collaboration, NSAC invited representatives of nuclear science advisory committees in Europe and in Japan as official observers and participants in our Long Range Plan meeting. The observers provided overviews of the programs and plans in Europe and Japan and, most importantly, took part in the scientific discussion leading to our recommendations. These exchanges were very important to the Long Range Plan Working Group, pointing out the complementarity of existing facilities and areas of mutual interest for new thrusts. The importance of continuing dialogue among the scientific communities, including early discussion of major facility initiatives (for example, building on the worldwide interest in radioactive beams), is apparent. Beyond this, linking the scientific discussion with the planning activities of responsible gevornment officials , much as this LRP process does in the US , should be encouraged .

In addition , nuclear physicists contribute to broadening the overall education of undergraduates by offering them opportunities to participate in challanging research projects. This is often a defining experience , since entirely new talents are developed in the pursuit of new knowledge as opposed to the classroom experience of gaining accumulated knowledege . While this is true throughout forefront science , nuclear physics offers some special opportunities for undergraduates , such as on-campus accelerator environments and collaboration in significant teams . The extensive support of such programs by nuclear scientists has expanded considerably the scope of science and engineering curricula. It also provides motivation for sustaining and improving university technical infrastructure for nuclear physics.

A second important corollary of fundamental research is use of the unique assets of the research enterprise to improve public scientific and technical literacy . Nuclear physicists are very active in programs that strengthen pre-college science and mathematics education . Many of the programs have a focus of increased participation by women and underrepresented minorities. Increasingly, NSF and DOE are supporting such outreach activities as natural extensions of their research programs. We strongly support such recognition of these activities as part of the responsibility of our research community. One very good example of the coherence among research and educational commitments is provided by the developments at and around CEBAF. The new scientific opportunities there have stimulated the creation of more than seventy faculty positions in the southeast, the development of new Ph.D. programs at historically black universities, the expansion of undergraduate research at predominantly minority institutions, and the participation of about 10,000 grade school children in week-long science programs. The support of extensive undergraduate research programs in nuclear science by many university-based groups and facilities has expanded considerably and is encouraging broader participation in science and engineering advanced education.

RESOURCES

NSAC received from the agencies explicit budgetary guidance for this Long Range Plan. For the Department of Energy, our Plan corresponds to a FY97 budget between $325M and $350M and then goes forward at a constant level of effort. The high end of the charge corresponds to the current FY95 budget adjusted for inflation; the low end corresponds to a 2% reduction from the FY96 Administration request, adjusted for inflation. We will take the DOE FY96 request for nuclear physics as our baseline, since it incorporates the most recent developments in our field. For the National Science Foundation, the charge specifies constant level of effort starting from the FY94 budget. This will require an increase in FY96 of approximately 8% with respect to the current (FY95) spending plan; this is slightly lower than the percentage increase proposed for the NSF Physics Division in the FY96 Administration request. In terms of spending power, the budgets for both agencies are down by nearly 20% from the actual levels of a few years ago. This has forced termination of scientifically productive programs in order to sustain a balanced program with reasonably healthy components. The two largest DOE-supported nuclear science facilities at the time of the 1989 LRP, the Bevalac and LAMPF, have ceased or will soon cease to operate as nuclear physics user facilities in large part to permit development of CEBAF and RHIC. Two NSF-supported university accelerators are no longer supported; others now receive reduced support. This process of priority-setting and renewal emphasizes the importance of utilizing operating facilities for science and for the scientists who use them in a cost-effective, efficient and productive manner, commensurate with the national investment.

Department of Energy

A budget profile for the DOE nuclear physics budget is shown in Figure 1. It conforms to the budget constraints of $350M in FY97 and constant level such a retrenchment would include substantially less utilization of new capabilities and thus scientific return on the associated investments. The development of new instrumentation needed to enhance scientific output, including that at the major facilities CEBAF and RHIC, would be highly constrained. If the low funding scenario were to persist, the highly recommended ISOL facility would probably be stretched out in the absence of a special initiative for incremental funding.

National Science Foundation

A budget profile for the NSF nuclear physics budget is shown in Figure 2. It conforms to the budget constraints of the charge. We stress that, although the NSF nuclear science budget is about one-eighth that of the DOE, this program plays a crucial role. The NSF supports nearly half of the university-based nuclear scientists, and many of those scientists play leading roles at the DOE-supported user facilities. In addition, the NSF program supports university-based intermediate energy user facilities, at Indiana and Michigan State Universities, with unique capabilities for proton and heavy ion induced reactions, respectively. These facilities enjoy substantial local and state support and have been important centers for accelerator physics research and education.

As with DOE, and for similar reasons, we recommend an increase in the research and equipment budgets (about 6% from FY95 to FY2000, in FY97 dollars). This will have a large impact on the conduct of forefront nuclear physics research by university scientists and their students. Within the charge, we also recommend upgrade of the MSU/NSCL facility to provide intense beams of radioactive nuclei via fragmentation. This will provide additional pressure on the operating budgets of the user facilities for several years. The LISS project at IUCF, even with substantial matching funds, has a construction cost well beyond that which can be supported by the NSF nuclear physics program budget (within the constant level of effort scenario of the commitment of financial resources and scientific careers. This Long Range Plan renews the process of responsible shaping of the nation's investment in nuclear science through a partnership between the research community and the public.

Figure 1. DOE Nuclear Physics Budget Profile in FY97 Dollars.

Notes.

1. Inflator/deflator to FY97 taken as 3% per year.
2. "Research" does not include CEBAF or Brookhaven heavy ion research activities. University research and other national laboratory reserach included, both experiment and theory.
3. "Equipment" includes capital equipment, accelerator improvement, and general plant projects.
4. "Operations" includes accelerator facility operating costs except for CEBAF and Brookhaven heavy ions.
5. "CEBAF" entry includes the end of construction funding through FY94, facility operations, and research.
6. "BNL HI" includes AGS and RHIC operations and heavy ion research.

Figure 2. NSF Nuclear Physics Budget Profile in FY97 Dollars.

Notes.

1. Inflator/deflator to FY97 taken as 3% per year.
2. "Research" includes university-based experiment and theory, together with support of small university-based accelerator laboratories, but not IUCF or MSU/NSCL.
3. "User Facilities" includes both facility operations and research at IUCF and at MSU/NSCL.
4. The LISS project costs exceed the charge and must be proposed to the NSF Major Research Equipment account.

NSF NUCLEAR PHYSICS BUDGET IN FY97 DOLLARS

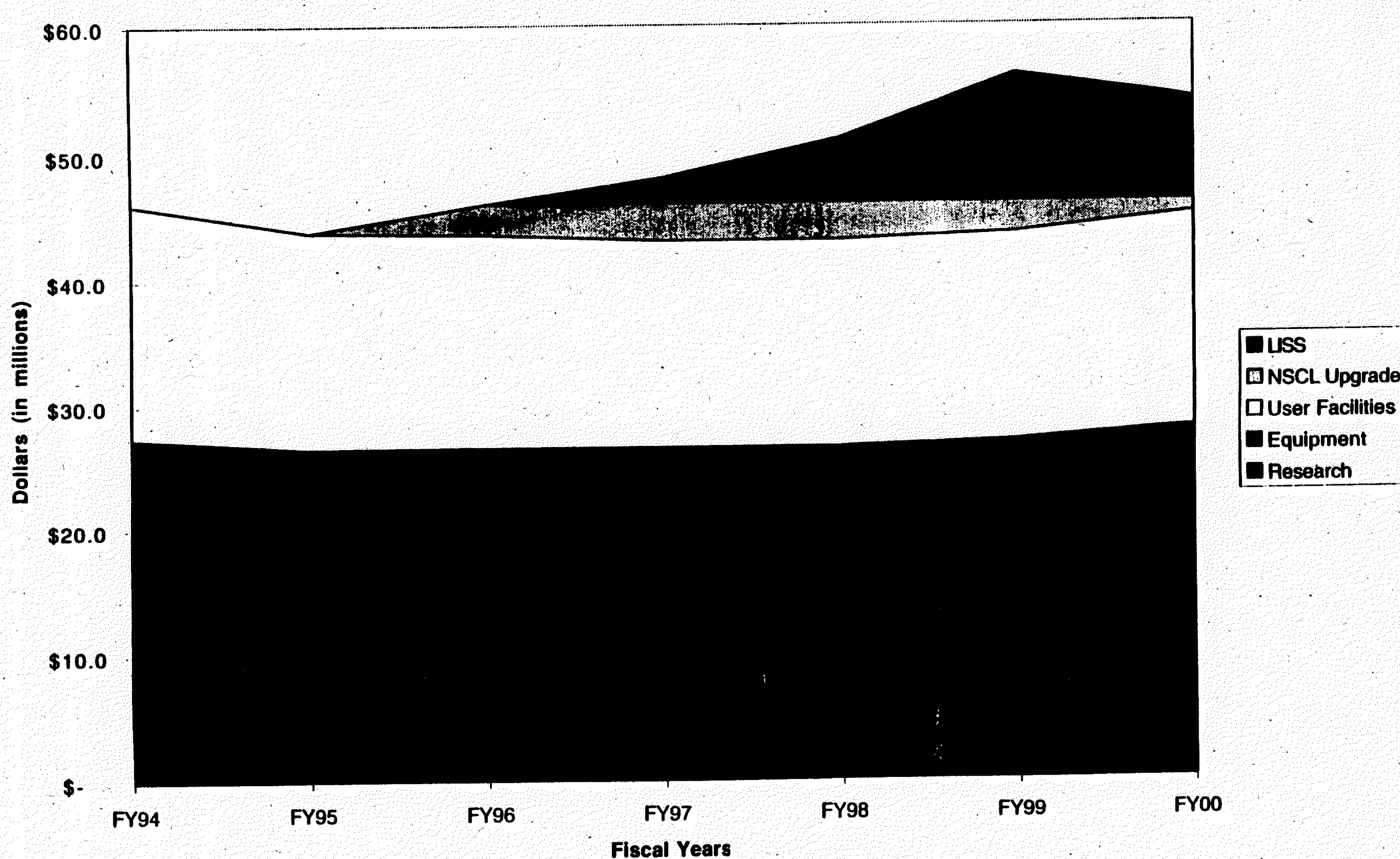

Figure 2