

REVIEW OF THE 1983 LONG RANGE PLAN FOR NUCLEAR SCIENCE
DOE/NSF Nuclear Science Advisory Committee
November, 1984

SUMMARY

At the request of the Department of Energy and the National Science Foundation the DOE/NSF Nuclear Science Advisory Committee has reviewed its 1983 Long Range Plan for Nuclear Science, taking into account the developments of the past year. The scientific priorities and recommendations of that Plan are reaffirmed.

1. Evolution of Plans for Nuclear Science

During the past decade, nuclear science -- the study of the nuclear many-particle system, its modes of motion and its response to a wide variety of external probes -- has incorporated important new ideas and achieved a new intellectual unity. It has been known for a long time that nuclei can be viewed on two levels, as systems of interacting nucleons (neutrons and protons) or as hadronic systems in which the role of excited nucleons and of mesons is taken into account explicitly. We now have begun, and see as a major opportunity for the future, the study of nuclei at a third and deeper level, in terms of the quark-gluon substructure and the many-body aspects of color confinement.

Long-range plans charting the future development of nuclear science were prepared in 1976, 1979, and 1983. As time passes, of course, relative priorities are modified and suggestions for the construction of new types of facilities are sharpened and brought to the point of specific proposals. The 1983 NSAC Long Range Plan and the view of nuclear science that it expresses are a natural continuation of earlier plans. We reaffirm the 1983 Long Range Plan, the view of nuclear science on which it is based and our belief in the scientific opportunities that it describes.

2. Broad Outline of the Long Range Plan

Nuclear physicists study the properties of atomic nuclei and nuclear matter, which form the overwhelming bulk of the world and the universe in which we live. These studies often require techniques that can probe or alter the state of a nucleus. With these probes the characteristic modes of nuclear excitation are sought, and then interpreted in terms of the degrees of freedom -- nucleonic, hadronic, or quark-gluon -- with which each mode is most naturally and simply described. With other more drastic probes the normal quiescent state of the nucleus may be disrupted and new classes of phenomena and even new phases of matter emerge. In addition, nuclear physics seeks to

uncover otherwise inaccessible properties of fundamental interactions and symmetries, and to examine aspects of the basic theories of these interactions and their relation to the properties of many-body systems.

This undertaking is by its very nature complex and many-faceted. Phenomena must be studied with a variety of external probes over wide ranges of energy. The range of probes includes the electromagnetic (photons, electrons, muons), the weak (neutrinos), and the hadronic (pions, kaons, nucleons, antinucleons, light nuclei and heavy-ions). The information obtained from the different reactions induced by these projectiles is overlapping and complementary. As the physical questions to be addressed become deeper and more subtle the need for combined attacks by a wide variety of probes becomes more acute.

The long-range plans for nuclear science have consistently recognized the multi-faceted character of the techniques of experimental nuclear science and the need for balance among its components. The 1983 Long Range Plan, augmented by the 1984 report of the NSAC subcommittee on a 4-GeV electron accelerator -- the Vogt report -- may be summarized as follows in terms of a base program and of several major new opportunities involving large accelerator facilities.

(A). The continuing base research program in nuclear physics, with existing facilities and those now being constructed, faces vital challenges and opportunities. After a decade of fiscal neglect it needs increased operating and equipment funds to meet these challenges. Not only are the new opportunities and challenges important in their own right, but without a vigorous program of ongoing research the ideas, the knowledge, and the training of scientists necessary, both to our society whose technological sophistication is steadily increasing and to future endeavors in the quest for knowledge, will not be forthcoming.

The fabric of nuclear science depends upon input from many different but complementary areas. The 1983 Long Range Plan summarized the most important scientific questions facing the frontiers of our field with its present resources. For the science to be healthy and productive it is essential that the interdependence of small and large scale experimentation be recognized and that, in particular, support of the small not be lost in the move to new very large national facilities. It is essential, too, that the recommendation of the Long Range Plan that appropriate support for modest upgrading, modernization and expansion of the best and most essential of existing accelerators and non-accelerator facilities be supported. Nuclear physics also requires adequate computing facilities, a subject currently being examined by an ad hoc NSAC subcommittee.

The base program of nuclear science at the nation's universities and national laboratories with existing facilities is the core of our science from which new ideas, new endeavors, new contributions to society and the nation, a new generation of scientists and the future strength of our field will grow. Maintaining and strengthening what is excellent in this base program is an urgent need that we address in (3) below.

(B) As first priority for new major construction, NSAC endorsed in 1982, and again in 1983, a 4-GeV CW electron accelerator. The very recent Vogt report, endorsed and transmitted by NSAC, reviews the scientific questions that can be addressed and reaffirms the central role of such an accelerator and its status as the first priority for major new construction in nuclear physics.

Throughout the past decade electromagnetic interactions have been consistently identified as a powerful and uniquely clean means of addressing a broad range of fundamental open questions in nuclear physics. The Vogt report enumerates the main elements of a structured plan for electromagnetic physics especially in the leading frontier area of the interface between nuclear phenomena and the strong interaction and its characterization in the framework of quarks and gluons. With new electromagnetic probes nuclear physics will deal with the important questions concerning nucleons, nucleon resonances and mesons in nuclei in a broad array of experiments ranging from the exploration of deep-hole states in nuclei to the production and propagation of pions, kaons and deltas in the nuclear medium. For the important issue of nucleon substructure - to what extent and under what circumstances the nucleus should be viewed in terms of quarks and gluons rather than in terms of nucleons and mesons - there are two important regimes for experiments. For an accelerator with a maximum energy in the vicinity of 4 GeV the scientific interest rests in the hadronic issues (excited nucleons for example) and in the issues pertaining to the confinement of quarks in nucleons and mesons. At much higher energies other experiments of a structured program of electromagnetic studies will deal with the asymptotic issues of QCD, a regime in which the quark interactions are much simpler.

Recent theoretical developments have sharpened the questions and heightened the interest in the entire structured program of electromagnetic research. The Vogt report describes the whole range of scientific opportunity now open to the United States from the 4 GeV facility which remains the highest priority major construction project of nuclear physics, to more vigorous use of present facilities of high energy physics, and including modest improvements to provide continuous beam capabilities at existing electromagnetic facilities up to about 1 GeV. Proposals for such upgrades merit prompt consideration.

(C). A second major scientific opportunity was identified in the 1983 NSAC Long Range Plan in the construction and the research program with a relativistic heavy-ion collider. Specific proposals for such a facility are now before the funding agencies. A heavy-ion collider will present the opportunity for an important new initiative, the study of hadronic matter in the entirely uncharted regions of high energy density and baryon density over large spatial distances. Relativistic heavy-ion collisions are a necessary further approach to questions at the QCD interface, probing quark-gluon degrees of freedom in highly excited states of matter, and complementing studies by electron scattering. In addition, such collisions will permit fundamental studies of QCD and confinement questions, inaccessible by any other means. Most excitingly, it is predicted that qualitatively new phenomena will be uncovered, including a new phase of hadronic matter -- the "quark-gluon plasma". While the special conditions necessary for such matter may

exist in the interiors of neutron stars and are thought to have existed during the first moments after the birth of the universe, the only means to produce and study such conditions in the laboratory is through relativistic heavy-ion collisions.

The program of heavy-ion research at lower energies with existing facilities was discussed in our 1983 report. The need for supporting the exciting research opportunities in this area, both at low energies, at the interface between nuclear structure and dynamics, and at energies approaching the pion production threshold and beyond, falls within the realm of the smaller existing facilities mentioned in (A) above.

(D). The Long Range Plan also stresses the importance of studies of the nucleus with light hadronic beams over a wide energy range. It calls for vigorous pursuit of this component of the scientific program by upgrading existing facilities and, for the future, points to the opportunities offered by a new facility with intense proton beams of about 10 GeV or more, one that will provide not only the higher-energy protons, but more intense pion, kaon, muon and antiproton beams. The production and propagation of pions, kaons, other mesons, and excited nucleons in nuclei is a rich field for exploration. Hypernuclei, nuclear systems of non-zero strangeness, can be studied in new ways with unprecedented accuracy. Secondary kaon and neutrino beams permit a wide variety of new tests of the minimal standard model which includes the very successful theory of the electroweak interaction. Finally, the use of high-energy hadronic probes will be an important complement to the high-energy electron and muon studies. In particular, since only hadrons interact with gluons and since electrons and muons are color blind, high energy hadronic probes are needed for a full study of the QCD interface.

(E). The 1983 NSAC Long Range Plan expressed concern at the declining numbers of graduate students in the physical sciences generally and in nuclear physics in particular. It is gratifying to note that the most recent surveys indicate that the number of students in the nuclear sciences is increasing. The exciting new opportunities in nuclear physics now and on its near term horizon are playing a role in this changing trend. In spite of this very recent increase, the number of fresh Ph.D.'s being trained in nuclear science is still insufficient to meet future demands of society, industry and government, and of the science itself. Efforts need to be continued to correct this insufficiency and, in particular, the importance of attracting high caliber graduate students and of providing the best possible training in nuclear science should be given prominent consideration in decisions on new facilities.

3. Implementation of the Long Range Plan

The major national nuclear science accelerator facilities presently are operating at a level of utilization that generally is lower than 60%. This is below the level we view as the minimum consistent with reasonable progress in the core program of nuclear science and does not allow prior investments in these facilities to provide the appropriate scientific returns to the nation. In a letter dated April 29, 1983, which was reemphasized in the 1983

Long Range Plan for Nuclear Science, we recommended a \$20 million incremental adjustment in operations and equipment funds for the ongoing research program. We give the highest immediate priority to this \$20 million increment in operating and equipment funds to restore the level of utilization of existing facilities, including improved instrumentation and programs to encourage and strengthen user groups and young investigators.

We see a major electromagnetic facility as having the highest priority for the construction of a large facility and a relativistic heavy-ion collider complementing it in an area which presents a related important opportunity. Specific recommendations for a new high-intensity multi-GeV proton facility lie beyond the current Long Range Plan. Nevertheless such a facility will have to be at the forefront of future planning for our field. As the facility requirements of our science become larger and more extensive, increasing attention will also have to be paid to international participation and cooperation, especially in connection with the major facilities considered here.

The Long Range Plan for nuclear science, developed and adapted over the past decade, and presented most recently in the 1983 NSAC report, is discussed above. It stresses the importance of increased support for the ongoing program of nuclear research and calls for new construction of major facilities. The steady upgrade of the best and most essential of present facilities should continue as scientific and technical opportunities present themselves at roughly the pace foreseen in the 1983 Long Range Plan. Maintenance of the momentum, progress, and vitality of nuclear physics requires the implementation of this Plan to proceed without periods of stagnation. We recognize that the framework of purely scientific considerations may have to be adjusted as the exigencies of specific managerial, technical and funding considerations change.

4. Conclusion

Our plan is the 1983 NSAC Long Range Plan, for which we reaffirm our support. The first priority for major construction is to provide first-rate facilities for electromagnetic physics in the few-GeV range. We urge the DOE to continue to do its utmost towards a timely construction of CEBAF. In particular, NSAC is concerned about the delay which has already occurred in this project and about the management problems not yet resolved. The next project, identified in the 1983 NSAC Long Range Plan, is a relativistic heavy-ion collider. The process of studying the designs, choosing the parameters and assessing proposals should start as soon as possible. We hope that construction of the 4-GeV CW electron machine and of the heavy-ion collider will be well under way by the late 1980's. Meanwhile we should discuss strategies for the high-energy hadron physics necessary for a balanced program of nuclear research into the 21'st century and make appropriate recommendations for the continued strength of the base program with the best existing facilities.

Nuclear science faces challenges of unprecedented scope and potential scientific impact. We have an opportunity to study the nuclear response to external probes over an enormous dynamic range. At low energy-momentum transfer, the nuclear response can be described to accuracies of a few percent

in terms of nucleon degrees of freedom. At higher energy-momentum transfer, we enter the hadronic regime of excited nucleons and transient mesons. At still higher energies the QCD interface is reached and we can study the mechanism of confinement in many-quark systems. Finally, at very high energy-momentum transfer, we enter the realm of perturbative QCD. Over this enormous dynamic range, the search will go on for new modes of excitation of the nucleus, for new insights into the charge, matter, and color-densities and currents in nuclei, and for new understanding of the nuclear many-body system and of the fundamental interactions and symmetries of nature.

To carry out this rich and very promising program will require facilities that provide a full range of probes -- weak, electromagnetic, hadronic and heavy-ion -- of high intensity, over a wide energy range. This many-faceted, balanced assault on the dynamics of many-hadron systems is the vision of the future that has animated long-range plans for nuclear science from the Friedlander report of 1976 to the 1983 NSAC Long Range Plan. We believe firmly in this vision and in the unprecedented scientific opportunities that it offers.