RECOMMENDATIONS FOR FY 1980 FACILITY CONSTRUCTION

April, 1978

The DOE/NSF Nuclear Science Advisory Committee

William A. Fowler
California Institute of Technology, Chairman

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Peter D. Barnes
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Lawrence Berkeley Laboratory

Edward A. Knapp
Los Alamos Scientific Laboratory

Robert E. Pollock
Indiana University

Thomas T. Sugihara
Texas A&M University

J. Dirk Walecka
Stanford University

Letter of Transmittal

April 14, 1978

Dr. James S. Kane
Department of Energy

Dr. Marcel Bardon
National Science Foundation

Dear James and Marcel:

You requested NUSAC to make recommendations with respect to nine facility construction proposals which DOE and NSF are considering for inclusion in the FY 1980 Budget. We respond here to that request by transmitting with our strong endorsement the attached report "Recommendations for FY 1980 Construction" prepared by the NUSAC 1978 Facilities Subcommittee.

In transmitting these recommendations, NUSAC notes that the Subcommittee acted within the framework of the first priorities for major new construction and facility-improvement programs specified in the Friedlander Report on the "Future of Nuclear Science". In broader context NUSAC wishes to take this opportunity to affirm its strong support in principle for Recommendation A of the Friedlander Report, which places highest priority on an immediate step increase in operating support for nuclear science. An independent evaluation of this problem by NUSAC has confirmed the serious effects of the low level of current operating funds, instrumentation, user group support and capital equipment budgets at nuclear science laboratories, particularly at the universities.

NUSAC was encouraged by the increments incorporated in the planning guidelines supplied to it by DOE/NSF. One of the funding scenarios suggested by DOE, a ten percent increase above inflation for FY 1980 and cost-of-living increases thereafter, was noted with satisfaction. This was also NUSAC's reaction to the possibility in the NSF guidelines of a one-time increment of the order of 10 million dollars, spread over three years and starting in 1980. Nonetheless, it is clear that these funding projections go only part way towards meeting the well documented needs for increases of funds for nuclear laboratories and user groups specified in Recommendation A. This increased the complexity of our task of identifying the optimum program for the construction of new facilities which are also clearly required if nuclear science is to remain healthy and robust.

NUSAC and its Facilities Subcommittee are acutely aware of the competition between operating funds and facility construction funds which has arisen under past and present planning guidelines. It will be an early objective of NUSAC to recommend for your future consideration a realistic ratio of operating to new facility funding. At the same time we will attempt to make specific recommendations in the budget categories referring to capital equipment and instrumentation.

We noted with satisfaction the deep involvement of the nuclear science community in the present advisory process. The thirteen members of NUSAC have participated; an additional six nuclear scientists served along with five members of NUSAC as members of the 1978 Facilities Subcommittee; six more served as consultants to the Subcommittee. The presentations of the nine facility proposals before the Subcommittee in open session were well attended and led to a healthy exchange of ideas concerning the present status and future of nuclear science. NUSAC is committed to continue the involvement of all elements of the nuclear science community in its deliberations and activities.

The specific recommendations of the NUSAC 1978 Facilities Subcommittee for FY 1980 construction are presented on pages 9 and 10 of the attached report. In a longer-range context, the FY 1980 construction plan should be viewed as the first step in a ten-year program to provide the needed facilities so that by 1988-89 the U.S. will be in a strong, competitive position in nuclear science research. Consideration of the Livingston Study Group Report on "The Role of Electron Accelerators in U.S. Medium Energy Nuclear Science" and the Friedlander Report, as well as our own deliberations, have led NUSAC to identify the following possible construction plan for the next decade. In addition to the recommended FY 1980 construction items we see a need for:

Upgrading of several existing facilities. Projects include energy boosters for heavy-ion accelerators, increasing the energy or duty factor of electron accelerators, and construction of kaon/antiproton and muon beam lines for nuclear structure research.

Construction of a high-energy, high-duty-factor electron accelerator.

Completion of a second large heavy-ion facility.

As the next stage beyond LAMPF, construction of a neutrino, kaon and antiproton facility and/or a relativistic heavy-ion facility.

The investment in such a construction program over the next decade would not be excessive, being approximately 10-15% of the total projected budget for nuclear science research. We note that significant developmental work needs to be done to provide realistic construction cost estimates and schedules. We urge DOE and NSF to pay special attention to this matter and to provide the necessary funds to the institutions undertaking these tasks. In this connection, NUSAC wishes to add a comment to the 1978 Facilities Subcommittee recommendation that more support be made available for accelerator development and instrumentation projects at universities: it is our conviction that an increased commitment in these areas will be made by university faculties if DOE and NSF encourage proposals of this nature.

NUSAC's recommendations on facility construction for FY 1980 are made in the framework of a wide-ranging overview of the U.S. program in nuclear science. These wider ranging considerations have prompted the following comments on what we regard as important issues.

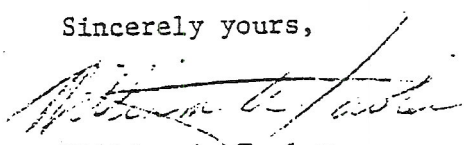
It is clear that for effective use to be made of these new facilities appropriate instrumentation for experiments will have to be provided. Nuclear research addresses increasingly complex problems and this complexity requires the development and utilization of correspondingly sophisticated technology. A new generation of spectrometers, detectors and data-handling systems must be conceived and built in consort with the new facilities. Our country has surrendered much of its traditional lead in instrumentation to Western Europe, and President Carter is correct in sensing that this is a serious situation which requires close attention and corrective action.

In our consideration of facility recommendations for FY 1980 and in many of our other deliberations, NUSAC has been brought face-to-face with the problems arising in nuclear science as more and more research activities are carried out at remote facilities, by user groups. It has become clear that a rationale is needed for deciding upon the appropriate mixture of small scale university-based research and that best done at centralized facilities. What is in order is proper attention to what constitutes "critical intellectual areas" within a particular research field as well as to what are the most efficient modes of utilization of the equipment and facilities. With this in mind NUSAC plans to conduct a thorough study of the "user-group" mode of research, which should yield background information for many of NUSAC's future activities, including recommendations for facility construction in FY 1981 and succeeding years.

Finally, the absolutely vital role of young scientists in nuclear research has been recognized over and over in our deliberations. We want to call this to your attention. NUSAC plans to study this question further and will be presenting its suggestions to you in the future.

We conclude this letter by reiterating NUSAC's willingness to cooperate with you in all of the aspects of planning for a healthy and dynamic program of research in nuclear science. We have found the exercise which led to the attached recommendations for FY 1980 most stimulating and instructive. We have received excellent cooperation from George Rogosa and Howel Pugh and their staffs. We look forward to further opportunities to assist in the planning for nuclear science in the United States.

Sincerely yours,



William A. Fowler
Institute Professor of Physics,
California Institute of Technology
Chairman, NUSAC

RECOMMENDATIONS FOR FY 1980 CONSTRUCTION

A Report to the DOE/NSF Nuclear Science Advisory Committee
by the NUSAC 1978 Facilities Subcommittee

Table of Contents

I. Subcommittee Procedures and Recommendations

I. 1. Preamble

Scope of Present Report

This report of the 1978 Facilities Subcommittee of the Nuclear Science Advisory Committee of DOE/NSF is in response to a request to NUSAC from DOE and NSF for recommendations with respect to nine construction proposals which are under consideration for inclusion in the FY 1980 budget.

These proposals are listed below by institution, with accompanying descriptive title of the project, its proposed cost (normalized to 1978 dollars), and date of completion.

1. Argonne National Laboratory: "ATLAS, A Precision Heavy-Ion Accelerator"; $4.7M; 1982
2. Brookhaven National Laboratory: "A Superconducting Cyclotron Addition to the Brookhaven Three-Stage Tandem"; $11.5M; 1982
3. Los Alamos Scientific Laboratory: "Staging Area and Office Building" $6.0M (Staging area; $2.3M, Building; $3.7M)
4. MIT: "An Energy-Doubling Recirculator for the Bates Linear Accelerator"; $1.7M; 1981/82
5. Michigan State University: "A National Facility for Research with Heavy Ions using Coupled Superconducting Cyclotrons"; $18.9M; 1984
6. Oak Ridge National Laboratory: "Holifield Heavy-Ion Research Facility -- Phase II"; $13.5M; 1984
7. University of Rochester: "A Heavy-Ion Post Accelerator"; $8.1M; 1983
8. University of Washington: "Post Accelerator Construction and Installation"; $5.1M; 1983
9. Yale University: "Conversion of the Yale MP Tandem Accelerator to the STU Status"; $3.8M; 1982

The funds requested total approximately $75M in 1978 dollars. The Michigan State and Rochester proposals were submitted by laboratories supported by NSF, the others by laboratories supported by DOE.

The membership of the NUSAC 1978 Facilities Subcommittee is listed in Appendix I. Consultants to the Subcommittee are listed in Appendix II. The Subcommittee is charged to present its reports to NUSAC, which will in turn make recommendations to the DOE and NSF. The funding agencies requested that the recommendations relating to FY 1980 be available before April 15, 1978. To meet this deadline the Subcommittee held meetings on March 13-15, and March 27-28, 1978. This report was submitted for the consideration of NUSAC at a meeting held April 7-8. Prior to

these meetings several site visits were conducted by teams of Subcommittee members and consultants. The purposes of these visits were to assist in the review of some of the proposed facilities and to assess the present state of the art in several technologies relevant to other proposals. These visits are listed in Appendix III. During the March 13-15 meeting presentations were made to the Subcommittee by representatives of the nine laboratories listed above. The agenda for this meeting is given in Appendix IV. During the March 27-28 meeting the present report to NUSAC was completed.

Because of the compressed time scale within which it was necessary to formulate the FY 1980 recommendations, it was not possible for the Subcommittee to respond to all elements of its charge in this report. Consideration of some proposals which are in existence (e.g., "The Caltech High-Current Accelerator"), in the process of submission (e.g., "The Eastern Meson Facility")or planned for in the near future (e.g., "The University of Colorado Accelerator" and "The Detection of Solar Neutrinos using Gallium") was precluded. Consideration of these as well as others which may be submitted is anticipated in due course.

Charge

The charge recommended for the Subcommittee by NUSAC is as follows: "The Subcommittee shall consider proposals, plans, needs and opportunities for major new facilities and for substantial modifications and improvements to existing facilities in the field of fundamental nuclear research in the U.S.A. Acting with due regard to the scientific priorities of the "Friedlander Report" (ref. 1), as modified and interpreted by NUSAC, the Subcommittee shall draft a plan or plans, viable in the light of probable funding levels, for implementation in FY 1980. The Subcommittee report which accompanies the plan or plans shall include a technical evaluation of the alternatives considered and a justification for the action recommended to NUSAC, and shall give careful attention to the net fiscal impact of any proposed new facilities upon ongoing programs. In arriving at implementation recommendations to NUSAC, the Subcommittee shall adhere to a schedule with maximum utility in the budgetary planning cycle of the funding agencies and shall, if possible, submit plans to NUSAC for consideration in the Spring of 1978."

"In preparation for longer-range planning by NUSAC, the Subcommittee shall gather and assess information on operating characteristics, costs, utilization and research function of existing facilities as well as proposed new facilities for fundamental nuclear research. The Subcommittee shall endeavor to recommend to NUSAC the proper range of capital invest-

ment in new facilities, relative to adequate support of existing facilities, for maintaining the strongest research posture through the next decade."

"The Subcommittee shall consider the factors relevant to encouragement of technical innovation and the maintenance in the U.S. nuclear community of a strong capability to respond to changing research needs with development of appropriate facilities."

Scientific Priorities

The Subcommittee's charge requested that "due regard" be paid to the scientific priorities of the report of the Friedlander Panel on the "Future of Nuclear Science", as these are modified and interpreted by NUSAC. The Subcommittee has been primarily concerned with the relationship of these priorities to construction projects. Listed in section 4.7 of the Friedlander Report are the highest priority items for new facility construction in nuclear science, as determined by that panel. The goal of this recommended construction is the orderly development of a balanced and vital national program in nuclear science.

These "First Priority" items for major new construction and facility improvement are:

"Large heavy-ion facility"
"SuperHILAC and Bevalac upgrading" (Funding for this project has been included in the FY 1979 DOE budget.)
"Upgrading of three low-energy accelerators"
"Bates energy doubler"

On page 66 of this same report, the construction of a staging area for LAMPF was strongly recommended as a means of enhancing the national research program in medium energy physics.

As discussed in the "Future of Nuclear Science" (see the pages of reference 1 as noted in the following) the first three items on the above list are to make possible research in, among others, the following topics: clustering and resonance phenonena (p.19), nuclei in states of very high angular momentum (p.20), nuclear matter at high compressions and high temperatures (p.21), nuclei with unusual neutron/proton ratios (p.21), the non-equilibrium statistical mechanics of a system consisting of a relatively small number of particles (p.23, p.25 et seq.) and, finally, the microscopic foundations of a hydrodynamic description of nuclear matter including diffusion (p.23, p.25 et seq.). These investigations will lead to new and fundamental knowledge of nuclear structure and reaction dynamics.

Within presently existing accelerator capabilites, phenomena such as resonances in collisions between ions of masses A=12 to A=16, generation of high-angular momentum states and deep inelastic scattering have been observed. These phenomena require study at the higher energies and higher precision which will be possible with the above proposed facilities. Moreover, with the large heavy-ion facility it may be possible to create and study new forms of nuclear matter and definitively answer questions about the existence of superheavy elements.

The Friedlander panel noted exceptional scientific interest inherent in heavy-ion beams of $A \sim 40$ in the energy range 50 MeV/A to 200 MeV/A and in beams of of $A \sim 200$ in the range 5-20 MeV/A. It is the opinion of the present Subcommittee that it is most desirable to achieve the goal of beams of $A \sim 40$ ions at 200 MeV/A within the next few years.

The fourth item on the Friedlander Report list was in response to a need to expand capabilities for research with electron beams, a need which was reaffirmed by the Livingston Panel (ref. 2). Doubling the energy of the Bates electron linear accelerator to 750 MeV by recirculation of its beam would achieve a doubling of the momentum transfer in scattering experiments and thus increase the "resolution" of the electron beam down to sizes of the order of 0.2 fm. The resolution thus obtained would significantly increase the capability of studying the dynamic and static charge and current distributions, including exchange effects, within nuclei. Investigation at energies presently available has revealed important limitations in the conventional description of nuclei which studies at higher energies should help clarify. The investigation of the (γ,p) process, which at presently available energies indicates significant anomalies, could be extended to higher energies. The study of axial currents and the behavior of excited nucleons within nuclei with the (γ,π) process also is within the compass of the higher photon energies which would result from the energy doubling.

The above remarks provide a very brief summary of the possibilities for scientific investigations which would be provided by the "first priority" construction program recommended in the Friedlander Report. An important part of the Subcommittee's task was to choose among competing proposals which sought to satisfy the goals of this program. The recommended large heavy-ion facility is the subject of four proposals: Brookhaven, Michigan State, Oak Ridge, and Rochester. The recommended upgrading of low-energy accelerators for heavy-ions is addressed by three proposals: Argonne, Washington and Yale. The remaining two proposals (MIT-Bates and Los Alamos-LAMPF) address recommended projects specific to those institutions. The recommended SuperHILAC-Bevalac upgrading has been included in the FY 1979 DOE budget request and is not discussed further.

Proposal Summaries

Brief descriptions of each of the nine proposals considered by the Subcommittee follow. In the case of the heavy-ion accelerators, the energies of the ions have been noted. Of course, there are other important qualities of the beam, such as average particle current, which must be considered as well.

1. The Argonne National Laboratory proposes an addition to its superconducting linear accelerator booster now under construction. The linac consists of split-ring resonators. The superconducting material is niobium. The injector is an FN tandem. This system is estimated to provide beams with about 26 MeV/A for small A and about 15 MeV/A for A $\sim$100, the most massive ions that can be accelerated assuming a gas stripper for the terminal of the tandem.
2. Brookhaven National Laboratory proposes to inject the heavy ions accelerated by its three-stage upgraded MP tandem facility into a new K=800 superconducting cyclotron. It is estimated that small-A ions will have a final energy of 100 MeV/A while large A ions will have energies of about 15 MeV/A. Use will be made of the experience gained with superconducting cyclotron magnets at Chalk River and MSU.
3. The Los Alamos Scientific Laboratory proposes the construction of an experiment staging area and a laboratory-office building for the Clinton P. Anderson Meson Facility (LAMPF). These additions are requested in order to improve the research capability of LAMPF by making possible the efficient assembly and check-out of experimental apparatus and to provide for the influx of outside users at LAMPF which has been much larger than anticipated. (The laboratory-office building would reduce by 30 to 40 the number of trailers which must now be utilized as temporary accomodations by visitors and staff members.)
4. MIT-Bates Laboratory proposes an energy-doubling recirculator for their linear accelerator which would provide electron beams with energies ranging up to 725 MeV with an average beam current in excess of 100 μa. The beam now produced would be brought back to the beginning of the accelerator by a magnetic transport system and reinjected. The beam-on-target duty factor would be slightly reduced from its present maximum value of 1.8%.
5. Michigan State University proposes to utilize the K=500 superconducting cyclotron now being constructed there as an injector for a K=800 superconducting cyclotron post accelerator. For ions below A $\sim$ 60, beam energies approach 200 MeV/A, while for large A values they are of the order of 18 MeV/A.

6. Oak Ridge National Laboratory proposes a high-field isochronous cyclotron utilizing superconducting main coils, to be injected with beams from its 25 MV tandem now under construction. This system is projected to provide ions of energy up to 150 MeV/A for small-A and at least 40 MeV/A for large-A ions. Use will be made of experience gained with superconducting cyclotron magnets at Chalk River and MSU.
7. The University of Rochester proposes to inject the heavy ions accelerated by a pre-accelerator plus MP-tandem system into a K=800 superconducting cyclotron. The proposal estimates that small-A ions and large-A ions accelerated by the system will acquire energies of 200 MeV/A and 18 MeV/A, respectively. Use will be of the K=800 cyclotron design proposed by MSU.
8. The University of Washington proposes a room-temperature linear accelerator booster to be injected with ion beams from its three-stage FN tandem. The linac would consist of triple-spiral resonator cavities. Operating with a 20% duty factor, the energy per nucleon of the accelerated ions would vary from 47 MeV for ^{1}H to 7.1 MeV for A $\sim$100.
9. Yale University proposes a conversion of its two-stage MP tandem to make possible higher terminal voltages. The length of the accelerating tube would be increased to 40 feet from the present 32 feet. The present tank which has an internal diameter of 18 feet in the terminal region would be replaced by one with a 25 foot internal diameter in this region. Overall, the new tank would have three times the volume of the old one and would be filled with an insulating gas consisting of an $SF_6/N_2/CO_2/H_2O$ mixture in the percentages 40/47/13/0.15. The proposed configuration is estimated by the Yale group to provide a terminal potential of at least 20 MV, while "22 MV is a realistic design goal". This accelerator would provide heavy-ion beams with energies ranging from 40-44 MeV for hydrogen beams to roughly 4.7 MeV/A for A $\sim$ 120.

Evaluation Criteria

The Subcommittee evaluations (see Section II) of the accelerator proposals are focused on the following issues: technical feasibility, scientific merit, capability of the proposing laboratory, user involvement (current or potential), ancillary equipment, costs, construction time and operating costs on completion. The first of these requires an examination of the design. Can the accelerator be built in the predicted time? Or, on the other hand, are there technical aspects which are as yet not understood

and could advisably be studied further? Second, what is the range of experimental parameters which the projected system will provide; that is, what nuclear species can be accelerated (in the case of the heavy-ion accelerators) and to what energies? Can the energy be varied easily? The particle currents, the energy resolution and the time structure of the beam are important aspects of the beam which need to be understood. The nature of the experiments which will become possible, the ancillary equipment which will be required, and the arrangement of the target areas must be examined. The number of experiments which can be performed simultaneously is an important parameter. In view of the fact that the number of heavy-ion and electron accelerators which will be constructed is small and demand is large, provision for users must be made for most of these facilities. The ability of the proposing laboratory to carry out the program is measured by availability of experienced personnel who will participate in construction, as well as by the scientific capability and experience of the in-house group who will perform experiments upon completion of the facility.

I. 2. Recommendations for Facility Construction in FY 1980

The Subcommittee strongly recommends:

- The construction of a major heavy-ion facility consisting of two coupled superconducting cyclotrons at Michigan State University

- The construction of the electron-beam recirculator proposed to double the energy of the MIT-Bates linear accelerator.

- The construction of an experiment staging area at LAMPF, the Clinton P. Anderson Meson Facility at Los Alamos.

With respect to the accelerator projects, these recommendations are based upon technical feasibility, scientific merit, and the role of the facilities in a balanced national program in nuclear science. The experiment staging area will significantly improve the effectiveness and the productivity of LAMPF, and will be particularly helpful to outside users of this national research facility.

The Subcommittee finds the proposal for the conversion of the Yale model MP tandem electrostatic accelerator into model STU status to be worthy of consideration for the FY 1980 budget. The Yale proposal, to be accomplished by extending the length of the accelerating column and enclosing it in a much larger tank, provides a reasonable extrapolation to higher energies of present electrostatic accelerator technology, and thus constitutes a significant component of a balanced national program.

Last in order of priority for the FY 1980 budget in the Subcommittee's judgement is the proposed laboratory-office building at LAMPF. The Subcommittee is convinced of the importance of this building for the effectiveness of LAMPF. It feels, however, that the plans which were presented for the utilization of the new space did not address in sufficient detail the general problems of research space, the interactions among LAMPF users and resident graduate students, and more general questions affecting the scientific vitality of LAMPF.

The Argonne National Laboratory proposal for extending their prototype superconducting booster with additional arrays of cavities was regarded positively by the Subcommittee. While excellent progress has been made on the individual elements of the prototype booster and on the tandem injector it seems prudent to wait for demonstrated operation of the prototype system before funding the ATLAS extension. It is expected that all questions regarding the system's operation will likely be resolved in time for consideration in the FY 1981 budget.

The opinion of the Subcommittee was that funding for neither the ORNL (Oak Ridge National Laboratory) Phase II proposal nor the BNL (Brookhaven National Laboratory) proposal would be optimal in FY 1980. In both cases it is clear that the designs presented to the Subcommittee are preliminary in many aspects. The Subcommittee encourages both laboratories to submit revised proposals and is particularly interested in receiving designs for accelerators which would have some performance characteristics superior to those of accelerators projected to be available in 1984.

The Subcommittee does not recommend FY 1980 funding of the proposals presented by the University of Washington and University of Rochester. In the case of the latter, the Subcommittee feels concern regarding the difficulty of assembling at Rochester the high level of technical proficiency required to build the proposed booster cyclotron on a time scale consistent with the proposed construction schedule. The panel did feel that the program of tandem improvements mentioned in the proposal is meritorious and suggests its submission as a separate proposal. In the opinion of the Subcommittee the University of Washington proposal required more demonstration of technical feasibility and of the existence of adequately proficient technical staff and adequate faculty participation. The Subcommittee did feel however that the concept of a room-temperature linear accelerator booster should be pursued.

The Subcommittee noted that universities have been an important source of innovative accelerator design concepts. However, the erosion in technical staff levels at university laboratories over the past decade has greatly reduced their ability to contribute in this area and in the development of new research instrumentation. The Subcommittee therefore strongly recommends that more funds be made available for the explicit purpose of supporting accelerator development and instrumentation projects at universities as well as national laboratories as an important investment in the future health of nuclear science.

I. 3. Evaluation of the Fiscal Impact of the FY 1980 Recommendations upon Operating Budgets.

The Subcommittee asked representatives of the DOE and the NSF for their comments about the likely impact of the foregoing recommendations upon the existing national program in nuclear science. In particular, questions were raised about whether provision of construction funds and adequate operating funds for the recommended new facilities would be possible without the reduction of operating funds of other facilities or the shutdown of some facilities.

The NSF representative, Dr. H. G. Pugh, noted that the recommended facility at Michigan State University is located at an NSF-funded laboratory. He reminded the Subcommittee of the NSF planning guidelines for Nuclear Science funding via NSF which had been given to NUSAC; namely (in 1979 dollars):

(1) FY 1979, funding at the requested level
FY 1980, a 3% increase over FY 1979
FY 1980-84, constant funding relative to FY 1980,

(2) In addition, the possibility of an increment of $10 million spread over three years; nuclear science could hope for at most one such increment in the next five years.

Dr. Pugh said that if these funding levels are made available in their entirety, including an increment of $10 million starting in 1980, the construction and operation of the MSU project could be accommodated as part of a sensible and scientifically productive plan for 1980 and beyond. He said, however, that if the increment were not made available he felt that the project could not reasonably be embarked upon with NSF funds. Finally, he reminded the Subcommittee that funding the MSU project would, within the guidelines, preclude funding by NSF of any other new proposal in Nuclear Science of comparable cost for several years.

The DOE representative, Dr. G. L. Rogosa, presented for the Subcommittee's consideration two funding scenarios for the DOE-supported program: (1) constant effective funding and (2) a 10% increase above inflation for FY 1980 and cost-of-living increases thereafter. The Subcommittee felt that for the higher level case (a 10% increase plus inflation) the Bates recirculator and the LAMPF staging area could certainly be accommodated without detrimental impact upon the operating and capital equipment allocations, and that the Yale proposal might also be accommodated. Furthermore, since both the Bates recirculator and the Yale proposal are rather modest upgradings to existing facilities, the effort of these projects would not have a major impact on the operating budget in future years.

Appendix I. Membership of the 1978 Facilities Subcommittee of the Nuclear Science Advisory Committee of DOE/NSF (NUSAC)

H. Feshbach, Massachusetts Institute of Technology, Chairman

D.P. Balamuth, University of Pennsylvania

P.D. Barnes, Carnegie-Mellon University

B.G. Harvey, Lawrence Berkeley Laboratory

E.M. Henley, University of Washington

E.A. Knapp, Los Alamos Scientific Laboratory

D.A. Lind, University of Colorado

S. Penner, National Bureau of Standards

R.E. Pollock, Indiana University

R.T. Siegel, College of William and Mary

V.E. Viola, University of Maryland

Appendix II. Consultants to the NUSAC 1978 Facilities Subcommittee

E.R. Beringer, Yale University

D.J. Clark, Lawrence Berkeley Laboratory

H.A. Grunder, Lawrence Berkeley Laboratory

R.K. Middleton, University of Pennsylvania

J.C.D. Milton, Chalk River Nuclear Laboratory

J. Ormrod, Chalk River Nuclear Laboratory

Appendix III. Site visits preparatory to the March 13-15 meeting of the NUSAC 1978 Facilities Subcommittee

March 1, 1978 Oak Ridge National Laboratory

Subcommittee participants: P. D. Barnes
H. A. Grunder
R. E. Pollock
V. E. Viola

Agency representatives: G. L. Rogosa, DOE
H. G. Pugh, NSF

March 2, 1978 Argonne National Laboratory

Subcommittee Participants: E. R. Beringer
E. A. Knapp
R. E. Pollock

Agency representatives: H. G. Pugh, NSF

March 8, 1978 National Electrostatics Corporation

Subcommittee participants: D. P. Balamuth
J. C. D. Milton

Agency representatives: W. S. Rodney, NSF

March 9, 1978 Michigan State University

Subcommittee participants: D. P. Balamuth
P. D. Barnes
D. J. Clark
J. Ormrod

Agency representatives: G. L. Rogosa, DOE
W. S. Rodney, NSF

Appendix IV. Agenda for the March 13-15, 1978 meeting of the NUSAC 1978 Facilities Subcommittee held at the NSF, 1800 G Street, NW., Washington, D.C.

13 March, Room 543

9:00 a.m. - 1:00 p.m.	Closed Session
1:00 p.m. - 7:30 p.m.	Presentations of Facility Proposals and discussion thereof. Approximate times:
	1:00 Los Alamos Meson Physics Facility Staging Area
	2:00 MIT-Bates Electron Linear Accelerator Energy Doubler
	3:30 University of Washington Heavy-Ion Post Accelerator
	5:30 Argonne National Laboratory Heavy-Ion Post Accelerator

14 March, Room 540

9:00 a.m. - 6:30 p.m.	Continuation of Presentations of Facility Proposals and discussion thereof. Approximate times:
	9:00 Michigan State University Coupled Cyclotrons
	11:00 Oak Ridge National Laboratory "Holifield Phase II."
	1:00 Lunch
	2:00 University of Rochester Heavy-Ion Post Accelerator
	3:30 Brookhaven National Laboratory Heavy-Ion Post Accelerator
	5:00 Yale University Tandem Stretch Project

15 March, Room 321

9:00 a.m. - 5:00 p.m.	Closed Session

II. Brief Summaries and Evaluation of Proposals Considered by The 1978 Facilities Subcommittee of NUSAC.

1. Argonne National Laboratory

The objective of the proposed ATLAS facility is to provide precision beams of heavy ions for nuclear physics research in the region of projectile energies (27 to 15 MeV/A for A=10 to 100, respectively) comparable to nucleon binding energies. Tandem-like energy resolution and beam quality, combined with a very highly bunched beam (<50 ps) will allow powerful new experimental approaches to nuclear physics. Most proposed national heavy-ion facilities are capable of much higher projectile energies, in the range 100-200 MeV/A for the lighter heavy ions. The ATLAS facility specifically addresses the lower energy range where nuclear structure effects should be most important. This is the energy region where high angular-momentum states, shape isomers, molecular resonances and many other aspects of nuclear structure are most likely to reveal themselves. The high precision which the ATLAS accelerator system will provide is required to explore this area.

The main ATLAS (Argonne Tandem Linear Accelerator System) accelerator is to be a superconducting linac consisting of an array of independently phased resonators of the split-ring type grouped in 7 accelerator sections. The Argonne group has been developing the technology for this system since 1975 and is now assembling a prototype booster accelerator of 4 sections to improve the heavy-ion capability of the ANL FN tandem. This prototype booster accelerator is expected to first accelerate heavy ions with a reduced cavity complement in mid-1978 and be completed in 1980. The addition of 3 more sections together with a new experimental hall constitute the ATLAS proposal. The status of the various components at this writing is:

A. Superconducting cavity resonators —
   The resonators for the prototype booster accelerator are in production now in Argonne shops. A method for detecting flaws in the niobium surfaces has been developed which allows rapid detection of faulty surface areas and it appears that these flaws can be repaired quickly and successully. The technology seems to be well in hand.

B. FN tandem system —
   During the last year the Argonne FN tandem was substantially upgraded by installing a high vacuum ($\sim 10^{-8}$ torr) accelerator tube and a 150-KeV injector system. Performance of this system has been excellent through the acceptance tests.

C. Buncher system --
A multiple-harmonic pre-tandem buncher system has been tested and shown to work properly. A post-tandem phasing and bunching system, which will prepare exceptionally narrow bunches for injection into the linac tanks, is also in operation.

D. Beam transport --
The magnetic system for the booster project seems to be a well-designed system capable of the performance necessary for correct operation of the linac.

The thought and calculational effort spent on the beam dynamics in the system seem adequate. Rather complete calculations of the phase motion and radial motion have been carried out An investigation of the steering effects of the split-ring electric fields shows them to be tractable with minor steering corrections. The frequency-control system for the superconducting resonators has been operated and shown to have adequate dynamic range. The helium distribution system for the booster is being assembled at present. No multi-cavity system has yet been operated with beam accelerated.

The R and D program leading to the construction of the boosters is thoroughly professional and success can be expected. However, since this would be the first time a complete superconducting linear accelerator for heavy ions will have been constructed, it seems prudent to wait until ANL has carried out their R and D program to the point where reliable operation of the booster linac with the FN tandem has been demonstrated before proceeding to consider funding of the ATLAS project. In this way, the many systems problems, such as alignment, cavity amplitude, phase control under beam loaded conditions, buncher operation, etc., can be worked out and any catastrophic problems detected. The Subcommittee does not now foresee any fundamental problems and expects that suitable operation will be demonstrated within a year. Thus all technical uncertainties on the operation of the system should be removed and funding of this project in FY 1981 should be considered.

The overall costs for ATLAS are estimated at $4.7M including an allowance of $.68M for contingency. The costs of the prototype booster project has been carried as an R and D project by DOE. The costs of this project have been $1.8M for the prototype booster, $0.2M for building addition, and $3.0M for related development activities making a total cost to date of $5.0M. To complete the prototype booster in 1980 an additional $0.57M plus $0.65M for experimental equipment is needed in FY 1980. The estimated operation cost increments attached to this proposal are $350K for the prototype booster and $350K more for the complete ATLAS.

2. Brookhaven National Laboratory

This proposal calls for the design and construction of a K=800 superconducting cyclotron with four sectors and with an extraction diameter of 1.6 meters, patterned after the Chalk River concept. The double MP tandem accelerator presently operating at BNL will be used to inject into the cyclotron, and the extracted beam will be routed into the present experimental areas. It was stated that the target rooms numbers 2, 3, and 4 and the equipment there available would be adequate for the program of research with the proposed higher energies. In addition to the cyclotron itself, the proposal calls for matching, bunching and transporting of the tandem beam to meet the injection requirements of the cyclotron and extracting and transporting the high-energy beam (after the cyclotron acceleration) to the present experimental area. Operational performance of the double MP tandem has been substantially improved in the past year so that 14 MV can be held reliably on the terminal of MP-7. The proposal also calls for the construction of a building of 8000 sq. ft. to house the cyclotron. The combined tandem-cyclotron system is proposed to accelerate heavy ions up to uranium, with energies ranging from 100 MeV/A for oxygen to 15 MeV/A for uranium, with intermediate energies for masses in between. Specifications call for 10 to 100 particle nanoamps of current for many ions throughout the periodic table and for the energy resolution of two to four parts in 10^4 .

The schedule for this project calls for a start of architectural and engineering work in the first quarter of FY 1980, construction to start the third quarter of FY 1980, with completion scheduled for the fourth quarter FY 1982. The total cost of the project, which includes contingencies and escalation, is $12.9M in 1980 dollars. Of that, $8.7M is assigned to the cyclotron. The proposal states that this number is an estimate based on (1) a partially completed conceptual design, (2) costs obtained by comparision with actual purchases for superconducting projects at BNL and elsewhere, and (3) current costs for actual construction in Suffolk County, the site of the facility. The incremental operating cost for the proposal facility is estimated at $1.1M annually in 1978 dollars.

The proposal contains essentially no technical information regarding the design and performance of the superconducting cyclotron. The proposed cyclotron is a copy of a similar cyclotron being constructed at Chalk River. During the presentation to the Subcommittee it was stated that it is the intent at BNL to utilize the experience gained from that project. Very little additional technical information regarding the design of the magnet and other components, or details on stripping, bunching, and phase-space matching, were presented. It is the evaluation of the Subcommittee that the BNL plan is still in a preliminary stage, with complete designs not yet developed.

A major concern was expressed within the Subcommittee about the technical manpower which BNL would have available to devote to this project, in view of the fact that they will have two other big projects, Isabelle and the synchrotron radiation source, under construction. George Vinyard, BNL Director, did speak to the commitment of BNL to provide this project with the full backing required for its success. Nevertheless, in spite of the substantial experience available at BNL in the design and construction of superconducting magnets, there was a concern that engineering strength for the design of the other components might be lacking. The proposal stated that the conceptual design for the project should be completed by September, 1978.

The Subcommittee felt that this proposal was not complete enough to permit recommending funding in FY 1980. Problems of loading of the tandem accelerators, gaseous vs. solid stripping, and bunched phase-space matching, as well as all the design problems of the very compact K=800 cyclotron, need to be addressed. Finally, there is some question about the adequacy of the current experimental areas and the equipment available for a substantial user operation at the higher energies. In particular, the Q3 D and recoil-mass spectrometers (both K=121) may not be well matched to the K=800 cyclotron.

3. Los Alamos Scientific Laboratory

This proposal has two components, 1) a laboratory-office building with an area of 25,000 sq. ft., estimated cost $4.5M, and 2) an experimental-support building of 7500 sq. ft., estimated cost $2.7M in 1980 dollars. These two projects have been in the LAMPF schedule of construction priorities since 1973. At that time the experimental-support building (staging area) was recommended for first priority by the LAMPF User's Group Technical Advisory Panel. The discussions of the present Subcommittee were concerned with the contribution of the proposed construction to increased research efficiency at LAMPF, in particular as this affects the outside users of this facility.

The two parts of the proposal were treated and discussed separately. The experimental-support building (staging area) will have a floor space of 7500 sq. ft. and be equipped with a 30-ton crane, power, and cooling water. It will provide space for assembly and check-out of experimental apparatus such as magnets, detector chambers, and similar gear, before they are moved on-line at one of the experimental channels. At the present time only a very small amount of space on the south side of the target line in beam area A is available for such purposes. The proposed staging area will extend the north side of beam area A to the east and would also provide space for future development of a new beam line for a low-energy pion and muon channel from target A5, which is currently servicing the radiobiology and therapy research facility. Since about 60% of the activity at LAMPF is generated by outside users, there is a large back-log on the available space for assembly and checkout of apparatus. Beam areas B and C are excluded from occupancy during LAMPF operations. There was a strong consensus in the Subcommittee that such a staging area was needed, was cost effective for the overall efficiency of the operations at LAMPF, and should be recommended for inclusion in the FY 1980 budget requests.

The laboratory-office building has also been on the user's priority list since 1973. The design for this building contained in the proposal calls for a three-story addition to be built with a connecting wing on the east side of the existing LAMPF operations building, MPR 4. Also, a small one-story additional adjacent to the computer area would be added to provide extra space for computer operations. This building would have a total area of 25,000 sq. ft. and would be used for LAMPF operations, instrumentation, computer, experimental areas, and beam line development groups from the MP division. It is designed to house 120 people.

At present about 140 operations and user-group personnel are housed in approximately 100 trailers. The inadequacies of these trailers contribute in many ways to decreased efficiency both for the operations personnel and for the users. The proposal states that many of the operations personnel presently housed in the main office building at LAMPF and in some of the laboratories in that building would be moved into this new area, thus providing space for visitors in the main office building. The dispersion of the outside users of the LAMPF facilities, particularly the gratuate students and post-docs, has been of considerable concern to the Users Group, which has recommended that more efficient facilities for users be provided.

During discussion before the Subcommittee the question was raised as to whether or not the proposed laboratory-office building would indeed assist the users groups once operations personnel are moved to this new addition. It was felt the efficiency would be substantially improved; on the other hand it was not made clear exactly how the space vacated in the headquarters building would be used to satisfy the needs of the various user groups. The lower priority of the laboratory-office building relative to the staging area which is contained in these recommendations resulted from the fact that a clear presentation was not made on how the facility would enhance the user operations at LAMPF. The Subcommittee expressed its concern with the high cost of construction of the laboratory office building.

4. Massachusetts Institute of Technology

The Massachusetts Institute of Technology has submitted a proposal for "An Energy-Doubling Recirculator for the Bates Linear Accelerator." The object of this proposal is to increase the beam energy capability of the Bates electron linac from its present maximum of less than 400 MeV to approximately 750 MeV. This increase is to be achieved by recirculating the accelerated beam through the present accelerating structure for a second pass. The cost estimate for the project is $1,945,000 in 1980 dollars. This estimate calls for a one-year procurement schedule so that if the proposal is funded for FY 1980, the recirculator could be completed by the summer of 1981.

At present, the Bates laboratory has an active and productive program in high-resolution electron scattering. There is active external user participation in the experimental program. The excellent resolution ($<1 \times 10^4$) of the "energy loss" spectrometer system allows Bates to accurately measure the electromagnetic form factors of nuclear states where high level density is the limiting element in obtaining reliable data. Doubling the energy will allow these measurements to be extended to considerably higher momentum transfers with a consequent improvement in the spatial resolution of the charge, current, and magnetization densities deduced from the data. At presently available momentum transfers, the higher energy capability will substantially reduce data collection times, since the basic Mott cross section increases as the square of the beam energy. Demands for beam time already exceed availability and the completion of the second experimental area under construction will expand the demand for beam time for experiments other than electron scattering. The proposed increase of beam energy will of course be valuable for many experimental programs in addition to that of electron scattering. A study of pion production in the $\Delta(1232)$ region is just one example in which the presently available beam energy is too low.

This project was listed as a <u>first priority</u> recommendation for facility improvement programs by the Friedlander Panel (Ref. 1), a recommendation which was reiterated by the Livingston Panel (Ref. 2).

There is no doubt that recirculation of the Bates linac beam for a second pass through the accelerator is feasible. Recirculation of high-energy electron beams has been demonstrated at Illinois and at Stanford, albeit at substantially lower current. Recirculation should be quite straightforward with the room-temperature accelerating structure at Bates. The first-pass and second-pass beams are decoupled to a significant extent since their energies differ by approximately a factor of ten at the low-energy end and nearly a factor of two at the high-energy end of the accelerator.

The Bates proposal presents a specific design of a transport system which can accomplish the desired recirculation. The recirculation is carried out by four dipole bending magnets and straight drift sections. Focusing is provided through pole-tip rotation and quadrupole magnet doublets. Transport calculations through second order have been carried out which show that the system will have more than adequate (5%) energy pass, will keep the beam size sufficiently small throughout the system, and will not significantly increase the beam phase space. They show that one-pass performance of the accelerator will not be degraded by the recirculator. Tune-up and operation of the two-pass system is described in the proposal. Tune-up in this mode is not expected to be significantly greater than for one-pass operation. The only degradation in performance will be a small (7%) decrease in beam duty cycle when the accelerator is used in the two-pass mode above 400 MeV. At lower energies the duty cycle can be increased substantially by recirculation.

It is clear that the Bates staff possesses the expertise required to design, build and operate the recirculation system. The people involved are the same group which developed the energy-loss spectrometer system at Bates. The technical problems in that project were substantially more difficult than the present proposal. There is nevertheless some concern that there may arise some conflict between the recirculator project and the development of the second experimental area at Bates. The same key people will be involved in both projects, and the group is small in number. The two projects must be carefully managed to assure that both are carried out in an efficient and timely manner.

The total cost of this proposal is estimated at $1,945,000, including a 25% contingency allowance and escalation at 7% per year to fiscal year 1980. A one-year procurement schedule and a three month shutdown of the accelerator for installation is estimated. These estimates appear reasonable in the Subcommittee's opinion.

The proposal to add an energy-doubling recirculator to the Bates linac has great scientific merit. There is no doubt about the technical feasibility of the project or the ability of the Bates staff to carry it out. Completion of this project will nearly double the energy and momentum-transfer range of electron accelerators available to the U.S. medium energy nuclear science program. Its execution at Bates presents a unique opportunity for achieving these objectives rapidly and inexpensively. At just below $2 million, the project is cost-effective. The committee therefore recommends funding of this proposal in FY 1980.

5. Michigan State University:

Michigan State University, in collaboration with a group of scientific sponsors representing nuclear scientists at approximately twenty mid-western universities, has proposed the construction of a laboratory for the study of heavy-ion nuclear science in East Lansing, Michigan. The core of the proposed project is an accelerating system consisting of two coupled cyclotrons, each with superconducting main coils and peak magnetic fields of approximately 5 Tesla. Positively charged ions from a PIG (Penning ion gauge) source in the center of the first ($K=ME/q^2$ = 500 MeV) cyclotron are accelerated and extracted. They are then transported into a second similar, cyclotron (K=800), stripped by passage through a thin foil to a higher charge state, and accelerated again. Final maximum energies are 200 MeV/A for projectiles with $A \sim 40$. With increasing mass this maximum energy decreases to about 18 MeV/A for uranium ions. At an energy of 18 MeV/A the beam intensity for uranium is 10^{11} particles per second. Higher beam intensities are obtained for lighter projectiles. The design upper limit of 200 MeV/A for projectiles with $A \sim 40$ has been chosen because of the desire to extend the operating range of the accelerator comfortably into the region where meson production can be observed in nucleus-nucleus collisions.

Fabrication of the magnet for the first (K=500) cyclotron has been completed as part of an ongoing program of accelerator development at Michigan State University. This magnet is presently undergoing extensive tests. The schedule proposed by MSU calls for obtaining a beam from the first cyclotron in the Fall of 1979. (This phase of the project has already been funded by NSF at a cost of approximately $3.4M). Phase II of the project, for which funding is now being requested, consists of construction of the second cyclotron, a substantial addition to the laboratory building for new experimental areas, and associated cryogenics, shielding, and beam transport elements. Part of the proposal costs are directed towards new experimental equipment, including a new computer, a large magnetic spectrograph and other items.

Phase II is scheduled to take 3.5 years; funding in FY 1980 implies availability of beams from the coupled cyclotrons by early 1984. The total cost of Phase II is $18.9M in 1978 dollars. This includes $13.5M in construction costs and $5.4M in engineering and development costs. The cost breakdown by category is: 800 MeV cyclotron (22.5%), building (28%), shielding and beam transport (17.5%), experimental facilities (32%). These costs are distributed in time as follows: 1980 ($5.2M), 1981 ($5.4M), 1982 ($5.4M), 1983 ($2.9M). Annual operating costs for the new facility are expected to be approximately $3.5M, including support for the research program of the in-house group.

The stated intention of the proposal is to operate the accelerator as a national facility, with beam time being made available to the entire community strictly on the basis of scientific merit. It is expected that sufficient services (machine operators, electronics pool, etc.) will be provided to outside users to enable them to maintain independent research efforts.

The consensus reached by the Subcommittee is that the technical feasibility of the coupled cyclotron project is established. Magnetic field measurements on the K=500 magnet show agreement between the previously calculated and observed fields at the 0.2% level. These results demonstrate that the 5 Tesla azimuthally varying field required for the K=500 cyclotron has, in fact, been achieved. Furthermore, the measurements show that fields of such magnets can be reliably calculated in advance, thereby enabling an unprecedented degree of certainty to be introduced into the design of the accelerator itself.

The Subcommittee also examined the detailed designs which exist for the remaining principal components of the K=500 cyclotron. The ion source, rf and extraction systems are well within the established competence of the MSU group. In several cases experimental tests of design assumptions have been made, including electrolytic tank measurements of electric fields in the central region and tests of extraction system components in the MSU 50 MeV cyclotron. A detailed design has also been made for the injection and stripping mechanism to be located in the second cyclotron. While the details of the design of the K=800 cyclotron are still evolving, the Subcommittee is satisfied that the extrapolations from the first machine that are involved in the construction of the K=800 are sufficiently small that no major problems should anticipated. This opinion is shared by the Subcommittee's consultants.

The Subcommittee is also of the opinion that the cost estimates presented by the Michigan State group are reasonably accurate. The magnet for the first cyclotron has been completed within the planned budget. Dr. Ormrod stated that the cost estimates presented agreed well with comparable items in the Chalk River budget.

It should be noted that the Subcommittee's evaluation of this project was strongly influenced by the outstanding past performance of both the cyclotron design and physics research groups of Michigan State University.

In particular, the laboratory's present 50 MeV cyclotron, which was designed and built under the supervision of the design group, is at the forefront of modern cyclotron design. The MSU effort has been characterized by strong coupling between machine development and the needs of the research program. The last aspect is of particular importance in the sense that the parameters of the coupled accelerator system will undoubtedly evolve as experience is gained with operation of the K=500 cyclotron.

The panel is unanimous in thinking that the proposed facility will dramatically advance the frontiers of research in heavy-ion nuclear science. The panel is confident of the overall technical feasibility of the project and of the ability of the Michigan State group to carry it through to completion. Funding for this project is FY 1980 is recommended as our highest priority for major new construction.

6. Oak Ridge National Laboratory

This proposal (Phase II) is for the construction of a K=800 superconducting cyclotron which would accelerate heavy-ion beams injected into it by the 25 MV tandem Van de Graaff accelerator presently under construction for ORNL by the National Electrostatics Corporation (as part of the Holifield Heavy-Ion Laboratory Phase I, which is already funded).

The design objective of this proposal is to reach about 150 MeV/A at the low end of the ion-mass range and at least 40 MeV/A for uranium ions. a 1 MeV reduction in injection energy would result in a 2 MeV reduction in uranium beam energy. The new cyclotron is to be built adjacent to the tandem injector; maximum utilization would be made of existing experimental areas, beam transport equipment, and experimental facilities. The estimated cost for Phase II is 13.5M in 1978 dollars. Any required increase in shielding from Phase I to Phase II is not included in this estimate. The scientific thrust of the Phase II proposal is partly to extend the range of topics already accessible in Phase I and partly to explore new topics by capitalizing on the much higher range of projectile energies that would become available. Among the former topics are deep inelastic scattering and peripheral reactions, production of nuclei far from the line of stability, search for production of superheavy nuclei, and excitation of giant resonances. At the upper end of the energy range of this facility one can attempt to study nuclear properties under conditions of increased density and to analyze pion production in ion-ion collisions. In addition there are heavy-ion atomic processes to be explored, e.g., the production of positrons by the high electromagnetic fields generated when highly ionized uranium ions collide, the atomic spectroscopy of the quasi-molecule of the two interacting heavy ions, and angular correlations in the X-ray decay of these states, and finally, the production of 2 or 3 electron atoms with $Z \sim 80$, in which retarded potentials will play a role.

In order to make an overall evaluation of the Phase II project, an analysis of the anticipated performance of the electrostatic injector accelerator is necessary. The desired characteristics for the beam injected into the cyclotron are low emittance and energy dispersion, high beam current and energy, flexibility in the choice of beam species, and good time-modulation features. All these characteristics have been designed into the sputter ion source and the 25 MV tandem electrostatic accelerator being built for ORNL by NEC.

The sputter source can generate negative ion beams of most of the 79 stable elements. Performance at the 13 p.μA current level has been

demonstrated for at least 14 of these elements. Large low-energy beam-tube acceptance is achieved by introducing a quadrupole lens into a dead section of the low-energy tube. Excessive beam-tube current loading is avoided by individual charge-state selection both at injection and in the terminal following a gas stripper. Although built for very high overall voltage operation,the accelerator has been designed for relatively modest voltage gradients on the tubes.

This accelerator can be used as a stand-alone device or as an injector for the Oak Ridge Isochronous Cyclotron (ORIC). The major modifications (of dees, trimmers and liner) of the latter machine required for injector operation have been made, and the cyclotron is now back in operation. All changes will be complete by April, 1979.

Building modifications at ORNL are well-advanced, with completion scheduled for July, 1978. Completion of accelerator installation and acceptance tests are scheduled to occur by July, 1979. Thus the experimental program for Phase I operation should begin by January, 1980.

The main coils of the proposed cyclotron will be NbTi superconductor immersed in liquid helium. Coils of this general type have been designed and built previously at ORNL, e.g., by the Tokamak simulation group. The magnetic field is shaped to provide optimum acceleration for uranium ions. The dee structures will be mounted on double stems in the three spiral-shaped valleys. Detailed orbit calculations are not yet available. Injection is somewhat complicated by the fact that beams from the tandem injector of different Q and A will have different B values; some variation in injection orbit and stripping foil angle must therefore be allowed for. In addition, recent studies of tandem accelerator injection into cyclotrons at Chalk River have pointed out the need to distinguish energy shifts from time shifts in pulses from the tandem injector. A solution to this problem has not yet been provided by ORNL. Design studies for beam extraction from the cyclotron are also not yet available.

Although the construction of the proposed booster will require an extension of the existing building to house the cyclotron, no expansion of the experimental area is planned. The beam lines will be redesigned, and the introduction of an RF beam splitter is under discussion. This will permit simultaneous utilization of the beam in two experimental areas. A substantial amount of ancillary equipment (net value $3.4M in FY 1978) will become available within the existing Phase I funding. This equipment includes a recoil-mass spectrometer, a 60-in diameter scattering chamber, a data-acquisition system, an on-line isotope separator, and a

split-pole magnetic spectrometer. No additional experimental equipment is requested in this proposal.

In connection with Phase I design and operation, a users organization was constituted in 1975. It currently has 300 members (147-university, 61-governmental, 50-ORNL, 9-industrial, 35-overseas) and has actively participated in establishing priorities for experimental apparatus, establishment of design criteria, and layout of the experimental area. In a joint project, ORNL and Vanderbilt University are now preparing for construction of a 5,000 sq. ft. office building to house the outside users of the facility.

The current cost estimate of this facility is $13.5M (FY 1978) the major items being the cyclotron ($5.7M), engineering ($2.1M), beam transport system ($1.0M), building construction ($0.9M), and contingency ($3.1M).

The cost of the cyclotron magnet is larger than the MSU request, due partly to the increased amount of iron used. If funded in FY 1980, this system is projected to be on-line and fully tested by January 1984. Beam line modifications would require that the tandem accelerator be shut down for about three months in mid-1982. ORIC would be shut down permanently in June 1983.

ORNL estimates that no incremental funds will be required to operate this facility. The power savings achieved by replacing ORIC by a superconducting cyclotron will provide the support funds necessary for any new personnel required. The projected Phase I operating costs show a requested increase for FY 1980 to FY 1983 of $3.0M to $3.7M (1978 dollars).

The Subcommittee has given careful consideration to this proposal, both with regard to its scientific and technical aspects and to its relation to the overall national program. It is an imaginative and forward-looking project based on a Phase I construction program that will provide one of the best injectors available for a superconducting cyclotron facility. In addition, the experimental areas and ancillary equipment now being generated and the user group that is now in operation will provide the mechanisms for a rapid and productive start for the expanded facility. The decision to realize the cost-saving in power and steel afforded by the switch to a superconducting magnet is to be applauded. The staff at ORNL is large and competent, its expertise being demonstrated by the impressive progress made on the Phase I construction project.

Nevertheless, the Subcommittee feels that both the nature and timing of the Phase I project and the recent decision to use superconducting cyclotron technology have created obstacles to the rapid execution of this new project. It is clear that the design presented is still preliminary in many aspects. The high field of the proposed magnet raises important beam-optics questions in connection with the transport of the beam from the tandem injector to the cyclotron, with the beam injection orbits and stripping location, and finally, with beam extraction. The preliminary aspect of the design raises questions in turn about the cost estimate. For example, are significant cost-savings to be had by reducing the amount of iron in the yoke? Finally,the Subcommittee is concerned that the need to bring the Phase I facility into operation and to develop design solutions to the Phase II project, both in the next eighteen months, will place unreasonable demands on the available manpower, especially at the middle-management level.

The Subcommittee concludes, therefore, that the funding of the Phase II project in FY 1980 would be premature. It wishes, however, to encourage ORNL to resubmit a proposal subsequently with detailed design calculations to support the technical feasibility arguments. In such a proposal careful attention should be given to development of a device with operating characteristics which surpass in some aspects those of other facilities likely to come into operation by 1984. In particular, ORNL may want to explore the scientific justification and technical feasibility of constructing a device with E/A > 200 MeV/A for light ions and E/A>100 MeV/A for the heavy ions (A> 150). In summary,the committee feels that a delay in the consideration of funding of Phase II will lead to both a more specific and attractive Phase II proposal and to an extension of the period during which Phase I operation will be productive.

7. University of Rochester

The basic accelerator configuration of this proposal begins with a negative 3 MV terminal (pressurized ion source) which produces a bunched and isotope-separated beam for injection into an upgraded version of the present Rochester MP tandem. The beam from the tandem can then either be used directly for experiments or directed to the central region of a cyclotron with superconducting magnet coils, where a foil stripper converts the beam to a higher charge state for final acceleration. The beam from the cyclotron can be brought back to feed the original experimental area via stronger switching magnets. Small building extensions are required to house the new source terminal and the cyclotron with associated beam transfer lines. The configuration requires no major period of disruption of normal tandem operations while the post accelerator is under construction. The only major new experimental equipment associated with the facility construction is a computer to replace an existing PDP 6 configuration.

The proposal assumes that the design and development of the superconducting coil cyclotron will be carried out by the group at Michigan State University under Professor H. G. Blosser. The cost estimate is consistent with this assumption and is therefore equal to the cost for a "carbon copy" of a fully designed and debugged cyclotron. The assumed design parameters are a rigidity limit at extraction equivalent to 800 Q^2/A MeV, a focusing limit of 400 Q MeV and an extraction radius of 1 meter.

An increase in the laboratory technical staff to approximately double the present level is proposed. Access by visiting scientists in a full user mode operation is envisioned. No provision is made for parallel usage via multiple beams. While very little space is presently available for major new target-station equipment such as new magnetic analyzers or equipment of comparable size brought by users, it is nevertheless possible to accommodate future needs by an extension to the present target area (not part of the current proposal). The proposal which has been considered by the Subcommittee was originally submitted to the NSF early in 1976, was amended later in 1976, and was revised again on 14 March 1978. The Rochester proposal was the first U.S. facility proposal for attaining nuclear collisions between all pairs of ions by utilization of superconducting cyclotron technology.

Rochester's strong and continuing interest in the construction and research operation of accelerators is evidenced by construction of the 20" cyclotron

in the late 1930's, the synchrocyclotron of the early 1950's and most recently by the MP Tandem Van de Graaff, which has been in use since 1966. Facility propoals for a high-voltage target station (1966), for a separated-sector cyclotron booster (1969), for an FN tandem injector (1974), and most recently for a superconducting cyclotron booster (1976), and a number of smaller improvements projects for the tandem proper show continuing active commitment to remain at the forefront of fundamental nuclear science.

Based on the information at its disposal, it is the consensus of the Subcommittee that, although the scientific need for a U.S. heavy-ion facility with properties at least equivalent to the projected performance of an MP tandem-K=800 cyclotron combination is well established, the uncertainties attendant to the present proposal are too large for it to be given high priority for FY 1980 funding.

Concerns expressed by members of the Subcommittee included the difficulties of assembling at Rochester on a time scale consistent with the proposed construction schedule the high level of expertise in cryogenic technology, in high-power radio frequency systems, in cyclotron orbit dynamics, in coupled-accelerator control systems, and in other technical areas, which would be required in order to commission and operate successfully an accelerator system of the proposed complexity. The present technical staff is not large and would be fully extended in maintaining tandem operation and in undertaking major ion-source and tandem modifications during the construction phase. It is not clear that the technical skills which would have to be developed at MSU during the cyclotron construction phase could be transplanted to Rochester at the appropriate time with sufficiently high probability to ensure the success of a project of critical importance to the future of U.S. heavy-ion nuclear science. It is not possible to be sure of the necessary commitment of the MSU group to the development of a cyclotron for Rochester at the same level as for a construction project of direct benefit to their own program. If such a cyclotron were already designed, built and debugged at MSU, then it would be possible for a lab with less in-house expertise to duplicate the design and to operate it successfully. There is a precedent in the LBL 88" design (copies at TAMU and Calcutta), the ORNL (ORIC) design (copies at NRL and Davis) and the MSU 50 MeV design (modified versions at Priceton and NASA Lewis). Except for commercial enterprises, there is no precendent for an original design by one lab for use in another. If both MSU and Rochester have acceptable injectors and schemes for research operation, it would seem preferable to situate the first booster at the design site, from the standpoint of the higher probability of rapid completion and satisfactory operation.

As an example of the non-trivial problems which can be encountered in taking over an existing design for a booster accelerator, and which is illustrative of the need for a strong in-house design group, the problem of matching the cyclotron to an MP tandem injector is noted. There is an upper limit to the energy gain of the cyclotron which is set either by the central geometry (foil-stripper mechanism, inward extent of dee tips, etc.) or by the ratio of ion charge after stripping to the charge state from the injector. Both the Chalk River and the MSU booster designs have a maximum energy gain which is ≤ 30 with $Q_2/Q_1 \leq 3$. For the ions in the range $19 < A < 40$, the matching condition leads to maximum energies about 60 to 80 MeV/A, values which are significantly below the projected performance in the proposal. At the high end of the mass range, where the magnet rigidity limits the energy output, the charge-change ratio which gives the best intensity might best be accommodated by a design modification for the cyclotron central region.

8. University of Washington

The University of Washington proposes to construct a room-temperature linac booster to be injected by their existing three-stage tandem accelerator. Following the linac, a series of magnets and quadrupoles would return the beam into the two existing experimental areas. The linac itself is designed to fit into an experimental area that is presently used only for storage. Thus no building additions are required.

The linac utilizes spiral resonators of the type developed at Los Alamos and Frankfurt and which are presently in use at Heidelberg. However, in the Washington design there would be three resonators per cavity rather than one as at Heidelberg.

In order to match the linac, the beam is bunched before and after the tandem accelerator to a final time width of less than 500 ps. Following the linac, it is proposed that the beam be passed through further spiral resonator cavities that would a) give about 50 ps bunches for time-of-flight experiments or b) convert the time resolution into energy resolution, $\Delta E/E < 3 \times 10^{-4}$ or c) flat-top the beam for coincidence work.

The spiral resonators in the 27 cavities would be mounted on "hatch covers" that can be removed. This is intended to permit the rapid installation of resonators with different numbers of spirals, thus changing the phase velocity so that the acceleration of light, medium and heavy ions could take place with minimum phase mismatch.

With the proposed 27 cavities at 20% duty factor, the low-medium mass ions would be accelerated to about 15 MeV/A. At A=238, the energy would be about 4 MeV/A. Protons and deuterons could be accelerated to about 45 MeV. A duty factor of 100% could be achieved with some loss of maximum beam energy. Polarized ions (e.g., ^{7}Li) could be accelerated, but the ion source is not included in the proposed budget.

The cost of the project is \$5.1M in 1978 dollars. Completion would require 3 years. The increment in the cost of operating the augmented laboratory would be \$400K/year.

It is the opinion of the Subcommittee that this proposal is not in a fully mature state. For example, lack of funds has prevented the pulsing of a cavity at high power levels. Even though some high-power-level tests have been made at Los Alamos, there is concern that there may still be major unresolved technical problems such as the following:

1) Troublesome vibrational modes, since the spiral -resonator structures are combined in groups of three in each cavity. Such a structure might have many more vibrational modes than the single-spiral-per-cavity system that was developed at Frankfurt and is under construction at Heidelberg. Experience with the Heidelberg/Frankfurt cavities might well be irrelevant to the proposed design. 2) The "hatch cover" system may not permit exchange of resonators in a reasonable time.

The Subcommittee is impressed by the scientific competence and productivity of the University of Washington staff and recognizes that construction of the booster would allow an excellent research program using light and heavy ions to be mounted. However, it is concerned about the ability of the University of Washington faculty and staff to design and construct this sophisticated accelerator. There are at the present time too few experienced and dedicated personnel to guarantee successful completion.

The Subcommittee therefore concludes that the University of Washington proposal should not be recommended for funding in FY 1980. However, it is the Subcommittee's opinion that room-temperature linac boosters deserve continued study. It is recommended that the funding agencies give a sympathetic reception to proposals for research and development in this area from the University of Washington or other institutions.

9. Yale University

The Wright Nuclear Structure Laboratory at Yale University proposes to increase the maximum terminal voltage capability of its accelerator facility by converting the present 14 MV MP tandem Van de Graaff to a stretched (STU) configuration that would achieve a terminal voltage of 20-22 MV. The research emphasis of this proposal is on the extension of current programs at Yale to regions of higher energy and ion mass while preserving high-precision characteristics of the available beams and the ability to perform light-ion studies. The primary modifications to the existing facility would consist of (1) increasing the number of accelerating sections from four to five; (2) replacing the present 18-ft. diameter tank with a 25-ft. diameter tank capable of maintaining 175 psi; (3) installation of a rotating-shaft mechanical power system in parallel with the current Pelletron charging chains; (4) enlargement of the injector terminal; (5) replacement of the present acceleration tubes, and (6) addition of a new 90° momentum-analyzing magnet to accommodate beams of higher magnetic rigidity. The cost of this conversion is $3.8M in 1978 dollars. No significant increase in the operating budget is foreseen as a result of this modification. Total time for completion of this project is 33 months.

Evaluation of the technical feasibility of reaching the proposed 20 MV terminal voltage in the STU tandem configuration has been based on the following tests: (1) operation of an MP tandem at 17 MV without acceleration tubes; (2) operation of the MP/TU tandem column at High Voltage Engineering Corporation at 21 MV without acceleration tubes, and (3) achievement of 16.5 MV in the TU tank at HVEC with four accelerating tube sections. The Subcommittee sought the opinion of a number of outside consultants concerning the prospects that the STU would be able to achieve stable operation with moderate-intensity beams at 20 MV terminal voltage. It was concluded that the 20 MV goal was technologically attainable. It was agreed that the increase in tank diameter should help solve some of the electrical breakdown problems common to MP tandems and that the increased gas pressure should also help. In addition, the quoted vacuum characteristics of the accelerator ($<3 \times 10^{-8}$ at base and 10^{-7} at terminal) should provide good beam transmission through the machine.

Since the engineering and manufacturing of the new components for the accelerator will be performed by HVEC, the responsibility for these aspects of the conversion does not rest with the Yale group. However, the responsibility for successful installation and operation of the STU tandem will be assumed by Yale. The accelerator group at Yale has had

extensive experience in the problems associated with tandem accelerators. The completion date of July 1, 1982 (assuming Oct. 1, 1979 funding) appears realistic.

It was noted by the Subcommittee that the Wright Laboratory possesses a strong scientific staff that has consistently produced innovative research and educated many young physicists. The program has been a broad one which, in addition to its contributions to the study of nuclear structure and reaction mechanisms, has contributed to the investigation of problems in astrophysics, atomic and molecular physics and materials science. The present program would be extended productively into a higher energy region by the STU conversion. When compared with the alternative of adding linac booster sections, as proposed by ANL and SUNY (Stony Brook), the facility also will have the advantage of extending the mass range of available ions. When placed in the perspective of developing a broad national program in nuclear science, the Yale proposal represents the strengthening of an important University-based group engaged in both light-ion and heavy-ion research. In addition, it will provide precision beams in the transitional energy region between present tandem accelerators and the higher energy beams from the ORNL 25 MV tandem and the booster projects at Stony Brook and ANL.

The cost for the proposed STU facility is $3.8M in 1978 dollars, distributed as follows: STU tank, $1.1M; (2) MP column extension, $1.1M (3) installation, $0.6M (4) 8 new tubes, $0.32M and smaller items, $0.6M The operating budget for the Wright Laboratory for FY 1978 is $1.3M, provided by the DOE. Since the proposal does not envisage formation of a users group or new experimental areas, no increase in the operating budget is projected beyond inflation and the possible addition of one or two research associates. The Yale group plans to continue the encouragement of outside collaborations without the creation of a formal users group. It was the view of the Subcommittee that, when considering improvement projects on smaller facilities, the existence of a users program may not be an important factor.

The proposed project is headed by a strong scientific staff with an innovative program. The increased energy will substantially enhance the research capability of this group for precision studies with both light-ion and heavy-ion beams. The project cost is $3.8M, with no major increase in operating budget anticipated. The project is scheduled for 33 months of construction, with a nine-month loss of research time for installation. The Subcommittee finds this project worthy of consideration for inclusion in the FY 1980 budget.

Reference 1. Future of Nuclear Science

Compiled by the Ad Hoc Panel on the Future of Nuclear Science, 1977.

Committee of Nuclear Science
Assembly of Mathematical and Physics Sciences
National Research Council - National Academy of Sciences
2101 Constitution Avenue
Washington, D.C. 20418

Reference 2. The Role of Electron Accelerators in U.S. Medium Energy Nuclear Science

Compiled by the Department of Energy/National Science Foundation Study Group, Published by Oak Ridge National Laboratory, 1977..