Report of the Subcommittee on the Implementation of the 1989 Long Range Plan for Nuclear Science

Submitted by the Nuclear Science Advisory Committee to the U.S. Department of Energy and The National Science Foundation

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Dr. William Happer
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U.S. Department of Energy
Washington, D.C.

Dr. David A. Sanchez
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The National Science Foundation
Washington, D.C.

Dear Dr. Happer and Dr. Sanchez,

This document responds to the DOE/NSF charge to NSAC of January 24, 1992. The charge requests advice on the priorities in nuclear science for implementation of the 1989 LRP under three specific budget scenarios, all beginning with the budgets contained in the FY93 Congressional Budget Submission. The complete DOE/NSF charge is appended to the report.

In preparing its response NSAC established a subcommittee comprised of eight leading scientists covering the breadth our science and chaired by Dr. J. Schiffer from Argonne National Laboratory and the University of Chicago. This subcommittee presented its report to NSAC on April 6. On April 10/11, 1992, NSAC accepted and endorsed the report. With this document, we are submitting the Subcommittee Report to you as NSAC's response to the charge. We also append two sections of the 1989 LRP for Nuclear Science.

The subcommittee report addresses the charge in considerable detail. Obviously the programmatic issues over the next five years involve scientific choices that affect the entire field, but have a most direct impact on the LAMPF program. Beyond its present research agenda, which is described in the report and which is unique in terms of the beams it exploits, LAMPF is considered by many in the field a possible staging ground for one of several initiatives that are now building up scientific momentum.

In considering the needs of the field as a whole in the light of the fiscal realities expressed in the DOE/NSF charge the Subcommittee set responsible priorities and made some hard choices. The time scale which the agencies set for the preparation of this report was extremely short considering the seriousness of the issues, and the Subcommittee and NSAC arrived at a consensus about nuclear science priorities for the next 5 years with efficiency. This should not mask the great pain with which this advice was prepared. Rather it expresses the wide support that the scientific priorities of the 1989 LRP enjoy in the nuclear science community.

We attach a summary of conclusions from the Subcommittee Report with some amplifications by NSAC.

On behalf on NSAC, sincerely,

Peter Paul

Peter Paul,
Chairman, NSAC

NSAC Summary of Subcommittee Report

April 15, 1992

1. The goals outlined in the 1989 Long Range Plan for Nuclear Science remain valid today. In the pursuit of these scientific goals the field is vibrant and forward looking. Since 1989 many significant advances over the wide energy domain of nuclear science have confirmed the scientific soundness of the LRP. Exciting opportunities lie ahead with the near completion of major instrumentation projects. Most importantly, construction of CEBAF and RHIC is moving forward at the scheduled pace. NSAC is looking with great anticipation to the beginning of the research activity at CEBAF in early 1994, and at RHIC in 1997. Although different in size, the NSF and DOE programs continue to be partners in advancing our field across its broad frontier.

2. In addressing the three budget scenarios of the charge, the Report outlines baseline reference budgets for both NSF and DOE, for the implementation of the LRP starting with the FY93 Congressional Budget Submission.

   For the DOE program this budget entails construction of CEBAF and RHIC on schedule, operation of CEBAF for research starting in FY94 and of RHIC in FY97, a vigorous base program, and completion of the most important experiments at LAMPF through FY95 as a necessary part of the orderly phase out of this facility indicated in the FY93 Congressional Budget Submission for DOE. This base budget would require one-time additions of less than $ 25M in FY94 and less than $ 20M in FY95 but reverts to a flat budget in FY96 or FY97, depending on whether funds for KAON or an initiative of equivalent size are included in FY96. The total expenditures of this budget between FY93 and FY97 are below those of a scenario with 2% real growth.

   In an inflation-corrected scenario without this temporary increase it is deemed impossible to effect a phase out of LAMPF that could be considered orderly. Thus this scenario sacrifices the chance to complete excellent and unique scientific programs.

A flat budget in as-spent dollars would seriously damage the entire field and compromise any chance of executing the LRP priorities. It would require immediate LAMPF phase out, reductions in the base program including caps on facility operations and a stretchout of RHIC construction into FY98.

3. As noted above, the FY93 Congressional Budget Submission for DOE stipulates that a transition plan should be developed for the orderly phase out of LAMPF. The Report addresses this issue and the associated scientific sacrifices in some detail.

   At present, LAMPF has first-rate experiments ready to start and likely to produce significant results in the near term. They utilize the facility's unique high quality beams of protons, pions, muons, neutrons and neutrinos and cannot be duplicated elsewhere. Experiments like MEGA and LSND will have fundamental impact. Other programs using the intense neutron beams of LANSCE have just recently made a major discovery involving parity violation in nuclei which needs confirmation and extension.

   It is thus the strong conclusion of the Report and of NSAC that an orderly phase out requires operation of LAMPF for 2 more years, i.e. through FY95. In the base budget scenario analysis of the Report this can be accomplished by one-time additions of less than $25M in FY94 and less than $20M in FY95, over the inflation-corrected FY93 budget.

4. The Report and NSAC reaffirm the emphasis expressed in the 1983 and 1989 LRP on the need for a high-intensity, multi-GeV hadron beam facility and the recommendation of the 1989 LRP for a cost-effective U.S. participation in the Canadian KAON project. The Report's base scenario envisions funding towards KAON starting in FY96, after RHIC construction has been substantially completed. Such participation would open up major new capabilities to explore the effects of strangeness in the nuclear medium and allow precision tests of the electro-weak force. A flat scenario would delay such a contribution until FY97.

   A discussion by the U.S. nuclear community of alternatives to achieve these im-

portant physics goals is needed soon in the event that KAON is not realized. In that case, the scientific and technical infrastructure in place at LAMPF would be a substantial asset, as exemplified by the excellent development program in high gradient superconducting resonators.

5. The discussion of the three NSF budget scenarios starts again with the definition of a base reference budget. This reference budget turns out to be close to the 2% real growth scenario.

   The NSF supports an essential component of the national effort in nuclear physics and provides funding for about 40% of the graduate students and 30% of the post-doctoral research associates trained in the field. The recent funding pattern at NSF has severely limited the extent to which the program could support new scientific ventures, jeopardizing the leadership role of university groups in the field. A 2% to 3% growth above inflation would have large leverage in funding some of the major opportunities.

   The Report thus strongly recommends a base budget with 2% real growth, which would correct the lag behind inflation of this program for the past several years, would allow the build up of the university-based user community and permit funding for a few highly selected new initiatives.

   In a no-growth scenario, important new initiatives will not come to fruition. Yet NSAC recommends retaining some growth in selected user and small laboratory programs in order to maintain the vitality of a rapidly evolving field and to allow a response to the most urgent scientific challenges. In oder to accomplish such growth it might be necessary to reduce operations at one of the large NSF user facilities, even at the expense of inflicting an unfortunate loss of scientific capability.

   A flat as-spent scenario would seriously compromise the effectiveness of the program and would require a comprehensive program review in order to identify and preserve the best parts of the NSF program. Such a reduction in scope would seriously undermine the very successful university-based NSF program jeopardizing its mission

in research and education.

6. The 1989 LRP cited several areas that may become ripe for exploitation by new initiatives later in this decade. Some of these, such as the plans for an Isospin Laboratory (a radioactive beam facility), PILAC (an energetic pion beam facility for hypernuclear studies) and a pulsed lepton source have already undergone significant development. Others are in an earlier planning stage.

   If the KAON project does not proceed, a constant DOE budget would allow for one such new initiative starting in FY96 or FY97.

   The NSF budget scenarios did not provide the option of a major new initiative, such as a large stand-alone detector, a major experiment at an accelerator, let alone a new accelerator. Nevertheless, such an initiative could be considered under the major capital equipment category after review by the nuclear science community.

7. The U.S. nuclear physics endeavor, building on a record of major achievements in understanding the structure of the nucleus and the laws that govern its constituents, is perched on the threshold of exciting new scientific initiatives. Near the end of the period of this review, world-class accelerators needed for these initiatives will be in place. Very modest budgetary flexibility over the next two years will allow the orderly evolution of the field and the realization of the exciting scientific opportunities delineated in the 1989 LRP and in the attached Report.

REPORT OF THE SUBCOMMITTEE ON THE IMPLEMENTATION OF THE 1989 LONG RANGE PLAN FOR NUCLEAR SCIENCE

Submitted to the Nuclear Science Advisory Committee of the Department of Energy and the National Science Foundation

April 6, 1992

by:

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OUTLINE

I. OVERVIEW

Background.

In January 1992 the Nuclear Science Advisory Committee of the Department of Energy and the National Science Foundation (NSAC) was asked for recommendations on priorities for Nuclear Science expenditures under constrained budget scenarios (Appendix A). To this end NSAC appointed a Subcommittee (Appendix B) to respond to its charge and make recommendations regarding the implementation of its Long Range Plan (Appendix C). This Subcommittee has held a series of meetings at which it heard presentations from representatives of facilities and other nuclear scientists (Appendix D).

NSAC had prepared the latest of its 'Long Range Plans for Nuclear Science' in 1989, only a little over two years ago, in which it summarized the scientific opportunities and the broad outlines of a plan. The subcommittee **strongly endorses** the physics put forward in the LRP and makes no attempt to modify any of its recommendations or priorities. Consequently, this report does not attempt to provide a full physics justification for the recommendations of the LRP but rather specific physics issues are noted, where they are pertinent to recommendations. The Subcommittee has attempted to fit the physics objectives of this plan and its scientific priorities into the budgetary framework of the DOE/NSF charge. While it was not practical to fine-tune specific budgets, the Subcommittee has attempted to develop overall guidance that can be used by the agencies in implementing specific scenarios consistent with the scientific priorities of the LRP.

Accomplishments and Developments since the 1989 Long Range Plan.

The 1989 Long Range Plan for Nuclear Science identified the most exciting scientific opportunities for the next decade:

- The exploration of the quark degrees of freedom and of the underlying theory of the strong interaction, QCD, in the nuclear medium. This includes the decisive attack on the meson degrees of freedom using the superior experimental power of the new CW high-energy electron beams.

- Study of the nuclear equation of state up to very high temperatures and nuclear densities, and of the quark-gluon plasma.

- Study of nuclear structure at the limits of temperature, angular momentum, and neutron-to-proton ratios. This includes opportunities of astrophysical significance.

- The use of the nuclear medium for precision studies of fundamental aspects of the strong and electroweak interactions. This includes the study of neutrinos of astrophysical and solar significance.

In the past two years, a number of developments have occurred that relate both to these science issues and to the facilities that are needed to explore them. The construction of CEBAF is proceeding apace and RHIC construction has started. Upgrades and improvements have been implemented at smaller facilities and several major detector developments such as Gammasphere and SNO, are under way. These new initiatives have been accompanied by significant growth in the number of graduate students over the last five years. This growth illustrates the continued vitality and intellectual attractiveness of the field.

Of utmost importance, a number of new physics results bearing on the central issues of the field are emerging. These accomplishments reflect an important interplay between the experimental and theoretical programs in nuclear science. Theoretical insight has been essential in providing directions for future experiments, quantitative predictions for experiments in progress and analyses and interpretation of data.

In the following, a selection of **physics highlights** are provided, to give a flavor of recent progress in nuclear science.

Elementary Symmetries.

Symmetries have long played an important role in nuclear physics. In 1989 – 90, unambiguous evidence for the breaking of charge symmetry (proton-neutron interchange), for which indirect and controversial evidence has been available for over 35 years, was seen in polarized neutron-proton scattering in experiments at both IUCF and TRIUMF. A systematic pattern of parity (mirror symmetry) violation, not anticipated in statistical models, was detected in polarized neutron-nucleus scattering near compound nuclear resonances at the LANSCE facility at LAMPF in 1991. At the fundamental level, these observations shed light on quark mass differences and the structure of the electroweak interaction, as reflected in the parity-violating component of the nucleon-nucleon interaction.

Missing Neutrinos from the Sun.

One of the most puzzling problems that faces physicists in this decade is the appar-

ent small flux of solar neutrinos striking the earth. Following the pioneering work of Ray Davis and collaborators, a new generation of solar neutrino detectors reported first results in 1991 on the low-energy solar neutrino flux. The Soviet-American Gallium Experiment (SAGE) detector is sensitive to the solar neutrinos produced in the p-p reaction that is the dominant process in the Sun. The SAGE collaboration recently reported an upper limit on the flux of these neutrinos and a second gallium experiment (GALLEX) is expected to report results later this year. The results are key in understanding the properties of the neutrinos, in particular the oscillations of flavor which may occur for neutrinos of finite mass as they pass through the matter in the Sun and travel to the Earth.

What is the Structure of the Proton?

A recent CERN experiment, studying the deep-inelastic scattering of polarized muons from polarized protons, revealed a rather surprising phenomenon: apparently the quarks contribute little to the proton's spin. This result may be interpreted as an indication that 'strange' quark-antiquark pairs have a substantial effect on the spin structure. Studies of weak form factors with neutrinos and parity-violating electron scattering are in preparation, in order to further explore this key issue, which has many ramifications for our understanding of structure within the building blocks of nuclei, the neutrons and protons.

The Shape of the Deuteron.

The charge distribution of the deuteron, the most elementary nucleus, has been measured for the first time with excellent spatial resolution. The prolate or elongated shape of the deuteron results from spin dependent proton-neutron interactions. The determination of the charge distribution required novel techniques for measuring the deuteron spin orientation during elastic electron scattering at very large momentum transfer. The results support the applicability of nuclear force models based on nucleons and mesons as a phenomenological method for incorporating the underlying quark and gluon degrees of freedom. An international collaboration carried out the highest momentum transfer measurements (where the sensitivity to models is greatest) at the Bates Laboratory and the result was published in 1991.

Identical Bands in Nuclear Structure.

Studies of states of high angular momentum in superdeformed nuclei at ANL, LBL, and elsewhere have revealed a remarkable phenomenon: rotational bands in some pairs

of adjacent even and odd mass nuclei display virtually identical spacings of energy levels. More recently, the same effect was seen at lower spins, and also for pairs of even-even nuclei. This argues that this phenomenon arises from very basic features of shell structure and reflects the underlying mechanism of collectivity.

Nuclear Halos.

The investigation of nuclei far from stability has yielded systems with very interesting properties. For instance an aggregate of 3 protons and 8 neutrons forms ^{11}Li, a nucleus that is barely bound against the emission of two neutrons, leading to a diffuse 'neutron halo' around the nucleus. There are predictions that such halo nuclei will exhibit novel dipole modes of excitation; these are being investigated in ongoing experiments. First studied at LBL, this nucleus has been the subject of intense investigation around the world in the past 2 – 3 years, at MSU and LAMPF, as well as in France and Japan.

Nuclear Size Measurements for Long Isotope and Isotone Chains.

Advances in the production and handling of exotic radioactive nuclei have made it possible to use ion traps and laser spectroscopy to measure masses, charge radii and nuclear moments, almost to the neutron and proton drip lines. Elegant atomic physics methods are now being applied to give increased sensitivity, and therefore allow study of more rarely produced species, as far from stability as ^{50}Ca,^{152}Yb and ^{190}Pb. These measurements, published in 1991 – 92, have shown changes in charge radius in these exotic nuclei which correlate with neutron as well as proton shells and sub-shells.

Strange Quarks and the Formation of Hot, Dense Hadronic Matter.

Enhanced production of hadrons containing strange quarks, particularly antibaryons, has been observed in recent (1990 – 91) studies of relativistic heavy ion collisions at Brookhaven and CERN. In particular, in the production of strange antibaryons a component is observed which scales with the square of the associated pion multiplicity. Both the scaling and the observed absolute rates are difficult to reproduce with a description based on the superposition of nucleon-nucleon collisions (including rescattering). These results clearly indicate that hot and dense regions of nuclear matter are formed in such encounters and survive long enough to strongly influence strange baryon production. Such a high density phase is a necessary precursor for the formation of the quark-gluon-plasma.

Massive Neutrinos?

The last year has seen a flurry of activity in an old subject: the measurement of the energies of electrons emitted in beta decay of a radioactive nucleus. Results from several laboratories were published (in 1991) with the interpretation that there seems to be a small component of the decay process accompanied by a massive "17-keV" neutrino. Other experiments, with similar precision, have failed to see the tell-tale signatures for such a component. These results are highly controversial at present and, since they do not require major facilities, they are the subject of intense experimental investigations at a number of laboratories.

Response to the Two Agencies.

The charge to the Subcommittee asked for a statement of the priorities of the program under three budget scenarios for both the DOE and NSF:

- A) a budget that is flat in dollars, with no allowance for inflation;
- B) a budget that is flat in inflation-corrected dollars;
- C) a budget that contains 2 – 3% real growth above inflation.

The Subcommittee derived scenarios corresponding to these totals as is detailed below.

Although the charge that engendered this subcommittee was issued jointly by DOE and NSF, the detailed requests from the two agencies had a somewhat different character. The focus of the Department of Energy was in terms of the major facilities for the field: LAMPF, CEBAF, and RHIC, and the possible advent of KAON. The urgency of issues associated with operating the large facilities is reflected in the language of the FY93 Congressional Budget Submission: "A transition plan will be developed with the Nuclear Physics Community to permit an orderly phaseout of LAMPF". The impact of the construction and operation of the major DOE facilities and the balance between these facilities and the rest of the research program at universities and national laboratories has been a major concern of the LRP and is included in the charge to NSAC. The issue of U.S. support for the Canadian KAON project is also a DOE matter. At the National Science Foundation, which funds nuclear physics with a much smaller budget that is spent entirely at universities, the concern of program officers focussed on the appropriate balance between two medium sized facilities, small facilities, and the support of user groups.

Although the science is a coherent whole, this report is split to address the somewhat differing concerns of the two agencies. The request in the charge regarding the relative emphases on University-based research and on facilities operated at National Laboratories is addressed in the course of the report.

DOE Summary.

The DOE research program in nuclear physics provides the major driving force to the field in the United States, and substantially around the world. However, in a climate of curtailed budgets and large new facilities approaching completion, some readjustments in the DOE program will be required. Some of these are already being implemented (e.g. the accelerated shutdown of the Bevalac, the scheduled phase out of the Holifield facility and of the FNG). It is the strong recommendation of the Subcommittee that the remaining base program at universities and national laboratories not be further impacted by budget stringencies. Several subareas of the base program are subjected to unscheduled and relatively severe cuts in FY93. Specifically, the FY93 reduction in support for nuclear theory at national laboratories, for operations of ATLAS and the 88" cyclotron, and for the beginning of the gold beam operation at the AGS are damaging to the vitality of the field. The Subcommittee recommends that the deleterious impact of these cuts be corrected to the extent possible.

The Subcommittee endorses the perspective of the Long Range Plan (LRP), and recommends that the construction of the new major facilities, CEBAF and RHIC, be completed without further delays, so that they may start their important research programs in a timely fashion. It also supports the scientific recommendation of the LRP regarding KAON. However, construction funds for this Canadian project, within the present budgetary framework, could only come toward the end of the period of RHIC construction.

The projected phase out of LAMPF indicated in the FY93 Congressional Budget Submission would affect what has been the major nuclear facility in the U.S. for two decades. During this time the LAMPF research program has been scientifically productive, exploiting its beams of protons, mesons and leptons and providing fresh insights into nuclear physics. At present, some first-rate and intellectually challenging experiments that utilize unique features of the LAMPF facility are almost ready to start and are likely to have significant results completed in the next few years. For the intellectual integrity of the field and for reaping the benefits of major investments of funds and effort, the Subcommittee strongly recommends that means be found to keep the LAMPF facility operational

through FY95. Beyond that point, continued operation of LAMPF would depend on the extent of support that can be obtained from the many areas outside of nuclear physics in which the LAMPF facility has been an essential contributor and on possible new nuclear physics initiatives.

With the advent of the large DOE facilities of CEBAF, and RHIC, and a possible future KAON, there are many new challenges in the future for the national community of nuclear physicists. However, if KAON is not realized, the issue of providing at least some of the scientific capabilities of a high-intensity hadron beam source for nuclear physics will need to be addressed later in this decade. The scientific infrastructure and expertise in place at LAMPF could then be a substantial asset.

In responding to the budgetary scenarios in the charge the Subcommittee focussed on the science outlined in the LRP and its implementation, thereby defining a **'base scenario'**. The total of the base scenario summed over the five-year period is **less than** the sum of the 2% growth scenario. Because of the commitments to existing large construction projects and the requirement that the phase out of LAMPF be orderly, the base budget requires an increase above scenario (C) in FY 94 and 95 but returns to the FY93 level by FY97 – thus making no longer-term commitment to an increased funding level in the years beyond.

With 3% growth, one of several attractive new initiatives may be started before the end of this five year period.

In (B), with no real growth, and the strong NSAC recommendation of October 1991 that the construction of CEBAF and RHIC not be impacted further, the LAMPF program would have to be terminated abruptly, with no chance of an 'orderly phaseout', and with a serious loss of science and of a recent investment in new experimental capabilities. The high priority measurements cited in this report would not be carried out and **all** the LAMPF programs would end precipitously.

Under (A), resulting in a real decline in budgets, any chance of executing the Long Range Plan priorities would be **seriously compromised**, with a very damaging impact on the research vitality of the field. Both accelerated LAMPF phase out and withdrawal from KAON would be necessary, reducing the base budget by roughly $150M over the five-year period. In addition, a $40M reduction should come from research funds, a cap on operating funds for facilities, and a stretch out of RHIC construction into FY98. Such a scenario would not provide the nation the appropriate scientific return on the major investments in facilities and skilled manpower already in place.

NSF Summary.

The NSF program is entirely university based and is comparable in size to the DOE university program. The two medium-sized user facilities at Michigan State and Indiana University are unique and based on technically innovative accelerators. Their research programs are vigorous and of high quality, and their capabilities complement those of the DOE facilities. The small facilities and the user groups supported by the NSF are both integral parts of the base program endorsed above. The NSF program, funded at slightly less than 15% of the DOE program, has historically produced nearly half of the PhD's in nuclear physics and employed nearly one third of the post-doctoral research associates in the field. Increases significantly below inflation in the last several years have begun to erode the base program at NSF supported institutions and have had a particularly bad impact on small facilities and user groups. Incremental funding in these areas, particularly in equipment and technical infrastructure, has a high leverage in physics output. The Subcommittee recommends strongly that such additional support be made available by NSF, so that users can become stronger partners in the research efforts at user facilities.

In responding to the budgetary scenarios in the charge the Subcommittee again focussed on the science outlined in the LRP and its implementation, arriving at a base scenario corresponding to the 2% growth scenario. This plan would enable the NSF program to address a variety of exciting forefront issues in the field and keep pace with the increasing technical complexity of experimental apparatus required for modern nuclear research.

With a 3% increase some of the very interesting new initiatives listed in the body of this report could be implemented in the NSF program.

In (B), important losses in research capability would have to occur, such as a reduction affecting one of the major user facilities. The real cuts implied by (A) imply a serious compromise of the NSF program with broader negative implications in both its scientific and educational goals. They would require an in-depth review to identify the strongest components of the program.

II. BUDGETARY IMPLICATIONS.

In response to the charge from NSAC, a budget scenario was constructed through FY97 which would encompass the essential research activities in the DOE/NSF nuclear physics program during this period. The starting point corresponds to the President's FY93 request to Congress for the two agencies. Although the Subcommittee recognizes that detailed budgets respond to each year's fiscal realities, this scenario can function as a basis in the planning process; it represents an orderly evolution of the field.

DOE Budget Discussion

Base Scenario:

The FY93 budget submission for nuclear physics, which does not reflect a full cost-of-living increase, represents a reduction in spending power over FY92. In addition, real costs associated with ES&H and other oversight activities have increased. Addressing these costs is implicitly included in these budget considerations.

The scenario in Table 1 represents the primary basis of the discussion in this report, and the following text contains some explanatory comments for each category listed. Note that all budgets are in FY93 dollars.

Explanations to Budget Table 1.

CEBAF/RHIC construction: The figures are from the project construction data sheets in the FY93 Budget Submission to Congress.

KAON: Present funding constraints and scientific priorities in FY94-95 require that a US contribution to KAON construction be deferred until FY96, unless incremental funds are made available. If the Canadian government does not proceed with the KAON project, a new initiative should be addressed in this time frame.

National Laboratory Operations: This category includes the operation of all user facilities at the National Laboratories.

BNL: This budget profile includes funds for a research program using the newly implemented Au beam capability at the AGS in FY94-95, followed by an increase to begin RHIC operations in FY97. The FY96 allocation will support essential preparations for RHIC. These budget figures include the heavy ion

Table 1: **Subcommittee Base Budget Scenario for DOE (FY93 M$). See explanatory notes which are an integral part of the Table.**

	FY92	FY93	FY94	FY95	FY96	FY97
MAJOR CONSTR.	101	104	102	82	87	51
CEBAF	50	33	16	0	0	0
RHIC	51	71	86	82	62	16
KAON					25	35
LAB. OPS.	117	109	128	134	119	132
BNL	19	17	20	27	38	63
CEBAF	24	28	45	45	45	45
LAMPF OPS.	44	44	44	44	20	10
BEVALAC OPS.	19	10	6	4	2	0
OTHER OPS.	11	10	13	14	14	14
RESEARCH	151	150	158	168	176	180
UNIVERSITIES	54	55	57	60	63	65
LAB. RESEARCH	58	56	58	60	63	65
EQUIPMENT	39	39	43	48	50	50
TOTAL	369	363	388	384	382	363
NEW INITIATIVE					10	35
					392	398

research funds within the BNL budget, but other BNL research activities are included in "Laboratory Research".

CEBAF: This operations budget is based on the construction project data sheet plus some directed initiatives for ES&H, technology transfer and education. CEBAF management has requested additional funding which will be reviewed in the near future. These budget figures include the funds for research activities by the CEBAF scientific staff.

LAMPF: The statement in the Congressional Budget Submission, that the phase out of LAMPF be **orderly**, is assumed as discussed elsewhere in the report.

Bevalac: A shutdown of all accelerator operations is assumed beginning in FY94, followed by preparation for decommissioning this facility.

Low Energy Heavy Ion Facilities: This represents a restoration of funds to correct for reductions in the FY93 budget and enables the exploitation of new capabilities such as Gammasphere and APEX.

Research: These items include the research activities at the Universities (including operation of University facilities) and at the National Laboratories (except BNL heavy ion research and CEBAF research, which are included in their operations budgets). The equipment budget includes AIP and GPP funds for accelerator facilities. Modern nuclear physics research requires larger apparatus of increasing complexity and technical sophistication. This will require increased funding for equipment projects. Recent examples in this trend are Gammasphere, SNO, and CEBAF equipment. Strong involvement of user groups is an essential feature of such projects and necessarily entails improvements in their technical infrastructure. It is estimated that an approximately 4% annual real growth will be required to address this need. Special attention should be given to University-based research and somewhat larger increases are indicated for this category.

Response to the Charge:

The needs for orderly implementation of the 1989 Long Range Plan are presented in the base scenario. The base scenario incorporates the following features: strengthening the research effort (particularly at universities) in a manner commensurate with the scientific and educational challenges of the coming decade; timely completion of CEBAF and

RHIC, two major new facilities which will provide a new research focus for a substantial number of scientists; phase out of the operations of the the Bevalac and Holifield facilities, and operation of LAMPF through FY95, consistent with accomplishment of the highest priority science; and a contribution to the construction of KAON. This base scenario has the same FY97 and FY93 budgets (inflation-corrected) but with an intermediate bulge in FY94 and 95. This bulge cannot be avoided if one includes both the required progress towards the important CEBAF and RHIC research goals and the orderly operation of the base research program. The detailed description of the activities associated with implementing the Long Range Plan in the context of this scenario is given in the DOE Program section of this report. All discussions are in FY93 dollars.

Scenario C: The base scenario has a profile which is above Scenario C in FY94-95 and below it in FY96-97. This is a modest growth picture which will position our science in a world-leading posture. The FY97 budget returns to the FY93 level. The Subcommittee strongly urges the modest temporary increase in the FY94-95 budgets needed to implement the essential Long Range Plan recommendations.

With a 3% annual growth rate, a modest initiative envisioned for mid-decade in the 1989 LRP can be started. As indicated in the LRP, the priority among possible initiatives will be determined in the context of more developed scientific and technical plans. In the relatively short time since the 1989 LRP, several interesting ideas have indeed been developed by various research groups. For example, the scientific case for a major radioactive beam facility (Isospin Laboratory) has been studied in some depth. The program would range from the study of nuclear structure far from the valley of stability to reaction studies of great importance in astrophysics to new studies of weak interaction decay processes. There are a number of options for the siting of such a future facility and several exploratory radioactive beam projects are under way. Other examples include a high-intensity pion beam at 1-2 GeV for hypernuclear physics and enhanced muon and neutrino sources for studies of electroweak effects, both of which would probably require some form of LAMPF operation. Additional possibilities will likely emerge over the next few years in response to new scientific issues.

Scenario B: This scenario requires a total five-year reduction of $65M from the base budget, with most of the reduction needed in FY94-95. With the strong NSAC recommendation of October 1991 that the construction of CEBAF and RHIC not be impacted

further, there is then little choice but to terminate the LAMPF program abruptly, with no chance of an 'orderly phaseout'. A serious loss of science and of investment of money and recent effort in new experimental capabilities would result. The high priority measurements cited in this report would not be carried out and **all** the LAMPF programs would have to end precipitously.

Scenario A: This scenario requires constant as-spent dollars. To translate this into FY93 dollars requires an assumption about inflation, taken at an average annual deflator of 3.4%, based on OMB projections. This scenario then represents a reduction of $184M from the base scenario over the five-year period; in FY97 the budget would be reduced to $307M. This would **seriously compromise** any chance of executing Long Range Plan priorities and have a very damaging impact on the research vitality of the field. Both accelerated LAMPF phase out and withdrawal from KAON would be necessary. In addition, a further reduction of $40M should come from a combination of research funds and a cap on operating funds for facilities – together with a stretchout of RHIC construction into FY98. Such a scenario would not provide the nation the appropriate scientific return on the major investments in facilities and skilled manpower already in place.

NSF Budget Discussion

Base Scenario:

The scenario that represents the primary basis of the discussion of the NSF program in this report is shown in Table 2 and the following text contains some explanatory comments for each category listed. Note that all budgets are in FY93 dollars.

Table 2: **Subcommittee Base Budget Scenario for NSF (FY93 M$) (See explanatory notes which are an integral part of the Table).**

	FY92	FY93	FY94	FY95	FY96	FY97
IUCF & MSU base grants	19.9	19.9	19.9	19.9	19.9	19.9
UNIV. LABS. base grants	9.8	9.9	10.1	10.4	10.7	10.8
USERS base grants	13.5	13.9	14.5	15.1	15.7	16.4
EQUIPMENT grants	2.0	3.0	3.1	3.1	3.3	3.4
OTHER	1.7	1.7	1.8	1.8	1.9	1.9
TOTAL	46.9	48.4	49.4	50.4	51.4	52.4

Explanations to Budget Table 2.

IUCF/MSU: These laboratories are the major nuclear physics user facilities operated by the NSF. They are both serving large user communities very effectively and both have had significant upgrades in recent years. Continued operation under constant dollar (inflation-corrected) budgets is assumed for these two facilities.

Major Equipment: "EQUIPMENT" includes both equipment grants for special equipment not included in the base grants and equipment items specifically mentioned in the budget document. This includes funds for completion of the S-800 spectrograph at MSU, and for a proposed spectrometer at IUCF.

Users: The NSF supports an excellent user program utilizing major NSF, DOE and foreign accelerator facilities as well as non-accelerator activities. Modern nuclear physics research requires larger apparatus of increasing complexity and technical sophistication. This will require increased funding for equipment projects. Recent typical examples in this trend are Gammasphere, SNO, and CEBAF equipment. Strong involvement of user groups is an essential feature of such projects and necessarily entails improvements in their technical infrastructure. It is estimated that approximately 4% annual real growth will be required to address this need.

University Laboratories: These laboratories have important in-house research programs and substantial user programs at larger facilities effectively employing the better infrastructure available to these groups. Only about 25% of funds supporting these laboratories is going toward accelerator operations. Approximately 2% annual real growth will be needed in this area.

Response to the Charge:

As in the case of DOE, in the NSF base scenario the needs for orderly implementation of the 1989 Long Range Plan are presented. It incorporates essential features of the LRP recommendations, particularly the strengthening of the research effort at universities in a manner commensurate with the scientific and educational challenges of the coming decade. In the following, as was done for DOE, these scenarios are always discussed in FY93 dollars.

Scenario C: This scenario represents 2%-3% real growth above inflation. The base scenario has 2% annual growth. This modest growth will position the NSF program to utilize the opportunities in the science and help put the field in a world-leading posture. The Subcommittee strongly urges that this modest growth, consistent with recent increases in the overall NSF research budget, be sustained.

A 3% per year growth scenario gives a 5 year sum approximately $5M greater. This would have a substantial impact on NSF's ability to pursue exciting new physics. The significance of such an increase becomes clear if one considers the possible initiatives being discussed in the NSF user community at the moment. A partial list includes: a new double beta decay experiment using liquid xenon; Borexino; a CEBAF detector (such as for parity violation studies); a special purpose detector for a high energy experiment such as HERMES; BLAST, a large acceptance detector for internal target studies with electrons; a major subsystem of a large RHIC detector such as PHENIX, or a special purpose small RHIC detector; a second IUCF spectrometer; an upgrade at MSU for enhanced radioactive beam capability; a new neutrino mass measurement. The sum of equipment costs associated with these initiatives substantially exceed the funds available over the 5 year period. Thus, the modest growth scenario has considerable leverage for the NSF nuclear physics program.

Scenario B: This scenario requires a reduction of $10M from the base budget. The

program could accommodate this by holding all funding categories constant. However this strategy would sacrifice the highly leveraged opportunity to pursue selected initiatives of the type described above and have a strongly dampening effect on the field. A better strategy might be to retain some growth in selected user and small lab programs while reducing operation at one of the two major user facilities.

Scenario A: This scenario requires constant as-spent dollars. As was done for the DOE budget, a 3.4% annual deflator was used. This scenario then yields a 5 year sum of $226M, a reduction of $26M from the base scenario. This would seriously compromise the effectiveness of the program. Squeezed operations at the large user facilities (MSU and/or IUCF) could not accommodate nearly so large a reduction. Neither could any credible reduction of the university lab effort. It is clear that a reduction of this magnitude would require a comprehensive program review, since any alternative would have severely negative consequences on the Foundation's research and education programs in nuclear physics. Such a reduction would undermine the very successful university-based program in nuclear physics at a time of significant expansion in the intellectual opportunities of the field and have a major negative impact on graduate students.

III. THE DOE RESEARCH PROGRAM

Nuclear Physics is at a crucial juncture. Several major facilities, now under construction, will open up a new frontier at the interface between hadronic matter as quarks and gluons (QCD) and the nuclear many body system. CEBAF, the first of these large facilities, is expected to come into operation in the next couple of years, the other, RHIC, later in the decade. The DOE supports all the large facilities in the field, as well as several more modest ones. With curtailed DOE budgets, readjustments in the activities of the field are inevitable. Some such readjustments have already occurred or are about to occur (e.g. the accelerated phase out of the Bevalac and the closing of the Holifield Facility).

Although it is essential to pursue the exciting physics uniquely possible at large facilities, the important scientific opportunities of the field extend across a variety of energies and distance scales. This diversity is a strength of the field and a source of its vitality. This is illustrated by the list of recent discoveries given in the overview which contains examples of physics carried out at facilities over the entire energy spectrum. It is thus essential that the excellent science supported by DOE at universities and national laboratories remain healthy in the face of the programmatic demands of the large facilities. It should also be evident that DOE support of user groups, of non-accelerator experimental physics (e.g. solar neutrino research), and of nuclear theory are integral and essential components of the total scientific effort of the field.

Since 1989 when the scientific priorities of the field were presented in the Long Range plan, progress has been made in implementing a number of its recommendations. Regarding the major facilities the subcommittee makes the following observations:

1. The Long Range Plan identified 'the timely completion of CEBAF and the beginning of its important research program' as the highest priority construction project for the field. The Subcommittee was pleased to learn about the progress on this project in terms of construction as well as preparation of equipment, and looks forward eagerly to the start of the research program at CEBAF in Spring 1994, and to 4 GeV research operation in late 1994.

2. The 1989 Long Range Plan assigned highest priority for new construction to the Relativistic Heavy Ion Collider, RHIC. The Subcommittee was pleased to note that the project has now moved to full construction, and that large experimental groups for detector construction have been formed. The Subcommittee expects that the RHIC detector capabilities will be ready to address essential physics issues of the

quark-gluon plasma when the collider becomes operational and look forward to the opening up of this exciting area of research in the near future.

3. The Long Range Plan also recommended that negotiations be started concerning U.S. participation in the Canadian KAON project. The Subcommittee continues to see the Canadian KAON project as an attractive and a cost-effective way for nuclear physics in the United States to achieve some of the important objectives of our field: for instance, in hypernuclear physics and in the physics associated with intense antiproton beams. However, until RHIC is substantially completed such support would have to come from outside the budgetary framework for the rest of the field within the United States. If the Canadian government does not proceed with KAON in a timely fashion, a new initiative should be addressed in this time frame.

4. Of the major facilities, LAMPF has to receive special attention, in view of the stringent budget outlines that were contained in the Subcommittee's charge. The research program at LAMPF has been scientifically productive over the past two decades, providing fresh insights into nuclear physics. At present, some first-rate and intellectually challenging experiments that utilize unique features of the LAMPF facility are almost ready to start and are likely to have significant results completed in the next few years. For the intellectual integrity of the field and for reaping the benefit of major investments of funds and effort, the Subcommittee strongly recommends that means be found to keep the LAMPF facility operational through FY95, possibly in a restricted mode with focus on obtaining results from these key experiments, (such as the ν – p measurement, MEGA, and the investigations of parity violation in neutron resonances). The Subcommittee was also impressed by the multiplicity of uses for LAMPF in fields of basic science other than nuclear physics and in more applied investigations.

A strength of nuclear physics, and its experimental side, is the multiplicity of ingenious techniques that its scientists bring to bear on the study of the properties of nuclear matter and nuclear interactions. Facilities may be 'electromagnetic', 'hadronic', etc – but physicists are able to transcend techniques. The scientific goals of the field are its basic motivation and driving force, and it is entirely appropriate that the user community for new nuclear physics facilities should grow out of the existing ones and thus benefit from

the accumulated skills, experience, and wisdom.

CEBAF

The use of electromagnetic probes is of central importance to the study of the structure and properties of nuclei and nucleons. In the last decade, experiments have revealed new and unexpected features of nuclear and hadronic systems. For example, studies of the electromagnetic response, both in quasielastic kinematics and for selected nuclear transitions, have mapped out the single-particle nature of nuclei with great precision and show the importance of short-range correlations for the first time. The role of meson exchange currents in elastic and inelastic electron scattering has been firmly established. The effects of nuclear binding on the quark-gluon substructure of the nucleon were first observed, leading to a new effort to understand nuclear matter at this fundamental level. The surprising discovery that little, if any, of the nucleon's spin appears to be carried by the quarks has forced a re-examination of our picture of the quark structure of the nucleon and spawned a new generation of exciting complementary experiments to explore this issue.

CEBAF, with its high-intensity CW electron beam at energies up to 4 GeV, is well positioned to continue this tradition. The unique capabilities that will become available at CEBAF in the next few years will make it the premiere facility for electromagnetic nuclear physics in the world. Coincidence experiments at CEBAF energies will enable direct exploration of nuclear short-range effects in regions of phase space that are currently unattainable. This will provide a stringent test of QCD models of the nuclear force at distances smaller than the radius of the nucleon itself. The possibility that strange quark-antiquark pairs contribute to the vector-current amplitudes of nucleons will be studied using parity-violating electron scattering. Multi-particle coincidence experiments measuring spin observables will allow detailed exploration of nucleon resonances to test the applicability of quark models and search for exotic excitation modes of the nucleon, such as hybrid baryons where the gluon field is excited.

At present, operation is anticipated to begin with 800 MeV beams in early 1994 and the research program with 4 GeV beams to start later that year. It is hoped that full-time, steady state operation of the complete facility will be achieved in FY96. CEBAF management has requested an increase in operating funds starting in FY96, and this request will be reviewed by NSAC later this year. A plan for the experimental program is in place, and over half of the beam time for the first three years of operation is already

committed to approved experiments. The central importance of CEBAF's capabilities to the field of nuclear physics justifies the continued emphasis on the timely completion of the facility and the initiation of its research program.

RHIC

RHIC is a collider for the heaviest atomic nuclei at energies of up to 100 GeV/nucleon. Its central physics purpose is to search for and measure properties of a new "deconfined" form of nuclear matter, the quark-gluon plasma. Construction has now started, with an anticipated completion date of 1997. The final prototype for its superconducting magnets exceeded magnetic field strength and field quality specifications. An extensive dialog between BNL and the nuclear and high-energy physics communities recently led to formation of major collaborations to mount two large experiments at RHIC. These collaborations include participation from Europe and Japan. Groups planning smaller experiments are also being established.

A quark-gluon plasma is expected at a mass-energy density some 10-20 times higher than anything produced to date in the laboratory. In such a plasma, the normal hadrons dissolve into their constituent quarks and gluons, which are then free to move over a large region of space-time. Similar conditions are thought to have existed previously about 1 microsecond after the Big Bang.

Planning for RHIC experiments has centered on the measurements needed to distinguish between a plasma and a hadron gas. These include measurements of phase-space densities of particles, where fluctuations in these densities signal critical phenomena; of spectra for heavy vector mesons, whose production might be hindered due to screening of the quark binding potential; of hadrons carrying multiple strange quarks whose production should be greatly enhanced in a plasma; of differences in the energy loss of a quark or gluon traversing hadronic vs. deconfined matter; of electromagnetic radiation, which should reflect the energy and number density of the emitting volume; and measurement of decay branching ratios of low-mass vector mesons, which should be affected by deconfinement or restoration of chiral symmetry.

The sum of the RHIC project funds designated for large detectors is limited and will require careful choices. Opportunities exist to attract further foreign participation to the collaborations and to enhance the base capabilities of both detectors through foreign contributions. It is imperative that detection capability be ready at the completion of RHIC, within the present budgetary framework of the RHIC project, that will be able to

address central physics questions concerning the existence and properties of a quark-gluon plasma.

The issue of manpower distribution within the heavy-ion community between the AGS Au-beam and CERN Pb-beam experiments on the one hand and construction of detectors for RHIC on the other will need to be addressed soon.

KAON

The proposed KAON facility at TRIUMF is a 100 μA, 30 GeV proton accelerator capable of delivering intense secondary beams of kaons, pions, antiprotons, muons, neutrinos, and other particles. With such a facility, a broad range of hadronic and electroweak issues in elementary particle and nuclear physics will be addressed. A number of the high-priority nuclear physics questions identified in the 1989 Long Range Plan can be explored at a new level of precision at a high intensity facility such as KAON.

Among these is the investigation of hypernuclei with unprecedented energy resolution of order 200 keV, and studies of antimatter annihilation in nuclear matter. A high resolution spectrometer capability, together with intense pion and kaon fluxes, would enable qualitative improvements in the knowledge of how strange baryons interact in the nuclear medium – how strange quarks interact in the non-perturbative low-energy regime of QCD. The present status of hypernuclear physics is analogous to the early days of nuclear structure physics, when very little information on energy levels, magnetic moments, transition rates, and approximate dynamical symmetries was known. Precise data on hypernuclear magnetic moments and weak decays, for instance, would relate to the key issue of partial deconfinement of quarks in a nucleus and the connection between meson exchange and explicit quark models for baryon-baryon forces.

At present, some hypernuclear research is carried out at the AGS, with a proton current of 1 μA. At CEBAF, with suitable detectors, there might be some capability to probe the spin-flip strength in hypernuclei at high resolution. If it became possible to proceed with PILAC at LAMPF, it would provide a capability for hypernuclear structure with pion beams comparable to that attainable at KAON.

In the 1989 Long Range Plan, it was recognized that physics with hadronic beams plays a central role in the future of nuclear science, and that many exciting scientific opportunities would be opened up if a high intensity hadron facility were to be built. With many of the facilities required for nuclear physics becoming large and costly, it is appropriate that the U.S. nuclear program participate in international endeavors to help achieve

its scientific objectives. Given that the operating costs of KAON would be entirely paid by Canada, U.S. involvement in the facility construction and detector development for KAON is seen as a cost effective strategy. However, although the Subcommittee strongly endorses the physics case articulated in the Long Range Plan for an intense hadron beam facility, it concludes (as did the LRP) that the requested construction funds, of order $100M, cannot be fitted into the budget required for the other components of the Nuclear Physics program until the construction of RHIC is substantially complete.

LAMPF

Current and foreseeable budgetary stringencies suggest that long-term LAMPF operation is in jeopardy. This is explicit in the FY93 President's Budget request, which states that "A transition plan will be developed with the Nuclear Physics community to permit an orderly phaseout of LAMPF." It is clear to the Subcommittee that significant scientific opportunities would be missed and substantial investments in new capabilities and experiments would go unexploited with a premature phase out. Furthermore, potentially important and unique options for new scientific programs at the end of this decade will be lost. The research programs being carried out at LAMPF go well beyond the traditional scope of nuclear physics, encompassing both other areas of fundamental physics and major applied physics programs.

The great diversity of LAMPF's programs stems from the fact that the very intense 800 MeV proton beam generates copious secondary beams of pions, muons, neutrons and neutrinos. All of these probes support active user programs. The centerpiece of current LAMPF research is the study of electro-weak physics with neutrinos, muons and neutrons. This program both uses the electroweak probe as a novel way to study nucleon and nuclear structure and pushes the limits of the Standard Model. Specific examples are:

1. Low energy neutrino-proton elastic scattering will provide unique information on the quark structure of the proton, specifically its strange quark content. This issue, raised by recent results in polarized lepton deep-inelastic scattering, is central to modern theories of hadron structure and is being pursued by new complementary experiments at several laboratories. At LAMPF, the data will be obtained with a new detector, the Liquid Scintillator Neutrino Detector, now in its final stages of construction. Data taking will start in 1993 and, with upgrade of the beam stop, sufficiently accurate results should be available by 1995.

2. Muon capture in polarized ^{3}He will be used to measure the induced pseudoscalar coupling constant in a nucleus. This coupling constant is of great interest in QCD; it is not present in the fundamental quark current but rather is "induced" by the strong interaction which confines quarks in hadrons. The polarization measurement will allow much greater precision than has been achieved to date. The MEGA detector, which has been in construction for several years and will start taking data in 1992, will search for the decay $\mu \rightarrow e+\gamma$ with two orders of magnitude greater sensitivity than has been achieved elsewhere. This transition provides a fundamental test of lepton family conservation. In the estimate of the Subcommittee these two muon experiments can achieve meaningful results with three years of data-taking.

3. The first LAMPF measurements of asymmetries in the resonant scattering of polarized epithermal neutrons, recently yielded an unexpected systematic behavior. This has been related to an average parity-violating matrix element which in turn must be related to the parity-violating nuclear force. Measurements on parity-violating strength functions in a number of key nuclei using LANSCE, the pulsed neutron spallation source of unmatched intensity, should obtain substantial data within the next two years. An extension of the program would search for time-reversal violation.

The Subcommittee recognizes that these highest priority programs now underway, many of them having required significant equipment development over a number of years, cannot achieve their goals in FY93. They need another two to three years of beam time. Since all of these initiatives involve extensive outside collaborations, both with faculty and with graduate students, not only would the science be lost but so would a major investment of the national community's manpower if LAMPF operations were terminated in FY94. In short, this would not be an orderly phase out. The Subcommittee strongly urges that incremental funds be sought to maintain LAMPF operations through FY95. Running more beam hours to focus on the highest priority experiments and curtailing other parts of the program may be necessary to achieve the scientific goals.

LAMPF also supports many interesting programs with hadron beams. For example, the Neutral Meson Spectrometer will start operating shortly and spin-observables in π+p charge-exchange and pion production will provide information that will constrain chiral perturbation theory. The NMS will also offer the possibility for studying both the single and double charge-exchange reactions with pions and may help clarify the structure of

Giant Resonances. The proton beam program has new instruments in place that will allow studies of polarized nucleon charge exchange scattering to isolate the longitudinal and transverse spin-isospin nuclear response functions. Large number of user groups are involved with these programs. Although some of programs may be lost in focussed operation, it may be possible to pursue others in such a mode with little incremental cost.

It should also be noted that many communities (nuclear physicists, particle physicists, atomic physicists, condensed matter physicists, materials scientists) benefit from LAMPF and that major current or planned applied programs can be served uniquely by LAMPF. For example, LANSCE is one of only two intense pulsed neutron sources in the U.S. Its program spans the fields of solid-state physics, chemistry, metallurgy, crystallography, biophysics and materials science. Important applied physics activities are both ongoing (e.g. radioisotope production, radiation effects in materials, and muon induced fusion) and under active consideration for development (e.g. nuclear waste transmutation and tritium production). All of these applications are based upon the availability of the very intense primary beam and secondary beams of neutrons and muons. Therefore, although historic patterns of LAMPF operations funding do not reflect this broad set of constituencies and applications, it may be that multiple funding sources would be appropriate and would preserve capabilities for pursuing some nuclear physics goals.

Finally, we turn to possible upgrades, since these also represent opportunities lost in a LAMPF phase out. These include several modest initiatives (i.e. up to a few million dollars) which could yield short-term dividends. A beam stop upgrade for in flight neutrinos would increase the counting rate for the neutrino program by a factor of five. A heavy-ion production target and mass separator would provide an opportunity for a novel atomic parity violation measurement in a series of isotopes and would establish some of the technology required for a radioactive beam facility. An ultracold neutron source based at LANSCE would provide possible future world-leading capabilities for precision measurements, such as further improving the bound on the neutron electric dipole moment.

For the longer term, a number of innovative and attractive upgrades in the \$50M to \$100M range would also be lost:

- PILAC, a proposed superconducting linac which would accelerate the secondary pion beam from LAMPF to 1 GeV with an intensity of 10^9 π^+ per second. The centerpiece of the physics program with PILAC would be an unprecedented ability to study hypernuclear physics. A critical element in PILAC is the ongoing development of superconducting cavities with the required characteristics;

- A Pulsed Lepton Source, providing a unique source of pulsed muons and neutrinos for fundamental measurements (this could be operated with LAMPF in a reduced mode, concurrently with operation of LANSCE.)

- A second-generation radioactive beam facility, providing beams of radioactive nuclei to study reactions of astrophysical interest, the properties of nuclei at the limits of stability, the nuclear physics of nuclei with exotic N/Z ratios, and the weak interactions.

The desirability of these upgrades is contingent on developments over the next few years, specifically with respect to KAON. If KAON is not beginning construction in the next years, the funding agencies and the nuclear and particle physics communities will need to readdress the issue of providing some of the KAON capabilities in the U.S. in the longer term. LAMPF would undoubtedly be central to such discussions.

Low-Energy Facilities

The low-energy facilities remain an essential scientific component of the field of nuclear physics. Indeed the Long Range Plan for Nuclear Science identified a number of areas where such facilities are crucial, including the precision studies at low energies of fundamental symmetries, of the nucleon-nucleon interaction, and of few-body systems, as well as the investigation of nuclear structure under extreme conditions: e.g. high spin, high excitation energy, and at the limits of the valley of beta stability. In the DOE program there are a few national user facilities with different capabilities that address such issues, as well as several university facilities.

a. The Low-Energy Heavy-Ion National User Facilities.

Three low-energy heavy-ion laboratories have been historically at the core of the base program for nuclear science at DOE: ATLAS at ANL, HHIRF at ORNL, and the 88" cyclotron at LBL. These facilities have collectively provided about 12,000 hours of research beam time in 1991. Although they have a substantial resident research staff, they are user facilities serving a wide constituency of university groups, with an array of advanced instrumentation suited for nuclear structure and reaction physics near the Coulomb barrier.

Among the notable recent scientific achievements of these laboratories has been the study of hot and cold nuclei at the limits of angular momentum and the investigation

of the static and dynamic properties of hot nuclear matter. Major dedicated pieces of instrumentation have been developed at these laboratories and some of them are still under construction: Gammasphere, to be located at LBL for the initial period of operation until about 1996; c.w. uranium beam capability and the APEX detector for electron-positron studies, as well the Fragment Mass Analyzer with a BGO array at ATLAS.

In addition to their research missions these laboratories make a substantial contribution to the education of students, and the training of postdocs in the technology of nuclear physics.

The Subcommittee concludes that these laboratories have timely research programs which address the scientific priorities of the Long Range Plan and thus merit continuing support at a level that allows efficient use of these facilities.

b. University Facilities

The DOE university nuclear-physics laboratories are a valuable research, teaching, and training resource for the country. They are engaged in forefront research in many diverse areas. They also offer an excellent training ground for students particularly because of the opportunities for the extensive hands-on experience possible at an in-house facility.

The largest of these, the Bates facility, has pioneered nuclear structure studies with high-resolution electron scattering, the investigation of few-body systems, and measurements with polarized electrons, including parity violation. The pulse stretcher ring, now under construction, will provide new capabilities with c.w. beams (polarized and unpolarized) such as polarized internal targets experiments and novel structure functions using the new out-of-plane spectrometer. When completed in 1992, this will emphasize physics that leads into and complements the research at CEBAF at higher energies and continues to attract excellent graduate students.

The DOE university laboratories with low-energy heavy and light ion beams make important contributions in a variety of areas: to nuclear structure, to nuclear astrophysics, exacting studies of nuclear symmetries and conservation laws (e.g. charge symmetry and charge independence, isospin, parity violation) and precise studies of the nuclear force (e.g. tensor components, 3-nucleon components) in the nuclear medium. Often such work involves sophisticated instrumentation and capabilities such as polarized beams and targets. Other programs, in the study of collectivity and correlations in heavier nuclei, stress giant resonances and phenomena at high spin, or focus on special topics such as weak interactions, chaos, and symmetry in highly excited states.

Groups based at these laboratories are often important components of collaborations at major national facilities; long-term in-house familiarity and experience in, for instance, spectrometer design and construction makes these groups valued partners in such efforts.

The university facilities form a cost-effective, highly leveraged, resource. They provide intellectual breadth to the field by addressing a wide variety of aspects of the physics of the nucleus and balance the technology of big and small science in the overall national amalgam. The DOE equipment initiative at university laboratories had a very positive impact on the research vitality at these institutions.

Other Experimental Activities.

An impressive and diverse array of nuclear physics studies is pursued either with stand-alone detectors, reactors or at high-energy physics accelerators. Recent examples are experiments on color transparency, and on anti-quark distributions in nuclei obtained from Drell-Yan processes which are carried out at high-energy physics accelerators. Tests of the Minimal Standard Model are performed in experiments on two-neutrino and neutrinoless beta decay and the understanding of the long-standing solar neutrino problem is sought using sophisticated, stand-alone detectors such as SAGE, GALLEX and SNO. Studies using synchrotron light sources and reactors focus on themes ranging from quadrupole excitations of the delta with polarized photons to nuclear structure studies of the interplay between collectivity and the single particle nature of nuclei. These activities represent cost-effective utilization of unique resources to address important and timely issues in nuclear physics.

IV. THE NSF RESEARCH PROGRAM

The research program supported by the National Science Foundation is an essential component of the national effort in nuclear physics. The NSF facilities address a variety of issues in the low and medium energy domain that were highlighted in the Long Range Plan for Nuclear Science. The Foundation's program has four distinct parts: two medium sized user facilities with unique characteristics, support for small university facilities and support for user groups at both DOE and NSF user facilities. All of the program is at universities and, although the dollar level of the NSF program is less than 15 % of the total funding of the field, it accounts for about 40% of graduate students supported and about 30% of postdoctoral associates.

The Subcommittee was asked to review these four components of the NSF program and to comment on their quality and the balance of funding between them. Thus, presentations were made to the Subcommittee not only on the two user facilities, but also on the user groups and small university laboratories supported by the Foundation. This request is the reason for certain asymmetries between the DOE and NSF parts of this report.

The National Superconducting Cyclotron Laboratory at MSU is, in the US, a unique facility in medium-energy heavy-ion research. A key focus of its research program is investigation of the equation of state of nuclear matter at intermediate excitation energy where the attractive and repulsive parts of the nuclear interaction balance. A new departure is the investigation of the properties of nuclei far from stability where new techniques are being developed to produce exotic nuclei and measure their properties. Funds are needed to complete a new spectrograph for this latter research. The Indiana University Cyclotron Facility has pioneered the development of a cooler ring for precision nuclear studies and has an active research program in nucleon-nucleon interactions as well as in the use of polarized protons for investigations of nuclear structure. The Subcommittee is pleased to note that the two physicists responsible for originating and implementing the novel concepts for these two facilities are the joint winners of the 1992 Bonner Prize of the American Physical Society.

The NSF provides extensive support for university physicists as users at facilities away from their home institutions. Indeed, about 40% of the funding for the smaller university facilities currently goes towards support of their user efforts at other facilities. This user program enables many more university groups to participate in forefront work at medium-scale and major user facilities than would otherwise be able. These user groups pursue a

broad range of topics ranging from low-energy nuclear structure to tests of QCD in nuclei.

The NSF also currently supports small facilities that carry out research programs with important elements of excellence while also providing foci for user activities and playing an important role in education of graduate students. These facilities have a strong effort in the areas of collective behavior and the properties of nuclei far from stability. Well-recognized efforts in nuclear astrophysics and investigation of fundamental symmetries are pursued.

The Subcommittee notes however that both the in-house research and the user activities would particularly benefit from incremental funding. In order to maintain their viability and record of excellence in research, the small facilities need to have support for occasional equipment and upgrade projects, and some of the user groups need equipment and development of their technical infrastructure.

The National Superconducting Cyclotron Laboratory At Michigan State University.

The National Superconducting Cyclotron Laboratory at Michigan State University (NSCL) is the major university-based heavy-ion facility in the national nuclear physics program. It is centered around a very modern accelerator, the K=1200 superconducting cyclotron providing heavy-ion beams from 10 to 200 MeV/u, and a large complement of front-line detection equipment. The excellent in-house faculty, both experimental and theoretical, provides a base program which supports over thirty graduate students. The significant intellectual leadership for the experimental program and the strong university commitment to nuclear physics are strengths of this laboratory and speak well for its long term viability. Much of the superconducting cyclotron technology as well as the superconducting beam-handling technology that led to the A1200 beam and reaction-product analysis system was developed in the laboratory.

NSCL has developed a users program of notable scale, with a good mix of inside vs. outside-led experiments. It is noteworthy and encouraging that large pieces of equipment are motivated and built by the users themselves. Funding for such equipment has come frequently from DOE.

The physics program of the laboratory ranges from nuclear reaction mechanisms at intermediate energy through properties and reactions of unstable nuclei, to astrophysical questions. A very productive program in nuclear reaction studies recently centered on nuclear matter flow, specifically the balance between attractive and repulsive scattering,

and on two-particle correlations and the extraction of in-medium cross sections using transport theory. The advent of the A1200 fragment analyzer system has opened a major new direction of research using secondary beams of unstable and exotic nuclei. Limits of stability near the proton drip-line in the mass region above Fe have been set which are of astrophysical interest, and work on the two-neutron decay of the 'halo nucleus' ^{11}Li as well as indications of the soft-dipole mode begin to pin down the properties of this exotic nucleus.

A proposed and already partially funded S800 spectrograph is an excellent initiative that will expand, in conjunction with the A1200 system, the program with secondary beams and will enrich the overall program in other areas. NSCL is an excellent laboratory, well managed and superbly staffed. The laboratory's emphasis on technical excellence has served it well and also benefits the larger nuclear physics community. The laboratory's staff also participates effectively in research at a number of other facilities.

The Indiana University Cyclotron Facility.

The Indiana University Cyclotron Facility (IUCF) is a very productive laboratory that focuses on experiments involving light-ion beams of 100-200 MeV kinetic energy. Its major accelerators are a large separated-sector cyclotron and a 500-MeV cooler-storage ring. Experiments carried out by its large and active user community frequently involve use of polarized beams; recent experiments also make use of stored beams and internal targets in the cooler ring. Indiana University demonstrates continuing strong support of this laboratory through sponsorship of facility improvements and physical plant expansion in addition to maintaining a large faculty presence. Some thirty in-house graduate students participate in the programs at IUCF.

This laboratory is noted for having established much of our knowledge of Gamow-Teller strengths and distributions through the (p,n) reaction. It has recently completed a pioneering measurement of charge-symmetry violation in the nucleon-nucleon interaction. This latter effort has convincingly demonstrated the effect of rho-omega mixing in the charge-symmetry violating amplitudes. This represents an important test of our ability to calculate nucleon-nucleon interaction effects in a meson exchange picture. The laboratory has been a world leader in the development of storage ring technology for cooled beams. The IUCF Cooler Ring is a highly successful accelerator technology project, with recent first successful demonstration of so-called "Siberian Snake" systems, which are vital for the storage of polarized beams. As a result of the work at IUCF, Siberian Snakes are now

under active development at several high-energy physics laboratories.

A number of well-chosen experiments are just getting underway, using both the external polarized nucleon beam and the stored beam in the Cooler. For example, spin observables in selected elementary excitations will be used to study in-medium effects on the nuclear force. Cooler experiments using internal targets (including polarized gas targets) will provide new information on threshold pion production and on the structure of three-body systems. For the longer term, there are several initiatives based at a proposed new spectrometer at the Cooler. These include: high-resolution charge exchange studies using the (d,^{2}He) reactions, which act as a complement to the extensive (p,n) studies noted above and help fully determine Gamow-Teller matrix elements; novel studies of hitherto unobserved $\pi^+ - \pi^-$ atoms; use of polarized nuclear targets to separate Fermi and Gamow-Teller strength; and new tests of charge-symmetry breaking. Further developments of these possibilities and the associated instrumentation needs will be important in determining the future Cooler research program. The laboratory's staff also participates effectively in research at a number of other facilities.

Users

The user program supported by the National Science Foundation includes current research activities spanning most of the forefront areas of the science and involve well over one hundred graduate students. Many frontier experiments addressing diverse issues have been proposed for the new CEBAF facility. Certain NSF supported user groups are playing significant leadership roles in detector development for the RHIC project. NSF users participate at all the major national nuclear physics facilities in the U.S., as well as at facilities in France, Canada, Japan and Switzerland.

Experiments carried out by NSF-supported users address numerous topics in nuclear structure including measurements of magnetic moments of nuclei far from stability, studies of shape coexistence and of highly deformed nuclei, and precise spectroscopic measurements using laser techniques. Experiments involving polarized beams or targets are used to investigate the spin response in nucleon scattering, as well as electromagnetic and neutral weak form factors of the nucleon in electron scattering. High-resolution electron scattering is used to determine the structure of few-body systems at short distances, to provide stringent tests of meson-exchange currents, relativistic effects, and models for off-shell nucleon form factors. Beams of unstable nuclei are used to study topics in astrophysics as well as to determine properties of these isotopes. High-energy beams at

large facilities are used to investigate stopping of energetic baryons, color transparency, and effects of the nuclear environment on hadron production, and production of exotic hadrons in which the gluon field is excited. Experiments proposed for upcoming facilities include measurements of short-range correlations, effects of meson-exchange currents, strange quark content of the proton, and structure of baryon resonances.

There is a need for increased equipment funds and technical infrastructure in the NSF user program, given the diversity and scale of forefront efforts undertaken. The design, construction, and testing of equipment, particularly at their home institutions, can be an essential component of user programs. The science benefits from the broader range of ideas and expertise thus brought to bear, and direct involvement with developing equipment adds an essential aspect to the educational process for both graduate and undergraduate students. Added money may certainly also be used to support more users – and the balance is a delicate one – but the Subcommittee felt that the improvement of technical infrastructure for those NSF user groups pursuing apparatus development and construction projects should be emphasized for incremental funding.

Small Facilities

The small university laboratories supported by the NSF are an important component of the national nuclear physics effort. Research groups at these laboratories pursue a wide variety of exciting problems in nuclear physics using their in-house accelerators and they form an important component of the user program. Indeed about 40% of funding for universities with in-house facilities goes towards support of their user efforts at other facilities. Here, in contrast to most of the other NSF-supported user groups, the infrastructure built up around the accelerator frequently serves as an important technical base for these outside activities. Their research programs involve about a hundred graduate students. Only about 25 % of the support of these laboratories is used for direct support of accelerator operations.

Significant science is carried out at the small NSF laboratories. Indeed, their broad range of activities, and the scope of the Subcommittee's charge, makes it impractical to make a comparative assessment of achievements by individual laboratories. Much of the physics revolves around the unique many-body aspects of nuclei and the correlations in nucleonic motions. New techniques and instruments allow the study of how nuclei are stressed when they are brought to extremes of angular momentum as well as to high temperatures and to unusual proton-to-neutron ratios. Studies of low lying quadrupole and

octupole modes, of multi-phonon states, of superdeformation, and of giant resonances in hot nuclei shed light on new manifestations of collectivity and phase-transition behavior and on how these are related to underlying dynamical symmetries and residual interactions. Equally important work focuses on investigations of fundamental symmetries and on nuclei far from stability. These nuclei are studied, both in their own right and to induce secondary reactions, in new efforts to understand nucleosynthesis and the evolution of stars and supernovae.

In addition to their many contribution to the science, these university-based laboratories provide the opportunity for extensive hands-on experience by both graduate and undergraduate students. Small university facilities also allow researchers to pursue difficult research problems, or to develop ingenious new techniques, that require extensive use of accelerator time and hence may not be feasible at national user facilities.

Budgets have not kept pace with inflation. Significant reductions have occurred (e.g., the closing of the Rutgers and Illinois facilities) and funding has been constrained elsewhere. Some of the remaining laboratories have benefited from modest accelerator upgrades and most of them have been able to add new detector systems and instrumentation. Strong support of both the in-house and user infrastructure at such laboratories is a cost-effective investment in excellent science and in the quality of graduate training and should be a priority.

Department of Energy
Washington, DC 20585

JAN 24 1992

Professor Peter Paul
Chairman
DOE/NSF Nuclear Science Advisory Committee
State University of New York
Stony Brook, New York 11794-3800

Dear Professor Paul:

In 1989, the Nuclear Science Advisory Committee (NSAC) completed work on a long-range plan for nuclear science in the 1990s. This report made three priority recommendations with respect to major new facilities (Continuous Electron Beam Accelerator Facility (CEBAF), Relativistic Heavy Ion Collider (RHIC), and the proposed Canadian accelerator facility (KAON)) and urged a continued "vigorous program using existing facilities." These recommendations were based on an assumed budgetary profile (in constant FY 1991 dollars) that contained modest growth for the Department of Energy (DOE) programs from FY 1991 to FY 1995, with a decline as RHIC construction tailed off to $340 million (in constant FY 1991 dollars) in FY 1997.

Since the issuance of that report, a number of events have created a need to re-examine and to make more explicit the priorities contained in the 1989 long-range plan. Under the Budget Enforcement Act of 1990, legislated budgetary caps for Federal spending have been imposed across the Government. In the FY 1992 budget submitted by the President to Congress, the Office of Energy Research (ER) was allocated out-year budgetary targets that, except for selected Presidential initiatives, are flat in as-spent dollars (and declining in constant dollars). This declining constant-dollar profile must support initiatives such as increased research and development to support the National Energy Strategy and increased expenditures to meet higher standards of environmental protection and worker health and safety at ER facilities. Thus, ER faces a budgetary scenario which may differ from that assumed by NSAC in 1989.

On September 19-20, 1991, the Secretary of Energy Advisory Board Task Force on Energy Research Priorities was asked to review the relative priority of various nuclear science programs among the programs of the Office of Energy Research. The Task Force endorsed earlier NSAC recommendations that the Bevalac at the Lawrence Berkeley Laboratory and the Holifield Heavy Ion Accelerator at the Oak Ridge National Laboratory be phased out, and encouraged DOE to move forward with the implementation of these recommendations at the earliest possible time. The Task Force also concluded that the incremental construction costs of RHIC would require economies in the ER Nuclear Physics program, such as in operation of the Los Alamos Meson Physics Facility. The Task Force also recommended consideration of other possible economies through alternative strategies for managing the RHIC project. Finally, the Task Force recommended the reconvening of NSAC to consider its most recent long-range plan in light of current and foreseeable budgetary stringencies.

Charge:

We would like NSAC to recommend on the following topics:

1. What are the priorities for DOE and NSF nuclear science expenditures over the next 5 years, under the following scenarios:

   - o a budget starting with the President's Budget request in FY 1993, followed by 4 years of level funding, in as-spent dollars;
   - o a budget starting with the President's Budget request in FY 1993, followed by 4 years of level funding, in constant dollars to allow for inflation;
   - o a budget starting with the President's Budget request in FY 1993, followed by 4 years of modest growth above inflation (e.g., 2 to 3 percent real growth).

2. What emphasis should be placed on university-based research and research facilities under these budgetary scenarios compared to the construction and/or operation of facilities at DOE National Laboratories?

3. Under any of these scenarios, should DOE make a contribution to the KAON project?

We look forward to your response and thank you for your efforts.

Sincerely,

for

David A. Sanchez
Assistant Director
Directorate for Mathematical
and Physical Sciences
National Science Foundation

William Happer
Director
Office of Energy Research
U.S. Department of Energy

Nuclear Structure Laboratory
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State University of New York
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Bitnet Paul@SUNYSBNP

StonyBrook

January 21, 1992

Professor John Schiffer
Physics Division, Bldg. 203
Argonne National Laboratory
9700 South Cass Ave
Argonne, IL 60439

Dear John,

In a letter dated xxx, 1992, NSAC has been charged by the funding agencies for nuclear science, DOE and NSF, to evaluate the impact on the national nuclear science program of three funding scenarios for the next five years beginning with in FY93. These scenarios begin with the Presidents budget request for FY93 and extrapolate to 1997 (1) flat in as -spent dollars, (2) flat in inflation corrected dollars, or (3) allow for a modest 2 % to 3 % real growth. The charge to NSAC contains two additional requests, on the balance between research on one hand and construction and/or operation of facilities on the other, and on possible DOE contributions to the KAON project. The full charge to NSAC is appended.

In response to this charge NSAC has established the Subcommittee on Implementation of the LRP for Nuclear Science, comprised of:

J. Schiffer (Argonne National Laboratory and University of Chicago), chairman;
R. Casten (Brookhaven National Laboratory);
G. Crawley (Michigan State University, NSAC member);
C. Dover (Brookhaven National Laboratory);
R. McKeown (California Institute of Technology);
E. Moniz (Massachusetts Institute of Technology, NSAC member);
R. Tribble (Texas A&M University, NSAC member);
G. Young (Oak Ridge National Laboratory);
P. Paul (State University of New York at Stony Brook, NSAC chair) ex-officio.

The request from NSAC to the Subcommittee is as follows:

(continued on page 2)

Draft Charge to the Subcommittee:

Based on the enclosed DOE/NSF letter dated xx/yy/92 to NSAC the subcommittee is asked to identify the major scientific opportunities that will be gained and lost, and the impact on the education and training of scientists, across the entire field of nuclear science, under the three out-year budgets scenarios specified in the charge to NSAC. The 1989 LRP for Nuclear Science should provide a guide to the scientific perspectives of the field.

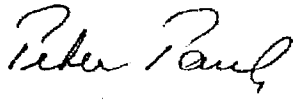
The report of the subcommittee should provide NSAC with recommendations on the implementation of the scientific priorities of the 1989 LRP, under the various budget scenarios for the years until 1997, as well as recommendations on items 2. and 3. of the DOE/NSF charge to NSAC.

The Division of Nuclear Physics of the American Physical Society has offered NSAC its assistance in providing for input from the wider nuclear physics community. It is expected that the subcommittee, at its open meetings, will set aside time for comments by individual scientists, as well as for scheduled presentations.

In order to formulate a timely response to the agency charge NSAC needs the subcommittee's report no later than April 6, 1992.

On behalf of the Nuclear Science Advisory Committee,

Sincerely,



Peter Paul
Chairman

Appendix: DOE/NSF Charge to NSAC

February 17-18, 1992
Meeting of NSAC Subcommittee on Implementation of LRP

Monday, February 17

9:00	Executive Session	closed
9:40	Break	
9:50	LAMPF presentation (Barnes, Hecker, Bowman, Mischke, Louis, Pocanic, McClelland, White, Vieira, Barnes)	open
12:20	Executive Session (lunch)	closed
2:30	Comments organized by the DNP (Eisenstein, Cates, Geesaman)	open
3:00	CEBAF presentation (Grunder, Isgur, Domingo, Leemann)	open
4:30	Bates presentation (Kowalski)	open
5:15	Executive Session	closed
7:00	Adjourn	

Tuesday, February 18

8:30	RHIC presentation (Bond, Ozaki)	open
10:00	Break	
10:15	KAON presentation (Vogt, Poutissou, van Oers)	open
11:15	Comments organized by the DNP (Parker, Kolata, Larson, Ernst, Haxton)	open
12:00	Lunch	
12:45	Executive Session	closed
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5:00	Adjourn	

March 6-7, 1992
Meeting of the NSAC Subcommittee on Implementation of LRP

Friday, March 6

9:00 a.m.	MSU presentation -- (S. Austin, B. Sherrill)	open
10:30	Break	
10:45	IUCF presentation -- (J. Cameron, S. Wissink, R. Pollock)	open
12:15	Lunch	closed
1:00	Small Facilities presentation -- (D. Balamuth)	open
2:00	User Groups presentation -- (C. Glashausser)	open
3:00	Discussion	closed
5:30	Meeting with W. Happer DOE	closed
7:30	Adjourn	

Saturday, March 7

8:30 a.m.	Discussion of issues for report	closed
5:00	Adjourn	

NATIONAL SCIENCE FOUNDATION
DETAILED MEETING AGENDA

NAME:	DOE/NSF Nuclear Science Advisory Committee
DATE AND TIME:	April 10, 1992 from 9:00 a.m. to 6:00 p.m. April 11, 1992 from 8:30 a.m. to 12:00 noon
PLACE:	National Science Foundation 1800 G Street, NW, Rm. 540 Washington, DC 20550
TYPE OF MEETING:	Open (*)
CONTACT PERSON:	John W. Lightbody, Program Director for Nuclear Physics, National Science Foundation, Washington, D.C. 20550, Phone: (202) 357-7993
MINUTES:	May be obtained from contact person
PURPOSE OF MEETING:	To advise the National Science Foundation and the Department of Energy on scientific priorities within the field of basic nuclear science research.

AGENDA:

Friday, April 10, 1992

09:00 - 09:05	Opening remarks by NSAC chair
09:05 - 10:00	Statements by Agencies (Bernthal, Hendrie, Lightbody)
10:00 - 10:30	Presentation and Discussion of revised Nuclear Data Report
10:30 - 10:50	Coffee break
10:50 - 11:30	Report by Subcommittee on Implementation of the NSAC Long Range Plan (J. Schiffer)
11:30 - 12:00	Initial NSAC discussion of Subcommittee Draft Report
12:00 - 12:30	Public Comments
12:30 - 13:30	Lunch
13:30 - 14:45	Discussion of NSAC response to NSF/DOE Charge on LRP Implementation
14:45 - 15:15	Discussion of procedures on DOE/NSF Charge on CEBAF Operations
15:15 - 15:35	Coffee Break
15:35 - 16:00	Public Comments
16:00 - 18:00	Preparation of NSAC draft report on DOE/NSF Charge on LRP Implementation
18:00 -	Adjourn

Saturday, April 11, 1992

08:30 - 12:00	Continued preparation of NSAC draft report on LRP Implementation
12:00 noon -	Adjourn

(*) Because of weekend security, persons wishing to attend the meeting on Saturday April 11 should get in touch with the above named contact person to arrange for out-of-hours entry to the building.

Nuclei, Nucleons, Quarks

Nuclear Science in the 1990's

A Long Range Plan for Nuclear Science

prepared by

The Nuclear Science Advisory Committee

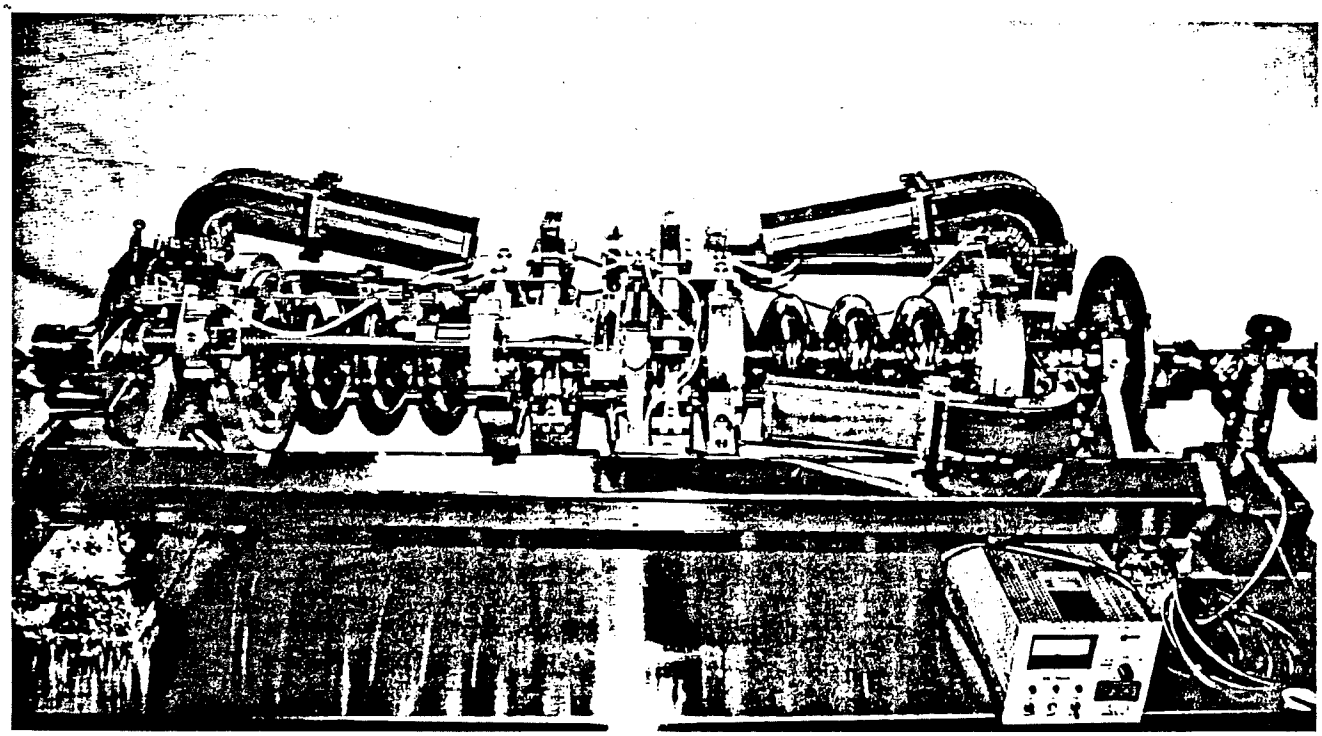
for

The U.S. Department of Energy

and

The National Science Foundation

December 1989



SUMMARY and RECOMMENDATIONS

The central thrust of nuclear science is the study of strongly interacting matter and of the forces that govern its structure and dynamics.

As we enter the last decade of the 20th century, this agenda ranges from large-scale collective nuclear behavior through the motions of individual nucleons and mesons (collectively called hadrons) in atomic nuclei, to the underlying distribution of quarks and gluons. It extends to conditions at the extremes of temperature and density which are of significance to astrophysics and cosmology and are conducive to the creation of new forms of strongly-interacting matter.

Another important focus is on the study of the electroweak force, which plays an important role in nuclear stability, and on precision tests of fundamental interactions.

Over the last 20 years our understanding of both the strong and electroweak interactions has undergone profound development, resulting in a theoretical framework referred to as the Standard Model. A major goal of nuclear physics today is the further exploration of this theory and its application to nuclear systems. A particular challenge is to show how the accepted theory of the strong interaction, quantum chromodynamics (QCD), which is cast in terms of unobservable quarks and gluons, can be developed to yield a low-energy description consistent with the baryons and mesons observed in the physical world. This development would provide a theory of hadronic matter of sufficient power and generality that it could be applied to almost all phenomena in the universe. New phenomena that give a glimpse of matter as it existed at the very beginning of time have already been predicted to occur in the collisions of heavy nuclei. The search for this "quark-gluon plasma", like the search for rare decays of strange mesons and of muons, may lead to improvements to the Standard Model.

At the same time, the nucleus, as a fundamental many-body system governed by the rules of quantum mechanics, continues to be a source of new phenomena, most interestingly at the limits of nuclear stability. The description of cooperative effects in terms of the interactions of the nuclear constituents, in a strongly correlated system such as the atomic nucleus, is a challenge to many-body theory.

The tools needed to pursue this broad and fundamental research program with efficiency are diverse. They both drive and depend upon significant advances in technology: (1) first and foremost, accelerators that produce high-quality beams of electrons, hadrons, and heavy ions, over a very large energy range; (2) detectors and targets that are novel in concept and complexity; and (3) large-scale computational facilities for theoretical work and data analysis.

The nation's ability to maintain nuclear science at the intellectual cutting edge, to provide research tools in a timely fashion and to support the necessary educational activities depends upon responsible long-range planning. This 1989 Long Range Plan (LRP) for Nuclear Science has been prepared in response to a joint request from the U. S. Department of Energy (DOE) and the National Science Foundation (NSF) to the Nuclear Science Advisory Committee (NSAC), to provide the agencies with advice for the next decade. While building upon the LRPs prepared in 1979 and 1983, NSAC undertook a thorough assessment of the new scientific opportunities in nuclear physics, and of the facilities and funding required to pursue these. Input was obtained from all segments of the nuclear science community through : "Town Meetings" sponsored by the Division of Nuclear Physics of the American Physical Society; presentations to NSAC by laboratory directors; and, finally, deliberations by a broadly representative Long-Range Plan Working Group (LRPWG) of 54 nuclear scientists, at a week- long meeting. The work and the recommendations of the LRPWG form the basis of this report.

Based on the major scientific opportunities described in the body of this text, the LRPWG began laying out the LRP by first addressing the issues of major new facilities. Specifically, the merits of the Relativistic Heavy Ion Collider which had been proposed in 1983, were re-evaluated extensively. The scientific merits of an advanced hadron facility,

KAON, were also discussed in detail. Accordingly, the recommendations with respect to major facilities are as follows:

1. The highest priority in U.S. nuclear science at this time is the timely completion of the Continuous Electron Beam Accelerator Facility (CEBAF) and the beginning of its important research program.

2. We strongly reaffirm the very high scientific importance of the Relativistic Heavy Ion Collider (RHIC). Since the last LRP, theoretical progress has strengthened the case for the existence of a quark-gluon plasma, and recent experiments demonstrate the likelihood that conditions favorable to its formation will be attained. RHIC will provide unprecedented opportunities to produce and study ultradense matter. Therefore, we strongly endorse the recommendation of the 1983 LRP and subsequent NSAC deliberations that RHIC has the highest priority for new construction in the nuclear physics program. We urge a swift beginning for this important project.

3. NSAC recently endorsed the fundamental and exciting scientific opportunities that will become available with a high-intensity, multi-GeV hadron facility. These opportunities will extend our knowledge both of the strong force, which determines nuclear dynamics based on quarks and gluons, and of the electroweak force, which provides stringent tests of the basic laws governing subatomic phenomena. The Canadian invitation for U.S. participation in the construction of an international research facility, KAON, with Canada providing full support for the operation of the facility, provides an exceptionally cost-effecti[illegible] way for the U.S. nuclear science community to address this important physics in a timely fashion. We recommend with very high priority that the U.S. enter into negotiations with Canada to participate in the construction and use of KAON.

The above facilities are essential to carry nuclear physics into the next century. They emphasize the high-energy frontier of nuclear physics. In addition, it is important to recognize the challenges and opportunities across the broad frontiers of nuclear science. Many of these can be addressed by existing facilities, in particular since several of them are new and most have acquired significant new capabilities in the recent past. A good number of these are located at universities and provide an important focus for research and educational activity close to the source of the next generation of scientists. This report outlines the wide scope of today's and tomorrow's nuclear physics, and the need for a variety of facilities, large and small. This leads to the following recommendation:

4. Crucial elements of nuclear physics are not addressed by the major new facilities of recommendations 1–3. Opportunities range across almost all subject areas discussed in this report. Indeed, the wide range of nuclear phenomena and the unity of the underlying understanding, from the phenomenology of nuclei through collective, nucleon, and meson degrees of freedom, and finally to quarks and gluons, is an essential feature of modern nuclear science. Exploration of these frontiers requires a vigorous program using existing facilities that provide electron, hadron, and heavy-ion beams across a wide energy range. The distribution of funds between ongoing programs and new initiatives should provide for a broadly based and balanced advance.

A number of additional smaller facilities are now being considered by various groups: an accelerator for radioactive beams; intense higher energy pion beams; a 0.5 to 1-GeV/nucleon high-resolution heavy ion accelerator; a proton cooler ring in the range of 10-20 GeV, for the exploitation of spin degrees of freedom; a facility for high fluxes of cold and ultracold neutrons for fundamental measurements. The conceptual development of some of these projects, or others of comparable scale, is important for the field's continuing vitality. We anticipate that at least one such project

will achieve high scientific viability over the period of this LRP.

Nuclear physics has always pushed against the boundaries of the field. The emergence of the fundamental theories of the strong and electroweak interactions and their combination in the Standard Model, and the recently increased interest in nuclear astrophysics arising from the spectacular observation of supernova neutrinos as well as the continuing solar neutrino puzzle, provide many new opportunities for nuclear physicists to contribute to the solution of some of the most fundamental questions of physics. Experiments in such areas often require tools not normally provided by nuclear laboratories. The needs for these activities are the subject of the following recommendation:

5. Precision tests of fundamental interactions probe physics at mass scales beyond the reach of any planned accelerator and beyond the Standard Model. Nuclear astrophysics provides both tests of nuclear physics in new regimes and perspectives on the evolution of the universe. Experiments at very high energies allow us to probe the quark structure of nuclei at very small distance scales. These activities are important to our field. Experiments in these areas employ a range of facilities from non-accelerator instruments through reactors and small accelerators, to the largest machines. We recommend effective pursuit of these topics by strong and timely support for the specialized instrumentation needs of this field, and the cost-effective use of the world's high-energy facilities.

An exciting example of such new instrumentation is the Sudbury Neutrino Observatory (SNO), a joint Canada-U.S.-U.K. project, for which NSAC recently enthusiastically endorsed U.S. participation.

As nuclear physicists open these new areas of investigation and deepen their explorations in traditional areas, a commensurate increase in theoretical activity is needed. New ideas must be developed and the predictive power within the framework of QCD must be improved. Each of the previous LRPs noted a need to strengthen the U.S. nuclear theory effort. Progress has been made recently in the funding for nuclear theory and through the founding of a National Institute for Nuclear Theory, but there is still an imbalance between the experimental and theoretical efforts in nuclear physics:

6. As nuclear science explores new frontiers, a strong theory program becomes increasingly essential. We therefore reaffirm the recommendations of the 1988 NSAC Report on Nuclear Theory, and the statements of previous LRPs calling for an expansion of the nuclear theory effort. We recommend that the agencies continue the recent trend of increased support for theory.

The broad range of scientific questions addressed by nuclear physics requires continuous technological developments. It is often through the invention and development of the required technology that nuclear physics makes its most important contributions to our technological society. This report describes many of these significant advances. We cite here only the Gammasphere project, which will greatly expand the horizons of nuclear spectroscopy. There is a broad consensus in the nuclear community that the present level of capital funds available for novel instrumentation is inadequate. In addition, as university groups are changing more and more to a user's role, an improved level of technical infrastructure at universities is required if the development of novel and complex detectors is to be effectively pursued by faculty and students. Thus we recommend as follows:

7. Nuclear physics is moving into many new experimental domains that require novel concepts and/or increasing complexity in detectors, targets, and other instrumentation. To realize the most promising new ideas and projects in this area requires an increase in capital equipment funds over the present level, and increasing attention to the technological support structure at university laboratories.

The quality and vitality of any scientific endeavor

are determined by the intellectual strength and the creativity of its scientists. Are there enough nuclear physicists to take up all the expanding challenges offered in this report? The number of active scientists in nuclear physics has been historically limited to about 1400, plus about 800 Ph.D. students, by a constant funding situation. Nevertheless, it is estimated that sufficient scientific manpower exists in the field to exploit the new facilities *and* maintain the important programs at the existing ones. Of course, as the major new accelerators which are the subject of recommendations 1–3 are realized, some redistribution of scientific effort must be expected.

The continuing and vigorous involvement of the universities, as the well-spring and training ground of future scientific manpower, in nuclear research programs is vital. Nuclear physics is fortunate to have many research facilities, some quite large, located at universities. We note with satisfaction the present strong interest of graduate students in our science. As an important part of our nation's basic research effort, nuclear physics will continue to play a significant role in the scientific education and training of young Americans.

8. We urge the agencies to maintain support for the educational and specifically the university-based programs that produce the skilled young scientists so vital to the well-being of nuclear science, and that provide high-level training of manpower for the many related sciences and the technology base of the country.

At this time, nuclear physics, like high energy physics, is moved by the intellectual development of its science to invest heavily in new facilities. Major scientific opportunities that had already been identified in 1983 will be lost to U.S. science unless construction of the appropriate facilities, most importantly RHIC, is started very soon. With this background in mind the LRPWG has carefully considered the minimum requirements for an effective and efficient nuclear physics program in the U.S. over the next decade.

We have constructed a budgetary profile that can accomplish the highest priority goals in nuclear science in a timely, cost-effective way. These goals include the effective utilization of key capabilities now in place or under construction, the realization of the major new facilities recommended in this plan, and the proper attention to the human and technical infrastructure that ensures continued success in research and education.

Our extrapolation starts with the assessment that the present needs for nuclear science come to (all in FY91 Dollars) about $340 Million in the DOE program and $50 Million in the NSF program. When these needs are extrapolated to 1997, beyond the completion of both CEBAF and RHIC, the programs in the field will require a base budget of at least $340 Million in the DOE program and $62 Million in the NSF program. These levels would provide for an austere, but scientifically viable, program, and recognize the need to increase funding for operation at some facilities, for increases in equipment funds and support for university users groups, as well as for nuclear theory.

They do not include funds for KAON, and we urge that new money be sought for this cooperative venture once it is approved by Canada. The above estimate also does not include funds for construction of a new smaller facility or upgrade. It is highly desirable to allow for construction or upgrade of at least one small facility in the time frame of this LRP, and we propose addition of about $20 Million per year in new construction funds later in the decade.

Nuclear physics is an important component of the intellectual, scientific and technological foundation of a prosperous, technologically developed society. Because of its connections to other fields adjoining its wide perimeter, nuclear physics plays a very significant role in supplying scientific manpower for industry and national laboratories. Nuclear physics continues to make essential contributions to our society – its industry, technology, and national defense –through advances in basic knowledge, through technical developments, and through the demonstration of new technical concepts. The size of the U.S. nuclear program has clearly recognized this important role in the past. It is our hope that this Long Range Plan will contribute to maintaining this role through the 1990s.

I NUCLEAR PHYSICS: AN EVOLVING SCIENCE

• The Science

The next decade of nuclear physics will build on over 60 years of discovery and progress. As nuclear physics evolved over this period, it spawned the sister discipline of elementary particle physics (high energy physics) and developed many experimental and theoretical methods that are now routinely used in atomic, molecular and condensed-matter physics. This fertility arises in part from the pivotal position of nuclear physics at the border between the physics of our daily experience and that of the subatomic world.

Today, the horizons of nuclear science are expanding in substantial ways. Our understanding of basic issues, such as nuclear collective motion and its relation to the underlying nucleon-nucleon force, has deepened as we have discovered more powerful experimental and theoretical techniques. Simultaneously, new frontiers are emerging: the properties of nuclear (or hadronic) matter at extremes of density and temperature; the connections between the meson-nucleon and the quark-gluon descriptions of strongly interacting systems; the application of the fundamental theory of the strong interaction, quantum chromodynamics, to nuclear systems; the nuclear physics of supernova explosions; the processes by which the elements were synthesized; and the exploitation of the nucleus as a medium for precise tests of the electroweak interaction and its connection to the strong interaction by the so-called Standard Model. The realm of nuclear physics now includes the study of all forms of natural and induced radioactivity, with emphasis on the production of new, exotic nuclei that have no counterparts among the stable elements that we encounter in our daily lives, as well as the study of neutrinos from the sun and other astrophysical phenomena. Nuclear phenomena of interest today thus involve natural scales that range from the shortest distances we can test with existing accelerators to those of the grandest events in astrophysics.

The recognition that quarks and gluons are the fundamental building blocks of strongly interacting particles, and thus of nuclear matter, and the advent of QCD as the fundamental theory of the strong interaction have had a great impact on nuclear physics over the last decade. They have expanded the horizons of nuclear physics into an energy domain that was, until very recently, considered the exclusive realm of elementary particle physics. This was already recognized in 1983 when the previous Long Range Plan was written. The trend has since become clearer and is now taking up more and more of the resources of the field, in terms of people as well as of accelerators and research funds. This change in balance is apparent in the ordering of the scientific topics that constitute the main body of this report. It is as natural today to begin the discussion of nuclei in terms of quarks and gluons as it was a decade ago to begin with nucleons and mesons. However, it is important to keep in mind the full panoply of nuclear phenomena. The nucleus, as the quintessential quantum-mechanical many-body system, is so rich in phenomena that many important new frontiers are opening up far from the level of detail where a description in terms of quarks becomes essential.

The historic evolution of nuclear physics, and with it the nuclear phenomena studied, are depicted schematically in Fig. 1. Nuclear history evolves from the top to the bottom of the figure. Not accidentally, this sequence also describes the nucleus on an increasingly finer length scale, i.e., as seen through increasingly powerful "microscopes." As the name implies, nuclei are at the center of atoms, with a dimension only about one hundred-thousandth that of an atom. This dimension is of the order of a few femtometers (1 fm = 10^{-15}m) which is commonly called a fermi after the great Italian-American physicist who first studied the interaction between neutrons and nuclei and who led the construction of the first nuclear reactor in 1942. Looking at the nucleus as a whole we can envision it as a droplet of liquid that can be deformed, that has oscillations and rotations, and that can change its shape or fission into two droplets. These phenomena are called "collective" because they involve many neutrons and protons in the nucleus moving in a concerted manner. So far, the nuclear liquid has been explored mostly at very low nuclear tem-

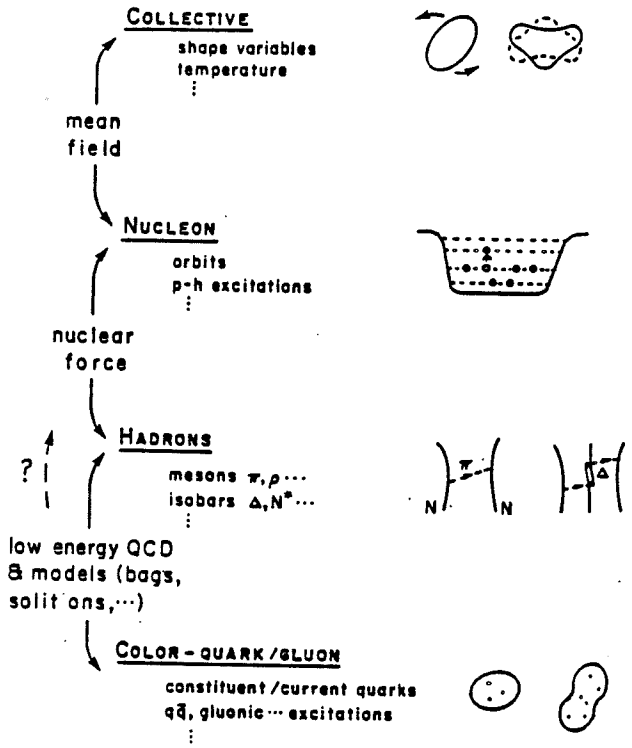


Figure 1: Diagram of nuclear properties and the models used to describe them, with increasingly fine spatial resolution ranging from the top to the bottom. At the finest detail the nucleus consists of quarks and gluons.

peratures, much like water near the freezing point. Only recently have physicists begun systematically to heat nuclei and to look at the nucleus as a thermodynamic system. Nuclear temperatures are expressed in million electron Volts (MeV). A temperature of 1 MeV is about one million times hotter than the surface of the sun. It has already been learned that whole nuclei can be heated up to a temperature of about 6 MeV, and that much hotter spots within nuclear matter can be created. It takes large amounts of energy on the very small scale of nuclei to heat the nucleus in order to study it as a thermodynamic system.

The nucleus is, of course, composed mostly of neutrons and protons (nucleons) which have dimensions of about 1 fermi. The nucleons move around in the nuclear "mean field" produced by *all* the nucleons, in an orderly way prescribed by quantum mechanics. Thus they can occupy only certain orbitals of specified energy and character. Much has been learned about these orbitals since their discovery in the 1940s. What remains to be learned is what happens when the mean field is stretched and strongly deformed, and when it is augmented by strong centrifugal forces created by very fast rotation of the nucleus.

Quantum mechanics dictates that only a limited, predetermined number of neutrons and protons can be fitted into each orbital. Thus the question arises of what happens if we grossly change the relative numbers of neutrons and protons from those that exist in stable nuclei. On earth, such exotic nuclei must be created by nuclear reactions. However, in astrophysical objects, such as neutron stars, they probably occur naturally. Fig. 2 shows the remarkable multitude of nuclei that are either stable (263 in number) or quasistable (potentially about 6000, of which so far only 2200 have been synthesized). Nuclei that contain certain "magic" numbers of neutrons and protons (indicated by either N or Z in Fig. 2) are especially stable, and an island of superheavy "stable" nuclei has been predicted since the 1960s far beyond the actinide elements.

Nucleons interact with each other by the so-called strong force. It is about a thousand times stronger than the electromagnetic force, which holds atoms together, and is effective only over a very short distance, about 1 fm, the size of a nucleon. Particles interact with each other by exchanging characteristic bits of energy, often in the form of other particles. In nuclei, the strong interaction between nucleons, for separations greater than the nucleon radius, can be quite successfully described in terms of the exchange of medium-weight particles called mesons, such as the π and ρ mesons. The strong interaction can also produce excitations of the nucleon itself, so-called isobars. Although much is known about the motions of nucleons in nuclei, much less is known about the motions of these isobars and the mesons in the nuclear medium. Some of the new accelerator capabilities in nuclear physics are aimed at elucidating these aspects.

It is now well known that nucleons are made up of quarks which interact by exchanging gluons. Three constituent quarks make up a nucleon, whereas a quark and an antiquark together produce a meson. It is then the ultimate aim of nuclear physics to relate the known phenomena of the nu-

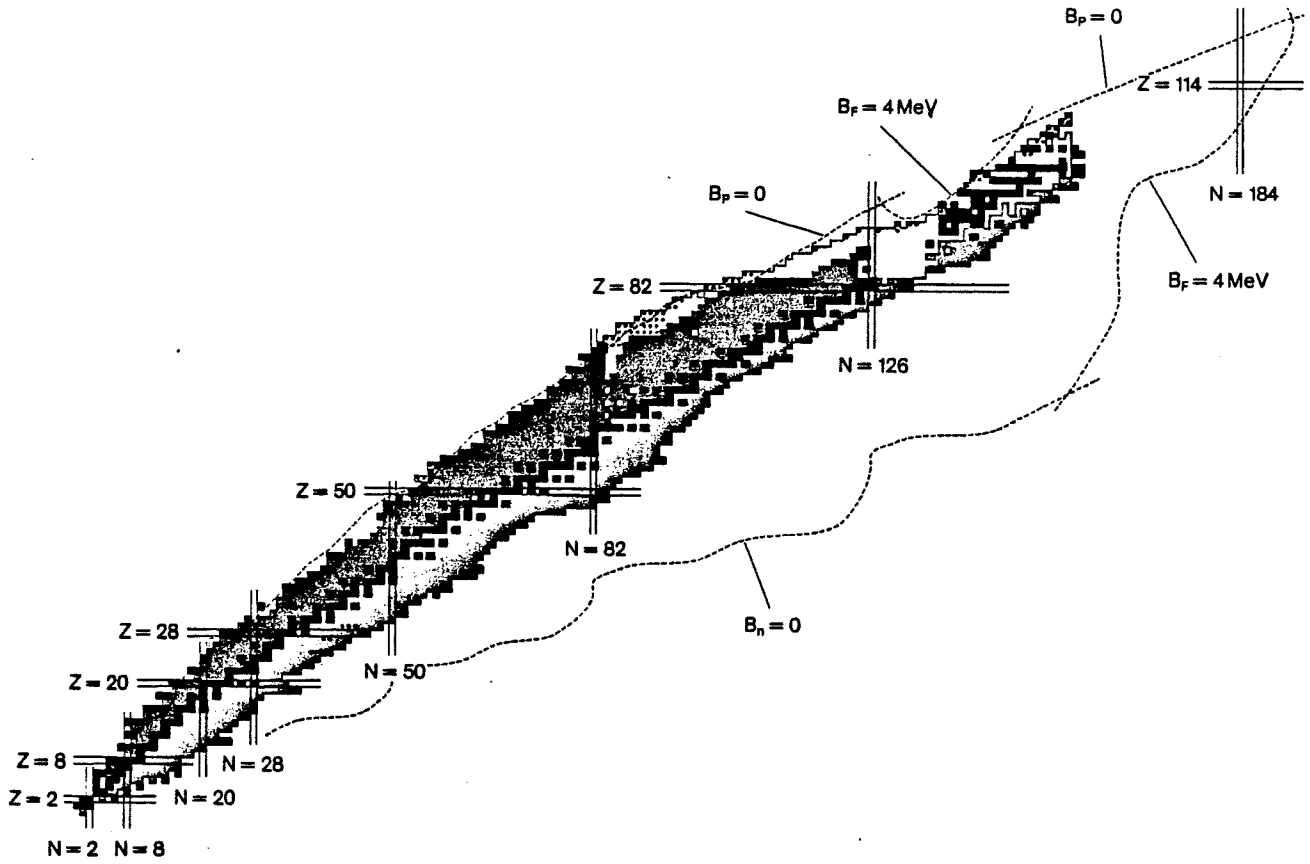


Figure 2: Island of stable or quasi-stable nuclei, defined by the dashed border contour. The black squares indicate the stable nuclei. The colored areas contain the quasi-stable nuclei that have been produced. Indicated N and Z numbers refer to magic numbers, and doubly-magic nuclei are especially stable. The actinide nuclei complete the known mass table at the upper right end. The long-sought superheavy nuclei would lie around Z=114, N=184.

clear medium to the quarks and gluons and the corresponding theory, QCD. This theory has already predicted completely new phenomena, such as the existence of a new form of matter, the quark-gluon plasma, at very high energy density. A major recommendation of this report is aimed at observing and studying this phenomenon. However, such predictions are as difficult to make as they are fundamental. The application of QCD is relatively straightforward at very high energies and high momentum transfer —the so-called perturbative region— but very complex at the energies normally associated with nuclear phenomena. This has led to simplifying models, such as holding the quarks together in "bags" that stand for the nucleons. Only at very high nuclear temperatures, about 150 MeV, may it be possible to "melt" these bags and allow quarks to range freely over the distance of a few nucleons. The energies required to induce this process are so high as to blur the boundary between nuclear and high-energy physics.

The step from nucleons and mesons to quarks and gluons has had still wider implications for nuclear science. This is because quarks come in six different "flavors". Two of these, the "up" and "down" quarks, are present as the major constituent quarks in normal nucleons. Another flavor, called "strange" quarks, can be created in laboratory experiments, thereby producing "strange" nucleons, called hyperons. These can be inserted into nuclei to form hypernuclei. The behavior of the strange quarks in nuclear matter is an important part of understanding the strong interaction in the nuclear medium. Again, a promising beginning has been made towards cataloguing the states of excitation of hypernuclei, but much more remains to be done. The creation of new forms of strange matter is one of these goals.

Nature also provides us with astrophysical "laboratories", such as stars, neutron stars, and supernovae, in which we can study the properties and behavior of nuclear matter under unusual condi-

tions. The energy density characterizing the transition from nucleons to quarks, or the reverse, was presumably produced at the birth of our universe, the Big Bang. This transition could have left its mark on the relative abundances of the light elements that we observe today. Similarly, a stellar collapse, such as indicated by the recent supernova observation, provides an opportunity to study nuclear matter at extremes of density and temperature, and with neutron-to-proton ratios that have not yet been reached in the laboratory. The skills of the nuclear physicist have become essential to any quantitative modeling of the physical and chemical processes that govern the long-term evolution of our universe.

Nuclear radioactivity has produced some of the most fundamental insights into nature and some of the most important practical applications of nuclear physics. This stems from the fact that beta radioactivity involves another fundamental force of nature, the weak interaction. The latter brings a new set of very light elementary particles, leptons, into play and is today understood within a framework that also includes the electromagnetic force. A key verification of this aspect of the Standard Model occurred recently, with the discovery of the W and Z particles, the predicted carriers of the weak force. The Standard Model also predicts the interaction between leptons and quarks, as depicted schematically in Fig. 3. While all known phenomena seem to fit within the Standard Model, including all the recently studied detailed properties of the Z particle, there are reasons to believe that the model is incomplete and must ultimately fail. Nuclei offer unique opportunities for isolating certain "low-energy" aspects of the Standard Model and testing it with high precision. Thus, probing the electro-weak interaction has become an area of common interest between nuclear and particle physicists.

•The Tools

This modern agenda stretches nuclear physics over a wider range of energies and phenomena than ever before in its history. A set of basic tools are needed, which is described in more detail in later sections of this report. It includes:

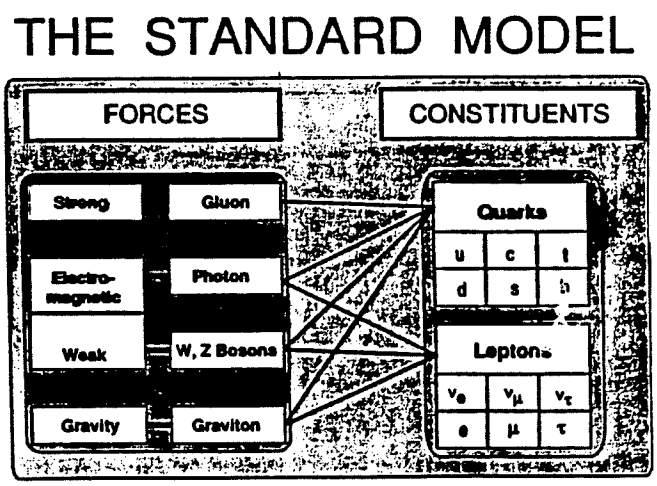


Figure 3: A list of the forces and their participants – quarks and leptons— that are interconnected by the Standard Model. The connections between the different sectors – strong, electromagnetic and weak– are indicated by the lines.

• *Electron beams* interact with nuclei or their charged constituents, the quarks, via the well-known electromagnetic interaction. Thus they provide a tool that can test unknown properties inside the nucleus in a precise way. Very energetic muon beams play a similar role in elucidating the quark structure of nucleons and nuclei.

• *Proton beams* are needed for several tasks: to test particular aspects of the interaction between nucleons; to produce other particles, such as mesons, neutrons, neutrinos, or even strange particles, and to study their interactions or decays; and to act as "vessels" of quarks to be brought into the target nucleus. An accelerator capable of producing these beams is broadly defined as a hadron facility.

• *Heavy-ion beams* of energetic nuclei, of almost any species available in the table of the stable and even unstable elements, can deposit large amounts of energy over a large part of the nuclear medium. They are needed to produce exotic nuclei; to compress and heat nuclear matter; or to induce rapid rotation of nuclei upon impact. Finally, they also serve as carriers of quarks and gluons.

• *Neutron beams* from reactors and accelerators are used for nuclear reactions or to produce nuclei far from stability as products from nuclear fission; highly polarized cold and ultracold neutrons serve as tools for precise tests of fundamental interactions.

The arsenal of nuclear physics accelerators has undergone a significant modernization and expansion since the 1983 LRP. However, as we explain more fully below, key facilities remain either to be completed (for electron beams), to be started (a relativistic heavy ion collider), or to be fully defined (an advanced hadron facility) at the time of the present report.

From the very beginning of nuclear science, nuclear physicists have been inventive builders of accelerators. Many different kinds of accelerators, initially conceived for nuclear physics, have since found applications in other sciences,including medicine. In many cases, nuclear physics accelerator development has pushed new technologies to their first large-scale applications. For example, superconducting high-precision magnets for cyclotrons and superconducting resonators for linear accelerators have been developed into mature technologies. These devices make it possible to produce energetic particle beams at great savings in electric power, and, because they lead to a reduction in accelerator size, at reduced construction costs. The concept of cooling a beam of protons or heavy ions, contained in a storage ring, by interaction with a cold electron beam has been successfully implemented, and, for heavy ions, recently demonstrated for the first time.

It was already recognized in 1983 that a new agenda for nuclear physics was emerging. This agenda would require new facilities for each of the three species of beams – electrons, protons, and heavy ions– to investigate the consequences of QCD in nuclei. Of necessity, these facilities would have to have much higher energy capability than any of the existing nuclear physics facilities and rival the scale of some high-energy physics projects. Typically they are designed to provide beams of high quality, high intensity and, recently, high duty factor. Responding to the new agenda, an initial step for electrons is the Continuous Electron Beam Accelerator Facility (CEBAF), now under construction at Newport News, Virginia. It will use superconducting resonators to produce three simultaneous intense electron beams at a peak energy of 4 GeV (4 billion electron volts).

The proposed project to increase our capability with heavy-ion beams is a very bold one. The Relativistic Heavy Ion Collider (RHIC), is a very cost-effective facility owing to previous development and construction that had been invested in an earlier proposed proton collider at Brookhaven National Laboratory. It will consist of two intersecting rings of superconducting magnets, 2.5 miles in circumference, in which energetic beams of nuclei from protons to gold will be accelerated, stored, and brought into collision at six interaction regions. Its energy capability of 100 GeV per nucleon for each beam will be uniquely suited for producing and studying the predicted quark-gluon plasma. For the third machine, the modern hadron facility, a group in Canada is presently proposing a proton accelerator, KAON, with a combination of beam energy and intensity unprecedented in nuclear physics. This accelerator would in turn provide the intense secondary beams needed for a thorough investigation of the nuclear physics of "strange" particles and for testing the limits of the Standard Model at nuclear energies.

• The Agenda

As we extend the nuclear physics agenda into the 1990s, we can summarize the central goals, based on the scientific discusssions in Chapter II (and in that sequence), as follows:

(1) Study of the nucleus as a strongly interacting many-body system, consisting of nucleons and mesons. This traditional focus can now take advantage of the theoretical anbd experimental advances of the past decade, and will use the new experimental facilities being readied, to introduce decisively excited states of the nucleons, and strange particles, into the nuclear medium.

(2) Exploration of the fundamental theory of the strong interaction, QCD, in the nuclear medium. This is a task for theoretical nuclear physics, which must find reliable and practical ways to apply QCD

to the nuclear energy range. Clearly this effort involves significant connections to elementary-particle theorists. It is also a task for experimental nuclear physics, one that relies crucially on new energetic electron and hadron facilities. Because quarks are primarily confined in the nucleons, it is important to study the nucleus on a dimensional scale that is small compared to 1 fm. This requires beams in the billion electron volt (GeV) range. On the other hand, some manifestations of quarks can be studied at somewhat lower energies by the use of ingenious methods such as polarized (i.e., spin-oriented) beams and targets. If strange quarks or mesons need to be produced then this again requires primary beams of high energy and high intensity.

(3) Study of the thermodynamic properties of nuclear matter, expressed in the equation of state, and its phase transitions. The most spectacular phase transition is that from normal nuclear matter to the quark-gluon plasma, a completely new form of matter. It is predicted to occur at a temperature of about 150 MeV. To produce the required conditions of energy- and mass density in nuclei demands the capabilities of the Relativistic Heavy Ion Collider. However, there is a large regime of lower temperatures and moderately increased densities that remain to be explored with lower-energy heavy-ion beams. The exploration of hot nuclear matter is still in its infancy.

(4) Searches for new phenomena at the very limits of nuclear stability. In this context a nucleus is considered stable even if it is created in a nuclear reaction in the laboratory and lives only for a brief moment. Even these broad stability limits are tested when the nucleus is formed under the stress of ever larger centrifugal forces or increasing temperatures, and with a very unusual composition of neutrons and protons. Some of these conditions prevail in astrophysical objects; so understanding their properties in the laboratory contributes to our understanding of the universe. The decades-old goal of reaching the predicted island of stability for superheavy, transuranic nuclei, and the recent possibility of producing regions of pure neutron matter in nuclei, are intriguing possibilities in this area.

(5) Exploration of the electroweak force and its connection to the quarks, as prescribed by the Standard Model, in the nuclear medium. In the laboratory, this often requires some of the most powerful accelerators available. But, if the object of study is astrophysical, such as the sun, a neutron star, or a supernova, some very sophisticated and large stand-alone detectors are needed.

As one considers this broad agenda, it is instructive to note a certain analogy with recent developments in another major field of science, molecular biology. A huge body of information on biological systems and effects has been accumulated, and is well understood and widely applied, without taking reference to the underlying "theory", namely, that all these properties are ultimately expressions of an alphabet of only four letters, the four nucleotides A,C,G,T, of the genetic code. Now, molecular biology is embarking on a huge project to determine the sequences of these letters in the human genome, in order to relate the "macroscopic" biological properties to the fundamental building blocks of biological systems. Substituting six quarks for the four nucleotides makes the analogy clear. Just as biology and molecular biology will need to maintain a broad effort *in addition* to the genome project, for the many aspects that do not require invoking the ultimate building blocks, so nuclear physics must make advances on a broad front, in addition to the quark-related programs.

The major scientific goals outlined above require new instrumentation and new technologies, as well as new ways of accumulating, processing and analyzing data. It is these aspects that have made nuclear physics, throughout its history, a major source of technical innovation for our industry and society. Nuclear techniques of a wide variety are used today in solid-state research and even in the production process of the most advanced semiconductor chips. The applications of radioactive three-dimensional imaging for medical diagnostics, and the use of beams of radiation for cancer treatments are widely known and continue to be further developed. The use of neutron beams to detect explosives and to produce the first practically useful wires of high-temperature superconducting materials, are very recent developments.