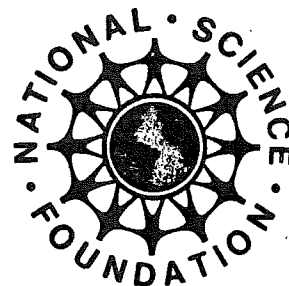

REPORT OF THE PANEL ON ELECTRON ACCELERATOR FACILITIES

DOE/NSF NUCLEAR SCIENCE ADVISORY COMMITTEE

APRIL 1983



U.S. DEPARTMENT OF ENERGY
OFFICE OF ENERGY RESEARCH
DIVISION OF NUCLEAR PHYSICS
WASHINGTON, D.C. 20545

AND

NATIONAL SCIENCE FOUNDATION
DIVISION OF PHYSICS
NUCLEAR SCIENCE SECTION
WASHINGTON, D.C. 20550

ARGONNE NATIONAL LABORATORY

9700 SOUTH CASS AVENUE, ARGONNE, ILLINOIS 60439

TELEPHONE 312/972-4066

April 29, 1983

Dr. James E. Leiss
Associate Director for High
Energy and Nuclear Physics
Office of Energy Research
U.S. Department of Energy
ER-23 GTN
Washington, DC 20545

Dr. Marcel Bardon
Director, Division of Physics
National Science Foundation
1800 G Street, N.W.
Washington, DC 20550

Dear Sirs:

The Nuclear Science Advisory Committee of the Department of Energy and the National Science Foundation herewith transmits, with its endorsement, the report of the Panel on Electron Accelerator Facilities.

This panel was formed at an NSAC meeting on January 12, 1983, and asked "...to review and evaluate electron accelerator facility proposals submitted by Argonne National Laboratory, University of Illinois, Massachusetts Institute of Technology, National Bureau of Standards, and Southeastern Universities Research Association." The essentials of the Panel's recommendations, quoted from the report, are as follows:

"This Panel finds that the highest priority for new accelerator construction in the U.S. nuclear physics program is for an electron accelerator of high duty factor capable of producing beams at any energy in the range from 500 MeV to 4000 MeV.

"That being the case, we consider the two fully developed proposals for such facilities before us, namely those from the Argonne National Laboratory and from the Southeastern Universities Research Association. It is a measure of the strength of the electromagnetic physics community in the country that two quite different proposals of this scope, magnitude, and quality are available for consideration. The decision between them has been a difficult one. The Technical Subpanel, after a very careful, independent analysis of both designs, has concluded that both designs are feasible ones and that either could very well form the basis for an extremely powerful national facility.

"Our decision between the two proposals then depends upon the relative weightings that we ascribe to the different problems facing the two groups of accelerator designers and to other considerations quite apart from technical ones. With such considerations in mind the Panel recommends:

That the proposal of the Southeastern Universities Research Association (SURA) for the construction of a linac-stretcher ring accelerator system capable of providing high duty-factor beams throughout the energy range from 0.5 to 4.0 GeV be accepted and that this facility be constructed and designated the National Electron Accelerator Laboratory (NEAL)."

The priority NSAC attaches to the construction of an electron accelerator of high duty factor in the few GeV range is the culmination of plans made over the past decade. The role of such an electron accelerator in nuclear research was emphasized in the Long Range Plan for Nuclear Science, presented to and accepted by DOE/NSF in 1979, and in numerous committee reports, starting with the 1977 report of the DOE/NSF Joint Study of Role of Electron Accelerators in U.S. Medium Energy Nuclear Science (the Livingston report).

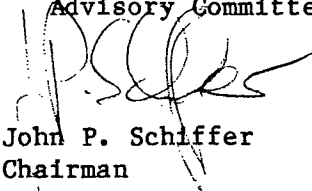
Nuclear physics is entering a period of expanding horizons; this presents an opportunity to shed new light on problems of long standing and to ask questions that could hardly have been imagined 15 years ago. The support for a 4 GeV CW electron accelerator should not obscure the fact that nuclear physics faces other scientific challenges and opportunities. This Committee shall place these in perspective as part of the new Long Range Plan for Nuclear Science to be completed in 1983.

In recommending a major new facility, it is essential also to recommend measures to ensure the continued growth and vitality of the research community that will use it. What is said here applies not only to the electromagnetic physics community but to the nuclear physics community as a whole. Major facilities in the United States are seriously underutilized, operating because of budgetary constraints at a fraction of full capacity. Much of their instrumentation is in serious need of modernization.

Accordingly, in addition to incremental funding for the construction and operation of the new electron accelerator, there is an immediate need for a significant injection of support to maintain the strength and balance of the nuclear research program. This will require some \$20 million per annum in incremental operating and equipment funds.

In conclusion, the Committee sends you the Report of the Panel on Electron Accelerator Facilities with its full endorsement, and recommends that it be implemented without delay.

On behalf of the Nuclear Science
Advisory Committee,


John P. Schiffer
Chairman

JPS/bw

Enclosure

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* Members of the Technical Subpanel.

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I. PRINCIPAL RECOMMENDATION:

This Panel finds that the highest priority for new accelerator construction in the U.S. nuclear physics program is for an electron accelerator of high duty factor capable of producing beams at any energy in the range from 500 MeV to 4000 MeV. After detailed study and consideration of the proposals for such facilities submitted to it, the Panel **recommends:**

That the proposal submitted by the Southeastern University Research Association (SURA) be accepted and funded for the construction of a new National Electron Accelerator Laboratory (NEAL) centering on a 4 GeV linear accelerator-stretcher ring system capable of delivering intense, high duty factor, electron beams in the energy range from 500 to 4000 MeV.

Additional recommendations relating to this principal one are to be found in the body of this report. As modified by the Panel consequent to its own studies and analyses, the estimated cost (in 1983 dollars) of the accelerator complex is 111.8 million dollars; of the entire laboratory is 146.8 million dollars; and the operating cost averaged over the first five years of operation is 18.1 million dollars per year. The projected 15 year total cost of the project is 418.3 million dollars. The construction period is estimated to be 4.5 years.

The member universities of SURA have already pledged five Commonwealth Professorships, 25 tenure or tenure track positions in experimental nuclear physics and at least five tenure or tenure track positions in theoretical nuclear physics in areas specifically related to the proposed facility. The NEAL Laboratory, from the outset, however, will be constructed and managed as a national rather than a regional facility and will provide the United States with a truly unique facility for research in electromagnetic physics.

II. INTRODUCTION

II-A. Activities of the Panel

The Panel on Electron Accelerator Facilities was established by the DOE/NSF Nuclear Science Advisory Committee (NSAC) during its meeting on January 12, 1983; the Panel membership is given on the frontispiece to this report. The charge to the Panel was as follows:

Within the context of: (1) the December 1979 "Long Range Plan for Nuclear Science"; (2) the scientific discussions of the NSAC Subcommittee on Electromagnetic Interactions report "The Role of Electromagnetic Interactions in Nuclear Science"; and (3) your own best scientific judgment, review and evaluate electron accelerator facility proposals submitted by Argonne National Laboratory, University of Illinois, Massachusetts Institute of Technology, National Bureau of Standards, and Southeastern Universities Research Association. Examine each of the proposed facilities as a possible component of the overall national program of basic nuclear research, and recommend the facility or combination of facilities which will best meet the United States needs for basic nuclear research with electromagnetic probes.

As an integral part of its review and evaluation of the five listed proposals, each proposing group was requested, by telephone on January 13 and confirming letter dated January 14, to provide the Panel with a listing of its major outstanding concerns relating to each of the other four proposals; such listings of concerns were then circulated to the five groups on January 31 in order that responses might be prepared. In parallel with this, a detailed questionnaire concerning the development of estimates of both construction and operating costs and the structure of, and justification for, such items as contingencies, overhead charges and the like was developed and forwarded to the five groups in order to permit greater intercomparability of the proposals.

A Technical Subpanel was established with membership drawn entirely from within the Panel and was charged with a detailed examination of the technical and accelerator physics aspects of each proposal and an expert evaluation of its feasibility, the adequacy of the R & D already accomplished, the nature of that remaining to be accomplished, and the like. During the period, February 10 - February 15, the Technical Panel scheduled site visits to each of the five proposing institutions; all were accomplished save that to MIT which coincided with the Blizzard of 1983. In its place the Technical Subpanel met with MIT representatives in Washington on February 16 and on February 26 the Chairman of the Subpanel visited MIT.

During a meeting of the Panel held in Washington February 17 - 19, a total of fifteen hours was devoted to public presentation of the five proposals, and responses to concerns raised by other proposing groups, by the technical subpanel, and by members of the Panel. Questions were also invited from the floor and active public discussion of each of the five proposals followed their presentation.

On February 19, the Panel met in closed session to focus on outstanding questions remaining after these presentations, for brief discussions with representatives of several of the proposing groups during which some of these questions were raised, and for preliminary discussion of this report and allocation of drafting responsibilities.

A substantial number of open questions of a technical nature remained and these were addressed by the Technical Subpanel; a further number relating to such topics as management, and to scientific and institutional support were addressed to the groups in question by letter from the Panel Chairman. Each of the five groups was also invited to provide the Panel with any additional information that it felt had been inadequately covered during its public presentation; four groups responded to this invitation and all questions addressed to the groups by the Panel were answered prior to its next meeting, on March 7, in Washington.

Discussions at this March 7 meeting focussed on the accelerator energy and the present requirements of electromagnetic physics, and produced general agreement concerning the needs of the field and the overall scope of the Panel recommendations. Substantial discussion was also devoted to the ancillary research instrumentation requirements of the field if the proposed facilities were to be effectively exploited. On the basis of these discussions and the detailed budgetary analyses of the Technical Subpanel, the Panel chose to recommend increased contingencies to reflect increased R & D requirements and increased equipment budgets for several of the proposals. The proposed budgetary information and the Panel's recommended revisions are summarized in Tables in Section IV-B. A corresponding table listing the characteristics of the accelerators in the five proposals in convenient summary fashion is to be found in Table IV-B-4.

Because there remained unresolved questions concerning the behavior, in particular, of the proposed 4 GeV accelerator facilities at the extremes of their proposed energy ranges, detailed decisions regarding recommendations were deferred until March 30 when the Panel next met, again in Washington.

In the interim, the remaining technical questions were resolved and sections of this report were redrafted in the light of the March 7 discussions and of additional material provided by the proposing groups. In order to avoid misstatements of fact, the Technical Subpanel forwarded draft sections of this report concerning each specific proposal to the corresponding group on March 29 with the request that they be reviewed for accuracy; the opinions stated are, however, those of the Technical Subpanel and were not open to argument or change.

Because the Panel had decided on March 7 to recommend construction of a 4 GeV accelerator as its highest priority, major attention was focussed on a comparison of the two fully developed 4 GeV proposals -- those from the Argonne National Laboratory and from the Southeastern Universities Research Association. Prior to the meeting each panel member had undertaken an independent analysis of the advantages and disadvantages of each facility as **the** major national accelerator facility, weighing all considerations as he saw fit and arriving at a choice. The detailed individual listings of advantages and disadvantages were made available to the Chairman of the Panel, and -- as a collection of letters -- to all the Panel members at the March 30 meeting, but were not photocopied or distributed. There were no disagreements regarding the actual **facts** of the situation although Panel members differed somewhat in their assignment of different **weights** to these individual facts.

On March 30, the Panel completed discussion of those questions remaining open at the earlier meeting, voted on its final recommendations as included in this report, and devoted substantial time to discussion and review of the contents of this report itself.

While the Panel was not unanimous in its voting, in each case the recommendations included herein received strong majorities.

Drafts of the Panel's completed report were circulated to its members for comment during the week of April 11 and to other members of NSAC during the week of April 18 prior to its formal presentation to NSAC during the scheduled open meeting, in Washington, on April 22.

II-B. CRITERIA USED BY THE PANEL

Clearly, in any panel containing members with as diverse background as does this one, individual members will weigh different factors as having different importance in arriving at their conclusions and votes. We have considered it to be of extreme importance in the present case, however, that there be no uncertainty or disagreement concerning the **facts** — technical, financial, institutional or otherwise — associated with our consideration of each of the proposals. To this end we have felt free to go back repeatedly to the proposing groups for further information or clarification whenever any uncertainty existed. Our Technical Subpanel has carried out an extremely detailed study of the proposed accelerator systems and has among its members internationally recognized experts on the accelerator types involved. Other subgroups of Panel members have examined the research equipment question in considerable detail and have carried out a very detailed analysis of the staffing and budget estimates.

With all these facts in hand, augmented of course by the three hours of public oral presentation and discussion that we arranged for each proposal, what were the criteria that influenced our judgements? As noted above, the exact ordering will be different for different panel members and of course may differ for projects of different scope. Among the criteria most frequently discussed, however, were these:

Importance of the Accessible Physics

Feasibility of the Proposed Accelerator System

Type and Seriousness of Possible Failures to Meet Specifications

Ability of the Proposing Group to Perform — Track Record

Attractiveness to the Scientific Community

Cost Effectiveness

Educational Potential

Potential for Facility Upgrading

Quality and Commitment of Internal Staff

Adequacy of Plant and Support Facilities

Potential Attractiveness to External Users

Provision for, and Experience with, External Users

Adequacy of Management Groups and Structures

Adequacy of Proposed Experimental Facilities

Adequacy of Proposed Staffing Levels

Institutional Support

Quality of Proposal Documentation

Quality of Proposal Presentation

Geographical Location, Access, and Environment

Impact on the Electromagnetic Physics Community

Impact on the Nuclear Physics Community

Advantages and Disadvantages of an Entirely New Laboratory

II-C. OVERVIEW OF THE SCIENTIFIC CHALLENGES

We appear to be on the threshold of much deeper and more extensive understanding of the atomic nucleus. In the face of the remarkable progress that has been made in recent years in understanding the structure and interactions of nuclear systems, the tremendous scope of the remaining open frontiers is often forgotten. Almost all of what we know about nuclei is restricted to energies near the Fermi surface — and to phenomena where nucleons are the overwhelmingly dominant participants. The deep nuclear interior, denied to most available probes by absorption phenomena, is largely unknown territory — as is the nuclear stratosphere. We are only beginning to understand what happens when nuclei are raised to very high temperatures.

It is already well established that even at relatively low temperatures, mesonic effects and effects reflecting the presence of excited nucleons are detectable in modern high resolution nuclear measurements. And at very high energies the quark structure of the nucleons themselves is well established but the effects of this structure on the properties of nuclei remain to be determined.

We are faced with the tantalizing possibility that quantum chromodynamics (QCD) may provide the theoretical framework for the understanding of the strong nuclear interaction that quantum electrodynamics (QED) has so successfully provided for the purely electromagnetic interaction.

And it is surely within the realm of nuclear physics to hope to understand the transitions between those phenomena wherein nucleons are the dominant performers through those dominated by mesons and baryons (excited nucleons) to those wherein quarks play the featured roles. We have no reason to believe that the transitions themselves will be dramatic i.e., low ordered phase transitions. Rather all available (very scanty) evidence points to gradual transitions. In a very crude sense we may think of the nucleons, with increasing available energy, first occupying more complex, more energetic configurations either as independent entities in a shell model sense or collectively as in giant resonances; with increasing energy the nucleons themselves become excited internally to form the Δ , N_1 , N_2 etc. and these in turn participate in the overall nuclear configuration; and at still higher energies we may think of the nucleons as **melting** -- but melting much more like glass than like ice. Indeed we already have some intriguing evidence from recent deep inelastic muon scattering at CERN that may bear on this point. It has generally been assumed that all nuclei are essentially equivalent and little different from a collection of isolated nucleons as far as deep inelastic scattering at very large four -- momentum transfer is concerned. Instead, as shown in Figure 1, the structure functions for deep inelastic muon scattering from iron and from deuterium differ substantially; this difference has been interpreted to imply that a) there is a tendency for quarks to percolate from nucleon to nucleon in iron, b) there is a large increase in the number of "sea" quarks in iron which may reflect pion or other meson-like components in the nuclear wave function, c) the fraction of the momentum per nucleon carried by gluons is significantly less in iron than it is in deuterium and d) there is a small probability for the existence, in iron, of aggregates of more than three quarks. This is clearly an early measurement and interpretation but already it suggests a wealth of nuclear information from the precise determination of nuclear structure functions over extended parameter ranges.

This measurement suggests that we **can** obtain quantitative information regarding these exciting new phenomena -- phenomena that in the most fundamental way bridge the artificial and often spurious separation between nuclear and elementary particle physics.

This is obviously a high energy illustration, but the situation is scarcely less challenging at low energies. We need to know how the nuclear many-body system responds to an electromagnetic probe and how this response can be understood in the light of microscopic structure, symmetries and simplicities.

Electromagnetic physics at relatively low energy has much to tell us about this critical interplay between particle and collective degrees of freedom. New experimental techniques, pioneered at MIT-Bates, for example, have made possible isolation and study of discrete quantum states of the nuclear system and systematic determinations of the charge $\rho(r)$ and magnetization $\mu(r)$ densities at accuracies better than the 1% level. We have learned, thereby, that the density distribution inside the nucleus is much smoother than we had believed and that the independent particle model is remarkably accurate, even deep in the nuclear interior. These facts pose an outstanding challenge to any detailed microscopic understanding of nuclear structure -- as do the new stretched-state particle-hole configurations excited in back angle inelastic electron scattering.

There is a wealth of critically important new information that only relatively low energy electrons can give us. Measurements of the decay modes of the giant electric and

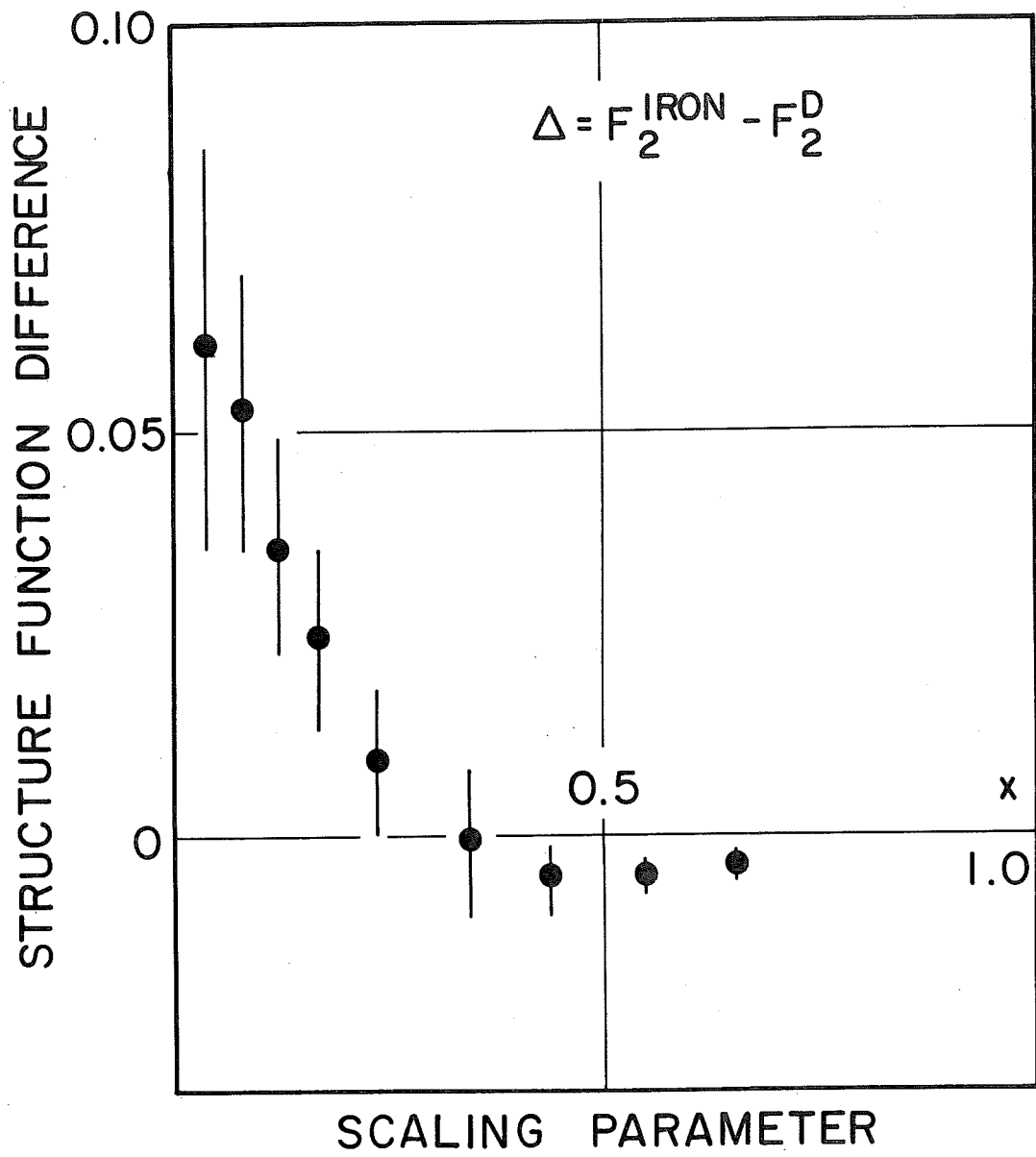


FIGURE 1

magnetic multipole resonances formed by inelastic electron scattering will tell us much about the structure of these resonances. Particle-knockout experiments will yield information about nucleon momentum distributions and about correlations between nucleons in nuclei. Most of these experiments will require coincidence measurements and these in turn require high duty factor accelerators.

As we move to intermediate energies, both mesonic effects and those reflecting intrinsic excitations of the nucleons themselves are expected to become of increasing importance. This is illustrated in striking fashion in Figure 2 which plots the proton inelastic structure function νW_2 as a function of the four-momentum transfer Q , and the scaling variable $\omega' = 1 + W^2/Q^2$. Here the Δ , N_1^* , and N_2^* isobars appear as peaks corresponding to missing masses of 1.23, 1.50 and 1.65 GeV, respectively. $W=2$ GeV is shown as a dashed line. It is striking that for large Q and W the isobar peaks essentially fade into the background and the structure function becomes a function effectively of the scaling variable only.

The suggestion is that this is a signature for underlying simplicity with the constituent quarks now responding essentially as free entities in a situation quantitatively describable in QCD terms. Here again we appear to be seeing a smooth transition from nucleon-meson physics to quark-gluon physics. It may well be that the two descriptions are complementary, with QCD being simple and appropriate at high energies, high momentum transfers, and small distances and a meson-nucleon description being the simple and appropriate one at lower energies, smaller momentum transfers, and larger distances.

The details of such a complementarity are simply not discernible from inclusive experiments and if our long history of nuclear experimentation has taught us anything it is that coincidence measurements, wherein particular channels and variables can be isolated for study, provide powerful access to new understanding. It is for this reason that the Panel strongly supports the Barnes Subcommittee recommendation that high duty factor is important at **all** energies.

It would be pointless to attempt any exhaustive coverage of electromagnetic physics here. Section III, which follows, provides a broad overview; the NSAC report **The Role of Electromagnetic Interactions in Nuclear Science** (Barnes Report) provides an up-to-date overview of the field as of mid-1982. This was preceded by the earlier 1977 DOE/NSF Joint Study **Role of Electron Accelerators in U.S. Medium Energy Nuclear Science** (Livingston Report) and by the Report of the Workshop on **Future Directions in Electromagnetic Nuclear Physics** (Stoler Report) of 1981. The reader is referred to these reports for details of the rich spectrum of nuclear physics which a high energy, flexible, electron accelerator facility would make accessible. The proposals under review by the present Panel each present substantial discussion of the part of this spectrum of greatest interest to the proposing group.

What has emerged from all of these reports and studies is a growing consensus within the U.S. nuclear physics community that the time is ripe for an attack, in force, on the new frontiers — at low energies, at high energies, and at all the energies in between — and a similar consensus that an essential component of our national effort in nuclear physics must be a variable energy electron accelerator facility capable of **both** high duty cycle and high energy.

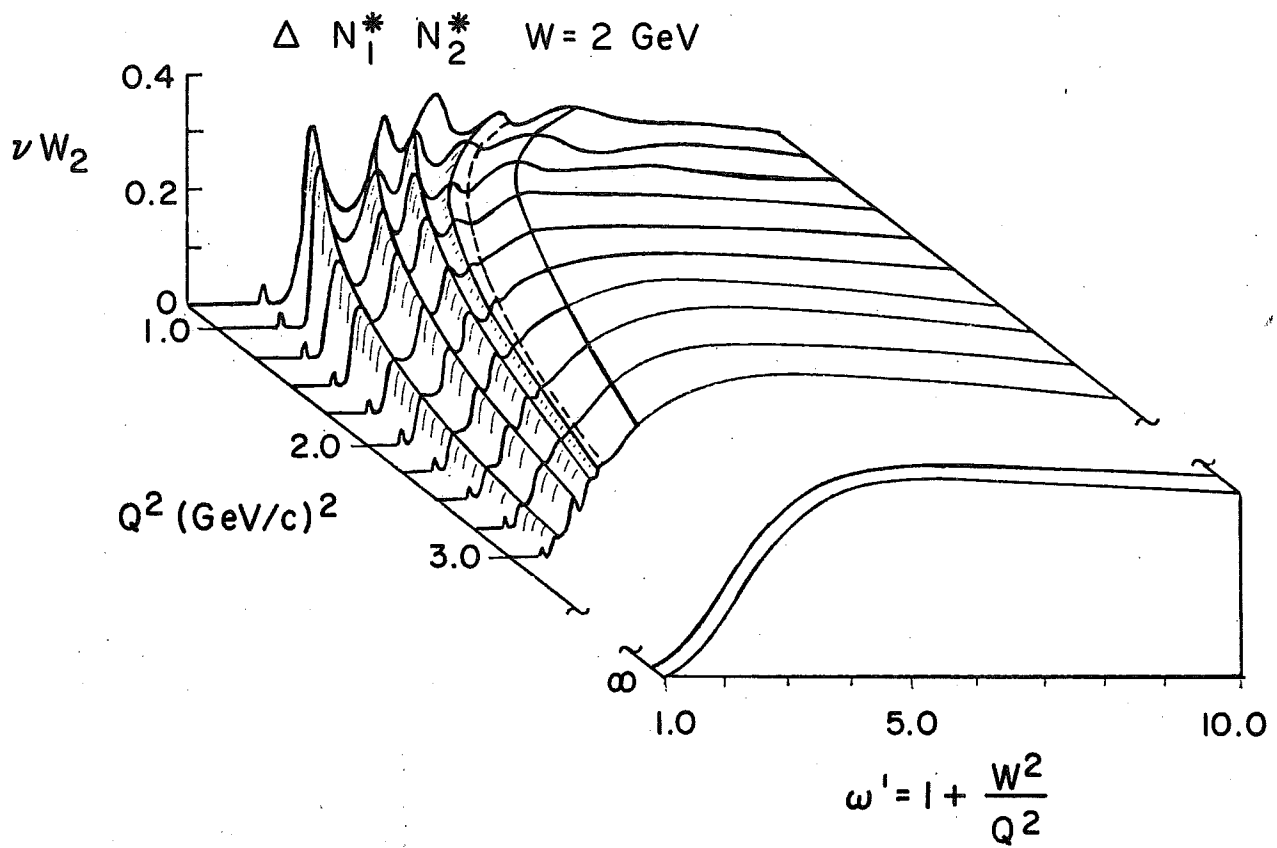


FIGURE 2

It is worthwhile to quote the recommendation of the NSAC Subcommittee on Electromagnetic Interactions (Peter Barnes, chairman) in its entirety:

The Subcommittee strongly recommends the construction of a variable energy electron beam facility capable of operation at both high intensity and high duty factor, and able to achieve an electron energy of about 4 GeV, for the purpose of making coincidence measurements on nuclear targets at large excitation energy and momentum transfer.

Among its findings, the Barnes Subcommittee also noted the following:

The Subcommittee concludes that investigations of complex nuclei with electron beams of 0.1-1.0 GeV, high duty factor, and high intensity would have an important impact on our understanding of nuclear structure and dynamics.

In short, the Barnes Subcommittee, after detailed study, found a wealth of experimental opportunities for exciting new physics over the entire range from 0.1 to 4 GeV and moreover found that high duty cycle was an important parameter over this entire range.

II-D. CONSIDERATIONS AFFECTING THE MAXIMUM ELECTRON ENERGY AND DUTY FACTOR

But the Barnes Subcommittee was not unanimous in its choice of 4 GeV as the desirable maximum energy of the recommended national electron accelerator facility, and this Panel has received strong arguments both for and against it.

In order to address in a more quantitative way this question of appropriate electron energy, we consider three areas of research: the short-range nucleon-nucleon correlations in nuclei, nucleon resonances and meson exchange currents, and the role of quark constituents for nuclear properties. These topics have high scientific priority; for a given framework used to describe the nucleus, we estimate that the experiments to be discussed impose the most stringent conditions on electron energy. For these areas of research, we first determine limits on the kinematical variables of interest, momentum transfer q and energy loss ν ; from these limits on q, ν we then derive the electron energy required. Here we discuss a few of the most relevant arguments only; a much more complete discussion may be found in the Report of the Barnes Subcommittee.

Properties of nuclear wave functions at short range -- beyond the region covered by the independent particle model ($K \leq 3 \text{ fm}^{-1}$) but still in the nucleon-only sector -- involve nucleon momenta $K=3-5 \text{ fm}^{-1}$. In knockout reactions ($e, e' X$) the momenta studied are of order $K \approx q$; for single arm experiments, K is somewhat larger than $q/2$. Taking as a typical value $K=(3/4) \times q=4 \text{ fm}^{-1}$ yields $q=5-6 \text{ fm}^{-1}$ (1-1.5 GeV/c). The second variable of interest, the energy transferred to the nucleus, is limited by nuclear excitation energies ($\leq 100 \text{ MeV}$) plus nucleon (pair) recoil energies. To minimize final state interactions, the latter should exceed 200 MeV per nucleon, yielding a total energy loss of 500 MeV. This combination of q, ν defines the range that should be accessible if the nucleus is to be investigated within the framework of a picture involving nucleonic constituents only.

The excitation of nucleon resonances (which is inseparable from the question of the short-range nucleon-nucleon interaction) involves initial momenta K somewhat larger than the Fermi momentum; resonances bound in the nucleus (i.e., $\Delta\Delta$ components) have momenta $2-3 \text{ fm}^{-1}$. According to the above criteria, their study requires a momentum transfer of $3-4 \text{ fm}^{-1}$. To excite those resonances that still appear as discrete peaks for the isolated nucleon, an excitation energy up to 800 MeV has to be provided. A total electron energy transfer of $\approx 1.3 \text{ GeV}$ allows for appropriate nucleon recoil energies and nuclear excitation.

Most demanding on electron energy is the investigation of the quark/nucleon interface in nuclei. Two types of arguments are general enough to give guidance in the absence of relevant experimental results or detailed theoretical understanding: spatial resolution desired and scaling limit.

From both experiment and theory we expect quark effects to become important at ranges $r \leq 0.5 \text{ fm}$. The repulsive core of phenomenological nucleon-nucleon interactions, analyzed in terms of meson exchange potentials, occurs at $r \approx 0.4 \text{ fm}$; the energies of odd-parity nucleon excited states, interpreted in terms of constituent quark models, give a bag-radius $r \approx 0.5 \text{ fm}$; the little bag models yield radii $\approx 0.4 \text{ fm}$, while the MIT bag model gives somewhat larger values; the nucleon radius, 0.8 fm , corrected for the contribution of the pion cloud, yields a corresponding value of $0.4-0.6 \text{ fm}$. If we want to investigate the effects of quarks - as opposed to the effects of the meson cloud - our electron microscope must have a spatial resolution that is smaller than 0.5 fm by a significant factor. Taking, as a minimal resolving power, $1/3$ of the "core" size, we can expect to be able to investigate the effects of quarks on nuclei, and vice versa, with reasonable detail. Given the fact that the electron samples the nucleus via a $\sin(qr)$ function, a spatial resolution $\Delta r \approx 0.5 \text{ fm}/3$ (FWHM) requires momentum transfers $q = 1.5/\Delta r = 10 \text{ fm}^{-1}$. An energy loss of $\nu = 1.3 \text{ GeV}$, as discussed above, is required if final states corresponding to discrete nucleon excitations are to be observed.

The scaling arguments start from the detailed investigation of nucleon structure functions performed in the past. Above a certain momentum/energy transfer the structure functions W_2 , as illustrated above in Figure 2, become a function of a single variable $X = Q^2/2m\nu$ with $Q^2 = q^2 - \nu^2$. This scaling shows that the physics has simplified, and become uniform. It is taken as proof that, in this regime, the quarks are almost asymptotically free, without interaction. This scaling region can be considered as a possible limit of nuclear physics; in this region nuclear confinement degrees of freedom become unimportant for an understanding of quark wave functions. We can hope that in the reasonably near future this scaling region, where physics is "simple", can be quantitatively understood using QCD. For the investigation of quarks in nuclei, including confinement, experimental studies such as those addressed in this report are required. In order to anchor these studies, points of contact with the scaling region would be most valuable. The experimental data for the nucleon (Figure 3) show that scaling occurs starting at values $Q^2 \geq 1 \text{ (GeV/c)}^2$ and $W^2 = M^2 - Q^2 + 2M\nu \geq 4 \text{ (GeV)}^2$.

Having defined the maximum momentum transfer and energy loss, the derivation of maximum electron energy requires one further consideration. To separate the different structure functions, which contain different physics, experiments must be performed

KINEMATICS FOR ELECTRON SCATTERING FROM A PROTON AT REST

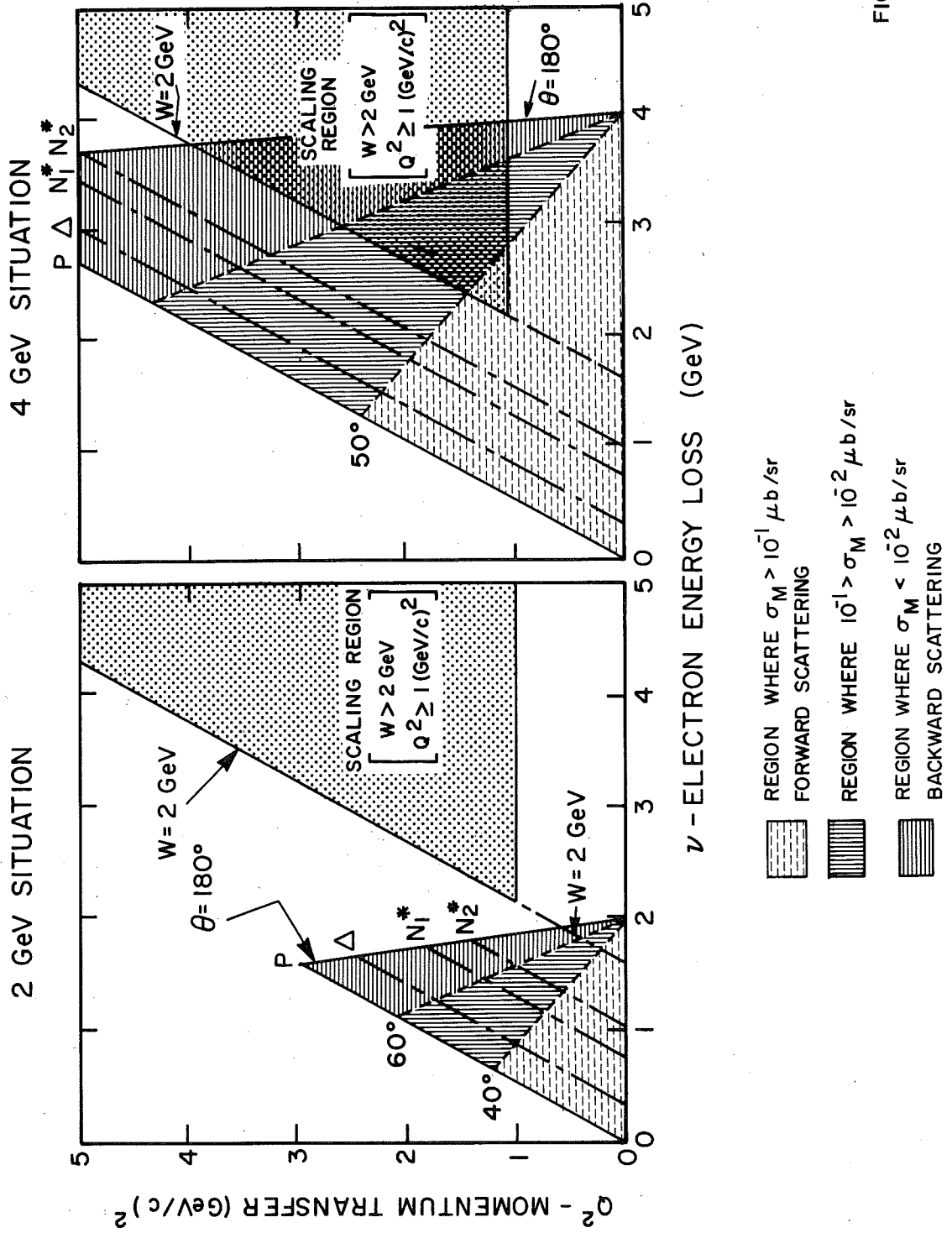


FIGURE 3

at angles θ such that the cross section at a given q can be separated into its longitudinal and transverse components:

$$\sigma(q, \nu) = \sigma_L(q, \nu) + \left(\frac{1}{2} + \tan^2(\theta/2)\right) \sigma_T(q, \nu)$$

The most demanding constraint results from the fact that, at large q , σ_T heavily dominates σ_L . To separate σ_L , the minimal contribution of σ_T is desirable; $\theta_{\max} = 50^\circ$ results in a σ_T contribution 44% larger than the minimal one possible.

Using this constraint, the electron energy needed can be calculated once q, ν are known. From the discussion of q, ν given above, the electron beam energies needed to study the nucleus in terms of nucleonic, mesonic and quark constituents are 1.7, 3 and ~ 4 GeV, respectively.

As an illustration, Figure 3 gives the kinematical regions accessible for incident electron energies of 2 GeV and 4 GeV. For the study of nuclear wave functions at short range, $q = 6 \text{ fm}^{-1}$, implies $Q^2 = 2 \text{ GeV}^2/c^2$ at $\nu = 500 \text{ MeV}$ and this, in turn, requires an incident energy of 1.7 GeV for $\theta = 50^\circ$. A similar incident energy is required for the excitation of nucleon resonances. The investigation of nuclei, with a spatial resolution of one third of the nucleon radius requires $Q^2 = 2.6 \text{ GeV}^2$ at $\nu = 1.2 \text{ GeV}$ implying an incident energy in excess of 3 GeV. It is apparent, from Figure 3, that essentially no contact with the scaling region is possible with a 2 GeV maximum electron energy whereas with a 4 GeV maximum energy a substantial region of potential study opens up.

We turn then to the question of required duty factor. It has been suggested, for example, that high duty factor is not essential at the higher energies and that the successes already achieved at SLAC with only 0.1% duty cycle are indicative of the kind of exploratory inclusive experiments that should receive major attention in the range where quark-gluon effects might be expected to be of significance.

It is unquestionably true that inclusive (e, e') experiments have had a great impact on elementary particle physics. The observation of the scattered lepton, only, involves an integration over all hadronic final states, and this greatly simplifies the description of the reaction. Inclusive experimental have been a success, in particular, because of the fact that quarks are asymptotically free. Scattering a lepton from such a quasifree quark leads to an extremely simple and clean reaction mechanism.

In the case of nuclear physics, this simplification does not occur; nucleons in nuclei are not free. In this case we have to, and want to, deal with the complications of the initial and final hadronic states. Even when considering quarks, we are interested primarily by the degree to which quarks are influenced by the nuclear medium. Under these circumstances, the above advantages of inclusive experiments are no longer present. Inclusive experiments as in other branches of nuclear physics, only give very global information that averages over many aspects of the underlying physics. Trivial, prominent processes often cover up the more interesting phenomena; the latter ones are partly accessible only in some corner of kinematical domains (in the case of (e, e') , extremely large momentum transfer, or large momentum and small energy transfer).

In order to understand the strongly **interacting** system in any detail, we must specify the reaction initiated by the electron in considerable detail. This can be done

only by detecting the products in the final hadronic state. In order to conserve the basic advantage of electrons — variability of the momentum transfer at given energy transfer — this implies coincidence experiments, and hence CW accelerators.

This argument for CW is true at **any** energy. It becomes the more imperative the more complicated the system we want to study. The most complex (and most interesting) question is the one concerning the nucleon-quark structure of nuclei. In the energy range where this question can be addressed, ~ 4 GeV, CW becomes a matter of crucial importance.

A most important, but often overlooked, reason for CW concerns future experiments involving parity violation, polarized (recoil) nuclei and hypernucleus production. These topics have high scientific priority, and the relevant experiments are very difficult because of the high statistical accuracy required (parity) or the small cross sections (efficiency of recoil nucleus polarimeter, low production cross section). These important experiments can be carried out if large solid angle detectors are built; these detectors cannot be magnetic spectrometers; the ratio of price to solid angle is simply too large. Less expensive, more sophisticated devices of large solid angle can be utilized provided that the total instantaneous rate of particles, both those of interest and the much more abundant ones from (physical) backgrounds, is not too large. Experience with today's electron-accelerators (duty factor $\sim 1\%$) clearly suggests the need for the highest duty factor available, i.e., C.W.

On the basis of all such arguments, the Panel has concluded, in agreement with the Barnes Subcommittee, and the arguments presented to it by the Argonne and SURA groups, that the highest priority — in terms of exciting new physics — must be given to a facility spanning the 0.5 to 4.0 GeV energy range with high duty factor. We have also, reflecting past experience in other areas of physics, and in the light of our considerable ignorance of this new higher energy range, given substantial weight in our considerations.

At the same time, and again in agreement with the Barnes Subcommittee, we have been much impressed by the richness of the physics that remains to be done in the 100 MeV - 1000 MeV range, particularly with beams of adequate duty factor to permit coincidence experiments.

Reflecting the relative simplicity of the electron as a probe, we are confident that studies involving electron beams will play an increasingly important role in nuclear physics. And we view it as a very healthy development that the former photonuclear and electronuclear communities are being drawn fully into the mainstream of U.S. nuclear physics.

While we have, as a Panel, given our highest priority to a very large national facility, we have been very mindful of the crucial importance of forging the strongest possible bonds with the university community. Unless some of the very best young graduate students are attracted into work in the electromagnetic field — and with the new facilities — the field will inevitably wither. We consider the maintenance of the highly productive groups at Illinois and at MIT to be extremely important to the national effort in the field. The possibility of drawing a large number of other universities into the field — through provision of tenure and tenure-track positions for both experimentalists and theorists, through active participation at an institutional level in management of the new

facility, that we recommend herein -- has also been given very serious consideration in our deliberations.

II-E. A Major Electron Facility in the Context of the 1979 NSAC Long Range Plan for Nuclear Science

When the 1979 Long Range Plan was assembled, it envisaged investments in a small CW electron accelerator in FY1982 as a logical outcome of the joint Stanford-Illinois cavity development program and budgeted three million dollars for it. In part this has already been accomplished through NSF funding of the Illinois program for acquisition of NBS/LANL style end magnets; in part, too, the construction of the 200 MeV CW accelerator at NBS under the NBS/LANL joint program and DOE support contributes to this investment.

As its major project in the electromagnetic field, however, the long range plan envisaged a 1-2 GeV CW electron accelerator costing a total of 50 million (\$1979) with funding scheduled to begin in FY1985 and to be completed in FY1987; this would correspond to ~73 million (\$1983).

As discussed above, the Panel now recommends construction of a higher energy facility -- 4 GeV rather than 2 GeV as a maximum energy. It is appropriate to consider how well the Barnes Subcommittee emphasis on the need for coverage from 0.1 to 4.0 GeV (with which we agree) will be implemented should our recommendations be accepted and followed.

Illinois is currently operating up to about 80 MeV and has already received NSF support for upgrading to 120 MeV with dipole end magnets identical to those under construction at NBS.

NBS is completing a 200 MeV CW accelerator at present.

MIT is currently operating at up to 1.8% duty cycle at ~720 MeV and has received DOE funding for additional radiofrequency power both to increase the maximum energy to 840 MeV and increase the operating reliability.

If constructed as planned, the Panel believes that the SURA facility will operate over the range 0.5-4.0 GeV at greater than 90% duty factor.

We thus find that the entire energy range is indeed covered by our recommendations; however, there is a gap between 200 and 500 MeV where no CW facility will be available. Indeed the Panel believes that a strong scientific case can be made for having some overlap with the lower end of the recommended SURA facility and would hope that in the future it will be possible to obtain CW performance at a second facility in the 200-800 MeV range.

To provide some international perspective, we plot in Figure 4, a modified version of Figure 21 of the Barnes report, the duty factor against maximum beam energy, for a number of the world's electron accelerator facilities. As is evident from this figure the recommended SURA facility will be a unique one which should prove extremely attractive to the entire international as well as the national community of scientists involved

in the use of high energy electromagnetic probes. In Figure 5 we plot the 1983 world distribution of high duty factor electron accelerator projects; this distribution is truly an international one and is a measure of the vitality and challenge of the field.

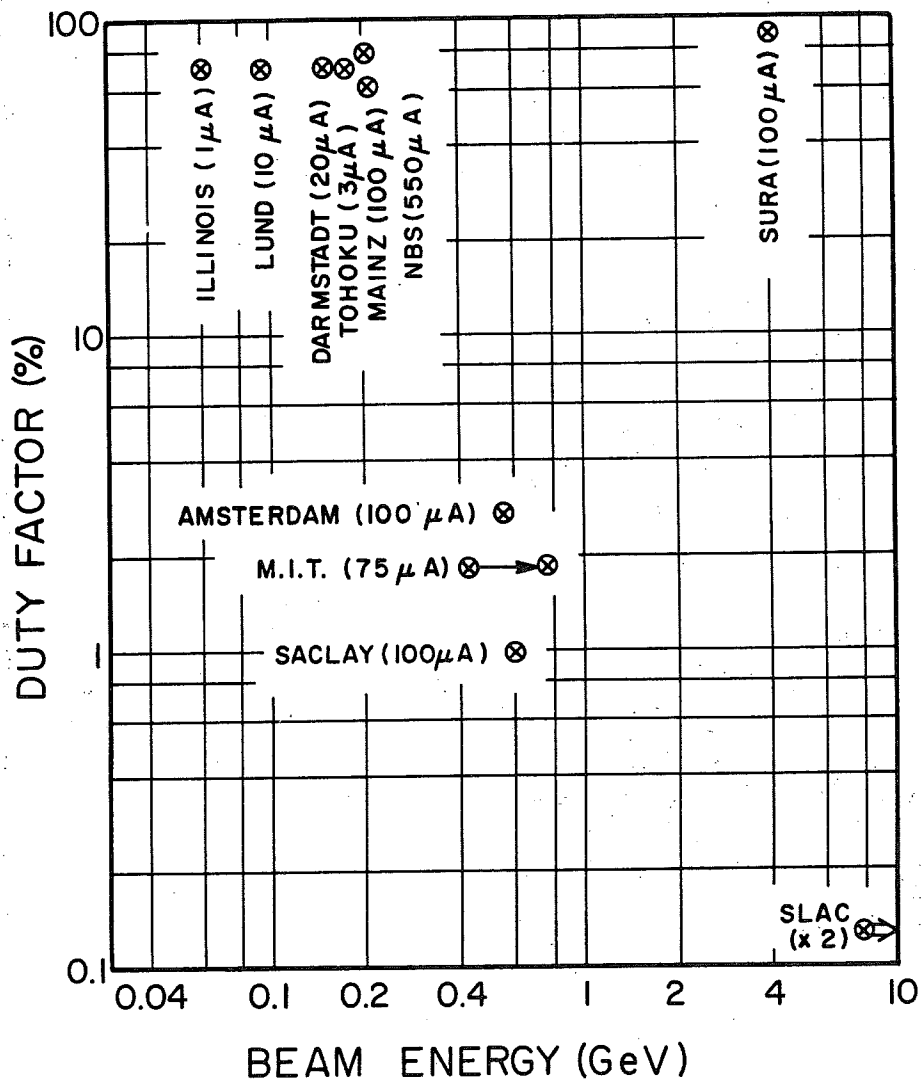
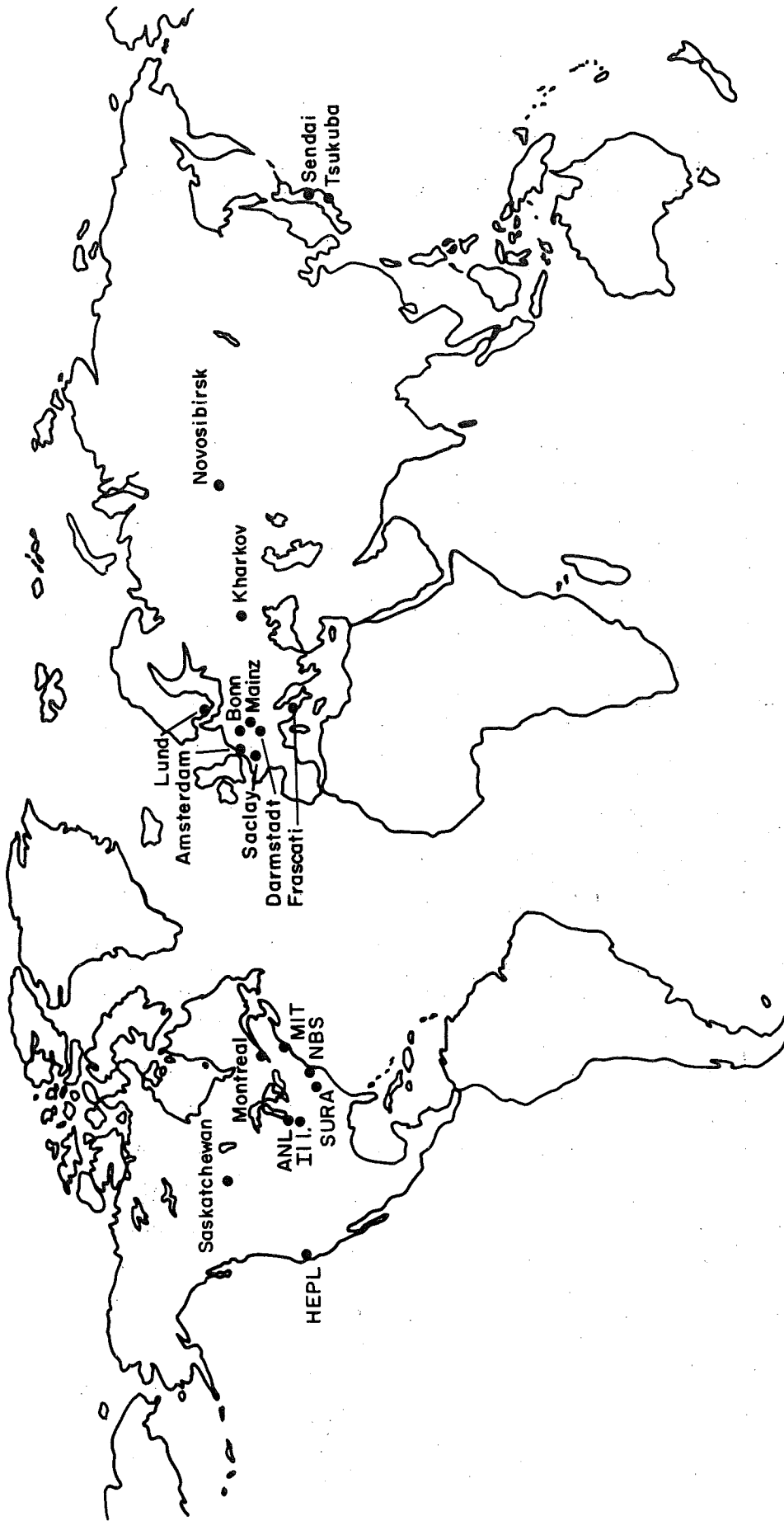


FIGURE 4



**WORLD DISTRIBUTION OF HIGH DUTY FACTOR
ELECTRON ACCELERATOR PROJECTS - 1983** **FIGURE 5**

III. GENERAL SCIENTIFIC JUSTIFICATION

As we have noted above, we are approaching fundamental, new understanding of the atomic nucleus from many different points of view. At the simplest level, the nucleus is a system of nonrelativistic nucleons interacting through a two-body potential. Although this "traditional" picture has been very successful in correlating vast amounts of data, it begins to break down at high excitation energies and short distances where nonnucleonic degrees of freedom come into play. For energies from several hundred MeV to several GeV, nuclei are hadronic systems composed of strongly interacting mesons and baryons (nucleons and their excitations). At even higher energies, recent developments in elementary-particle physics strongly suggest that parton degrees of freedom (quarks and gluons) will play a role, although there is as yet little experimental or theoretical understanding of how these properties are manifest, or modified, in multibaryon systems.

The elaboration and integration of these three levels of understanding of the nucleus (nucleons, hadrons, and partons) will be a major task for nuclear science over the next two decades. Our present knowledge is spotty. We are on firmest ground at the nuclear level, although many comparisons between precise data and detailed models must yet be carried out before our understanding is truly complete. Of particular interest are the nature and origin of collective motion and the short-distance behavior of the nuclear wave function. At the hadronic level, we have learned much from the intermediate energy studies with electron, nucleon, and pion beams over the last decade, but many crucial questions are yet to be answered. Finally, the parton level is largely **terra incognita**, although it offers the intriguing opportunity for understanding nuclei as manifestations of the strong interaction in the most fundamental terms.

The electron facilities discussed in this report will allow new experimental studies of nuclei across the whole spectrum of their properties. The electromagnetic interaction provides a unique probe for the study of the nucleus. The point-like nature of the electron and the known detailed theory of the electromagnetic interaction make data from this probe readily interpretable, and the penetration of electrons and photons throughout the nuclear volume provides an excellent complement to strongly absorbed hadronic probes. Moreover, the kinematics of electron scattering are such that **the momentum and energy delivered to a nucleus can be varied independently**, so that a broad range of the nuclear response can be studied.

The many scientific opportunities afforded by CW electron beams from 100 MeV to 4 GeV have been fully documented in the five proposals we have considered, in the "Stoler Report" produced by the electromagnetic nuclear physics community, and in the report entitled **The Role of Electromagnetic Interactions in Nuclear Science** (the "Barnes Report"). Below, we mention only a few of the more important studies which address nuclear properties at each of the three levels.

At the nucleon level, much remains to be done in the study of ground state charge and current density distributions and in the study of transition densities for discrete excited states. Elastic and inelastic electron scattering provides precise and otherwise unobtainable information on nuclear wave functions; the continuation of high resolution experiments in this energy region is essential as a complement to intermediate energy hadronic probes. The ability to study $(e, e' \gamma)$ and $(e, e' N)$ processes for discrete nuclear states will provide stringent tests of microscopic nuclear structure calculations. Furthermore, such precision measurements serve as departure points for higher energy experiments aimed at understanding the hadron and parton degrees of freedom.

A major advantage of a high duty-factor/high-current electron beam at an energy of about 1 GeV would be the ability to perform $(e, e' X)$ coincidence experiments and observe correlations in energy and angle for final state products. The study of giant resonances can be significantly refined through such measurements. Angular correlations at fixed momentum and energy transfer can be studied to determine J^π for an observed resonance. The isolation of specific final states provides transition form factors and information on the coupling of the giant resonances to these states; out of plane coincidence measurements can be used to separate charge and current transition densities.

New insights into the nuclear wave function should also result. For example, $(e, e' N)$ reactions allow the study of deep-lying shell model orbitals and the momentum distribution of nucleons within the nucleus. With the high-resolution tagged photon beams to be available with the new facilities, coincidence experiments can be extended to the real photon limit. In addition, photon beams can be used for elastic photon scattering and quasi-deuteron photon absorption, in which (γ, np) measurements provide information on relative nucleon momenta in complex nuclei.

At the hadronic level, electromagnetic probes offer different advantages for exploring nuclear structure. Light nuclei ($A \leq 4$) are simple enough that their properties can be calculated from nucleon potentials, e.g., the "exact" three-body approach, and thus the effects of meson exchange currents and isobar degrees of freedom can be isolated with confidence. Interesting experiments include measurements of proton structure functions at high momentum transfers and scattering from the deuteron to obtain the neutron structure functions.

The comparison of electron scattering from light and heavy nuclei should be particularly revealing. In contrast to proton and pion probes, the electromagnetic interaction allows a real or virtual photon to penetrate the entire nuclear volume and create excitations deep within the nucleus. Reactions with real photons, including (γ, π) , $(\gamma, \pi N)$, (γ, ρ) , (γ, ω) and others allow one to probe the relationship of photons to vector mesons and to study the presence, propagation, and interaction of mesons and isobars. At these higher excitation energies, quasi-free nucleon scattering, quasi-production mechanisms dominate the interactions and can be studied effectively through $(e, e N)$, $(e, e' \pi)$, $(e, e' N \pi)$. Since the long-range interaction between nucleons is mediated by pions, such experiments are important steps toward understanding nuclei at the hadronic level. Pion production via M1 excitation of the nucleon allows the investigation of most of the energy range where the $(3,3)$ resonance is dominant.

At the parton level, it is generally believed that quantum chromodynamics (QCD) is the basic theory of the strong interaction, i.e., the nuclear interaction. The evidence for quarks and gluons as the basic constituents of mesons, nucleons and nuclei, is now overwhelming. Although the theory predicts asymptotic freedom at very short quark separations, it is dominated by strong color confining interactions at separations relevant to nuclear physics. As stated in the report entitled **The Role of Electromagnetic Interactions in Nuclear Science**: "The study of the transition between standard nucleon-meson degrees of freedom and the subconstituent quark-gluon QCD degrees of freedom is clearly one of the most important future areas of investigation in nuclear physics." The region of interest cannot be described by perturbative QCD and requires many-body approaches familiar to nuclear physics. The physics associated with quark confinement is likely to be important for decisive tests of QCD and also for the understanding of short-distance nuclear phenomena such as internucleon correlations. Thus, experimental investigations with electrons of energies up to 4 GeV will be great assets in developing a

more sophisticated description of confinement and improved theories for short-distance nuclear physics.

An understanding of the transition from hadron to parton degrees of freedom is aided greatly by anchors at both low and at high energies. As mentioned above, the language of hadrons is well suited to energies up to about 1 GeV. For energies above 10 GeV, on the other hand, the scattering of electrons can be described as occurring from essentially free quarks. An electron accelerator providing energies up to about 4 GeV offers exciting opportunities for investigating nuclei and the strong interaction in the region of energies where these two apparently distinct approaches must merge. In this transition region, confinement and possible coherent quark effects (e.g., diquarks) may be important and can be probed. At the high end of the energy region, with energy losses of ≥ 2 GeV and at momentum transfers ≥ 1 GeV/c, it has been found that the scaling approximation works well. At lower energy losses and/or momentum transfers, deviations from a description in terms of hadrons will give clues to the underlying structure. Common "intuitive" models may not work here.

The electromagnetic study of light nuclei ($A \geq 4$) has particular advantage for exploring and understanding nuclear systems at the parton level. Recoil tensor polarization experiments, polarization transfer measurements, and high momentum transfer quasi-elastic scattering to obtain resolutions of 0.1-0.2 fm are sensitive to the quark substructure. Coincidence experiments with emitted nucleons and mesons will be helpful in studying the transition region between the hadron and parton limits and may help us understand how nucleons deform as they approach each other and how, for example, the three confined quarks in each nucleon merge to form a confined 6-quark deuteron. The dynamics of this transition can be studied with high momentum transfer coincidence experiments, in which an outgoing nucleon is detected with various energies. Measurements of the electric and magnetic structures of the $A=3$ nuclei have already shown that present models are inadequate. Further coincidence measurements are required to develop adequate theories and models. Polarization information, for instance, on emitted nucleons, provides information on the spin degrees of freedom of the quark distribution functions.

Experiments with photons and electrons for the production of vector mesons may be helpful to our understanding of mesons in terms of quarks and antiquarks. The photo- and electro-production of kaons and hypernuclei explore the "sea" quark distribution in nucleons, since strange quarks are involved. Furthermore, new opportunities in hypernuclear physics can be opened with such experiments. Via the $(e, e' K^+)$ reaction in particular, lambda and sigma hypernuclei can be produced with probes that interact weakly in both the initial and final states. In contrast to the (K, π) reaction, both spin-flip and non-spin-flip transitions can be induced. As a consequence of the momentum mismatch, the (γ, K) reaction can be used to emphasize the excitation of higher angular momentum states.

Quite apart from its potential for studies of nuclei per se, an electron accelerator with a polarized beam would have a high potential for the study of fundamental symmetries. Experiments could be performed to test quantum electrodynamics and to search for time reversal violation and $\Delta I=2$ electromagnetic processes. Parity-violating asymmetries reflecting weak neutral currents grow as the square of the momentum transfers and thus become easier to measure at high electron energies and with high current beams. Parity violation measurements could be used to test the weak conserved vector current and pure V, A theory as well as to study the semileptonic and nonleptonic weak

interactions. Semileptonic weak interactions below 1 GeV should be dominated by couplings to protons and neutrons in the target rather than the incoherent quark coupling observed in measurements above 10 GeV. This permits measurements of a different linear combination of electron-quark weak couplings. Measurements of parity non-conservation in discrete nuclear states and in the Δ resonance region will help to determine nonleptonic weak currents and the weak interactions of mesons and resonances. Since the weak interactions are of very short range, parity violation experiments may be particularly helpful in elucidating quark distributions and confinement features.

In summary, there is an unusually broad set of scientific motivations for studying nuclei with high-intensity/high duty-factor electron beams of energy up to 4 GeV. The questions which can be addressed are at the forefront of nuclear science and its interface with elementary-particle physics. The information so obtained will continue the precise studies of the traditional aspects of nuclear structure, and reveal new aspects of nuclei as systems of both hadrons and partons.

IV. CONSIDERATION OF INDIVIDUAL PROPOSALS

In this section we turn to the five proposals that the Panel was charged to review and evaluate. We have not discussed the individual research programs, since to do so would involve substantial repetition of the material summarized in Section III and covered in detail in the Barnes report. Rather, we will here concentrate on the technical aspects of the proposals.

In order to place the discussion in context, however, we begin with a brief overview of the accelerator technology available in the energy range of interest.

IV-A. COMPARISON OF ELECTRON ACCELERATION POSSIBILITIES

With current technology, there are only two methods of achieving GeV-range electron beams with a very high duty cycle (approximately 100%). These are (1) the combination linear accelerator/electron storage ring operated in the "stretcher" mode and (2) the microtron. The former is the more familiar and will be discussed first.

IV-A.1 Linear Accelerator/Electron Storage Ring Method

The linear accelerator/electron storage ring method is quite straightforward: electrons from a high-current pulsed linear accelerator (linac) are injected into a storage ring, from which they are extracted slowly and uniformly during the time intervals between linac pulses. In order to achieve reasonably high **average** beam currents from the stretcher, the linac must provide high **peak** beam currents at a high repetition rate, and injection into the stretcher ring must be very efficient. Because extraction cannot start until after injection is complete, the linac pulse length must be short compared with the time between pulses in order that the duty cycle of the extracted beam be as high as possible. To ensure that the beam from the stretcher is uniform over time, the linac beam quality must be good; this is because there is little time available for "conditioning" the stored beam in the ring if a duty cycle of greater than 90% is to be achieved.

For high peak currents in pulsed linacs, the cumulative beam breakup instability which can degrade beam quality must be considered. This instability occurs when an electron bunch passes off-center through an rf structure and excites transverse deflecting modes. These transverse fields deflect subsequent electron bunches, which in turn excite these modes even more strongly. The severity of this instability depends on the peak current in the linac, the length of the pulse, the length of the linac, and the amount of transverse focusing present.

Once in the ring, the stored beam must be kept free of the myriad longitudinal and transverse instabilities that plague high-current electron storage rings. Although the theory for predicting such instabilities is much better developed now than it was a few years ago, it is still far from complete. In particular, the growth rates of multibunch instabilities are now known, so it is not clear whether these instabilities will manifest themselves in the storage times of the pulse stretcher. Of equal importance is that the extraction process must be very precisely controlled. Finally, because the time between injection and the beginning of extraction must be short, the injection energy must be the same as the extraction energy, i.e., there can be no acceleration in the storage ring. Thus, for example, a 4-GeV stretcher ring requires a 4-GeV injector. Variation of the output energy requires that the energy of both the stretcher ring and its injector be varied and that the injection and extraction systems be retuned. Moreover, only one output energy is possible at a time.

In principle, all of the required techniques have been demonstrated in one way or another during the past two decades, but to date no beam stretcher for electrons (save one relatively low energy test device) has been built. The successful construction of such a machine in the GeV range will require the coordination of a great deal of complicated science and technology.

Beam injection into the stretcher ring is accomplished by means of single-turn fast vertical injection or by three-turn fast horizontal injection operating with a horizontal tune close to a one-third-integer value. With a fast-turn-off orbit perturbation (kicker fall time much less than an orbit time), essentially lossless beam injection is a well-established technique; it has been employed successfully and reliably at a number of proton and electron synchrotron facilities.

As stated above, the beam is extracted from the duty-cycle stretcher ring during the interval between beam injection pulses. With a typical injection rate of 1 kHz, the extraction process is achieved by means of a slow resonant extraction mode with a beam-spill duration of 1 msec. In essence, therefore, such a cycle constitutes a rather fast "slow resonant extraction" mode. The total spill occurs in about 1000 orbits for the stretcher rings of relevance here, as compared with the slow extraction cycle of a proton synchrotron, where the total spill occurs typically over 10^6 orbits.

Two modes of resonant extraction are under consideration in the proposals discussed here: the resonance may be excited by operating with the fractional part of the betatron frequency near either a one-half-integer or a one-third-integer value. For either the half-integer or the one-third-integer mode, a perturbing element is used to shift the machine tune to generate a finite-width resonant stopband, after which the particle orbits grow in amplitude at an exponential rate. Nearly lossless beam extraction for either mode of resonant extraction is obtained by intercepting the outward-spiraling particles with an electrostatic wire-septum deflection unit that directs the beam via a thicker septum magnet into the external beam channel. The beam-extraction efficiency is given by the first septum thickness divided by the resonant-growth step size for a particle with a transverse oscillation amplitude equal to the distance of the septum from the equilibrium orbit.

Because the electrostatic wire septum is essentially of "zero thickness" at the beam energies under consideration here, very high beam-extraction efficiencies are possible. Both at CERN, where the half-integer resonant mode is used, and at Brookhaven, where the one-third-integer resonant mode is used, beam-extraction efficiencies in excess of 98% have been measured for proton beams. Control over the resonant process, completeness of the beam spill, and the phase space characteristics of the extracted beam are the criteria used to determine the type of resonance chosen for a particular machine.

With single-turn fast injection, as is used in the SURA case, either mode of extraction would be acceptable, whereas with three-turn fast injection, as is used in the MIT-Bates case, the nature of the transverse phase space distribution ("hollow beam") may favor the one-third-integer resonant mode in order to obtain a smaller time averaged transverse phase space of the extracted beam. Note that for the cases relevant here, the lattice synchrotron-radiation damping time is long compared with the beam dwell time, so that a "memory" of the transverse phase space distribution at injection tends to be preserved.

Of great importance is the time structure of the extracted beam. Resonant component excitation and dipole excitation ripple will lead to time modulation of the beam intensity. Beam feedback can be employed, but its response speed is limited because particles bound for extraction remain for tens of turns inside the machine. Experience at the cited proton facilities has shown, however, that with adequate ripple control, fast beam feedback, and the use of a repetitive parameter-correction cycle ("learning cycle"), beam modulation can be kept to less than about 20%. Resonant extraction from a stretcher ring can provide for a CW beam with 90% duty cycle during the "smooth" part of the beam spill, with a macroscopic time structure having approximately 20- μ sec gaps every 1000 μ sec and with a microscopic time structure given by the frequency of the rf acceleration system.

In the stretcher ring designs considered here, a racetrack lattice has been adopted in which two long, dispersion-free straight sections are joined to two achromatic arc sections. The use of dispersion-free straight sections for location of the injection and ejection components provides for simpler matched injection and for beam ejection that does not, in first order, couple the beam momentum distribution into the extraction process.

For the use of polarized beams, it is essential to preserve transverse (vertical) polarization in the stretcher ring. Since the stretcher ring operates in a DC mode (beam injection at final energy), avoiding depolarizing resonances is straightforward by choosing a suitable vertical tune for specific ring energy values. Depolarization due to radiative polarization will be no problem for low-energy operation, but--because $\tau_p \propto C \rho^2 \gamma^{-5}$ is approximately 1 hour at 4 GeV -- it must be considered at energies above 4 GeV. Nevertheless, external beams with a high degree of transverse polarization can be obtained from these stretcher rings, as can longitudinally polarized beams by means of external transverse-to-longitudinal spin rotators.

IV-A.2 Microtron Method

The microtron, or electron cyclotron, is relatively unfamiliar, although many low-energy pulsed microtrons have been built since the device was first proposed by Veksler in 1945. Essentially, electrons are made to pass through the same accelerating structure, or structures, repetitively by use of a beam transport system that has the property of making each orbit exactly $n\lambda$ longer than the previous orbit, where n is the integral mode number (1,2,3,...) and λ is the wavelength of the accelerating field. Thus, synchronicity with the accelerating wave is maintained, and very efficient use of the accelerating system is achieved. For reasons of phase acceptance, n is generally less than 5.

The beam transport system can be designed for any number of orbits, but 50 is typical. At the end of the last orbit, the electrons are extracted with an energy of $N\Delta E + E_i$, where N is the number of orbits, ΔE is the energy gain per orbit, and E_i is the microtron injection energy. The energy gain per orbit, the magnetic field in the return magnets, B , and the accelerating-field wavelength are related by a simple expression of the form $\Delta E = An\lambda B$, where A is a constant dependent on the geometry of the microtron beam transport system. This expression shows the constraint on the energy gain per orbit that is imposed by technologically feasible magnets.

At lower energies, where quantum excitation is small, the microtron beam quality can be very high because no complicated injection or extraction gymnastics are required. Therefore, low-energy microtrons are conceptually simple and well-suited to

operation at 100% duty cycle with beams in the 100- μ A range. Moreover, the individual orbits are separated horizontally, and thus steering on an orbit-by-orbit basis is possible. These accelerators are, in effect, coiled-up transport systems between one or more rf accelerating cavities. Hence the problems of controlling the path length between passes through the accelerating cavities and of obtaining the proper transverse position and angle of the beam are similar to those that must be solved in a typical beam transport system.

For a 100% duty cycle, which is the case of interest here, the accelerating structure will operate at relatively low gradients (by pulsed linac standards), which means that it must be quite long in order to achieve a high energy gain per orbit. In addition, to achieve the high shunt impedance necessary for maintaining the accelerating gradients, the accelerating structure must operate at relatively high frequencies and with a small bore size (compared with accelerating structures in storage rings). This requires very accurate control and correction of errors in the beam transport system, both to maintain the necessary phase between the rf accelerating voltage and the beam bunches passing through the accelerating structure and to maintain the transverse position of the beam relative to the bore of the structure.

Because the total time that electrons spend in the microtron is extremely short compared with the time they would spend in a storage ring, instabilities characteristic of storage rings do not occur in microtrons. Only two types of beam instabilities appear to be of concern. The first, cumulative beam breakup, is the same as that found in linacs and has already been discussed. The second, regenerative breakup, occurs when the transverse modes excited by an electron bunch deflect the same bunch on subsequent passes through the linac structure.

The current passing through the rf structure in a microtron is much lower than the peak current passing through the rf structure of a pulsed linac, but the pulse length is much greater. Thus, the Q of the rf structure plays a more important role for the beam breakup instabilities in a microtron. This may explain why beam breakup has been a major limitation on the intensity in microtrons with superconducting accelerating structures but has not been a problem, at present intensity levels, in microtrons with room-temperature accelerating structures.

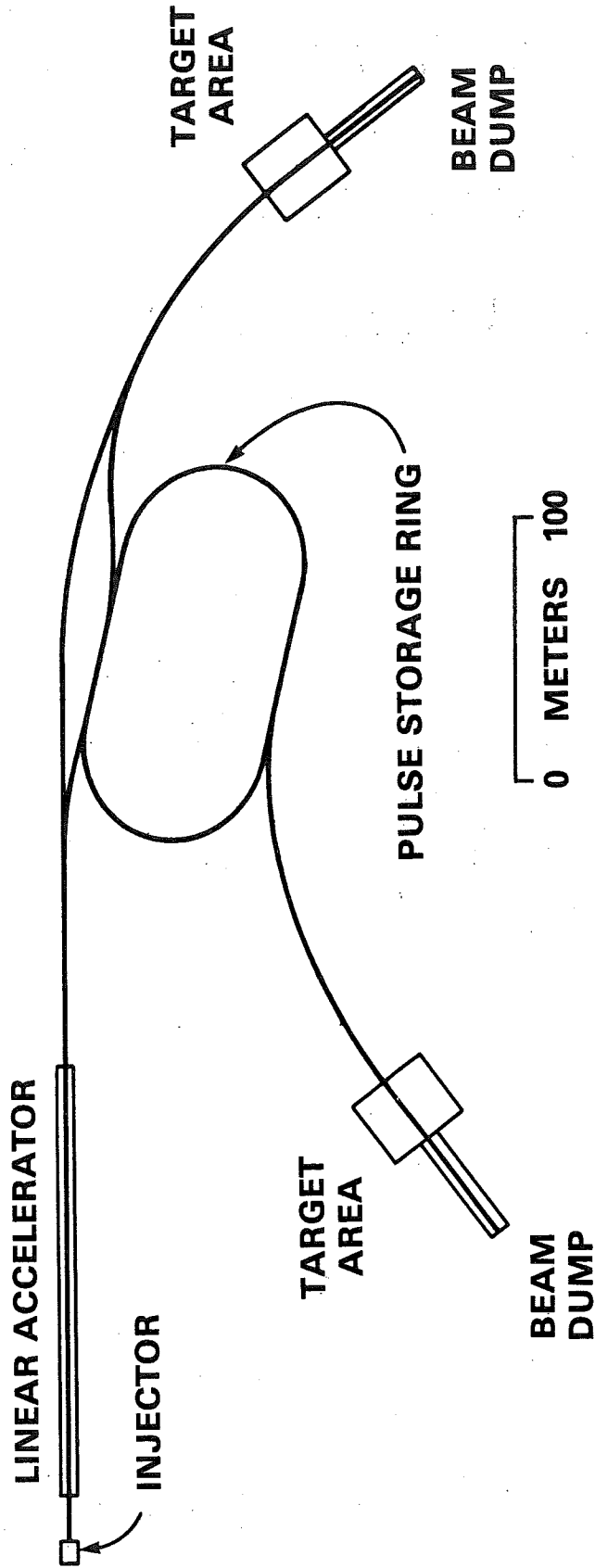
Although the effects of synchrotron radiation are important for all electron beams with energies above a few GeV, they are of particular concern for high-energy microtrons. The change in the electron energy due to synchrotron radiation loss in a bending magnet produces a change in the orbit of the electron. The average orbit shift due to synchrotron radiation loss can be corrected by the addition of compensating bending fields. However, because the electrons emit quanta in a random manner, with a spread in the radiated energy, growth occurs in both the transverse and longitudinal phase space emittances. For high-energy microtrons, this effect determines the beam emittance and will be a major factor in choosing the accelerating-structure aperture.

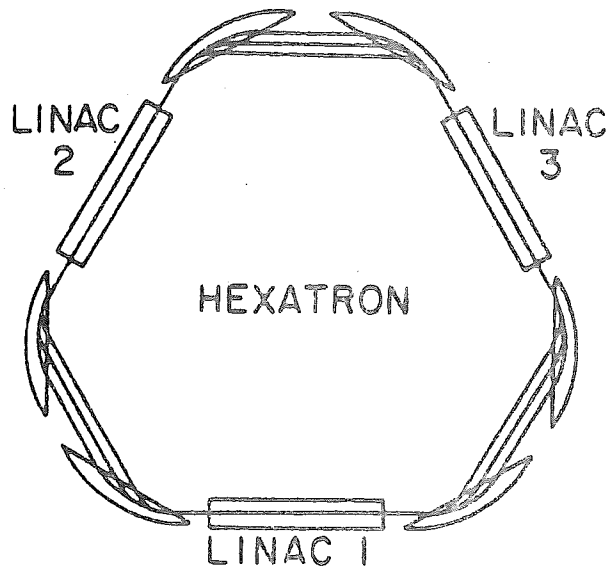
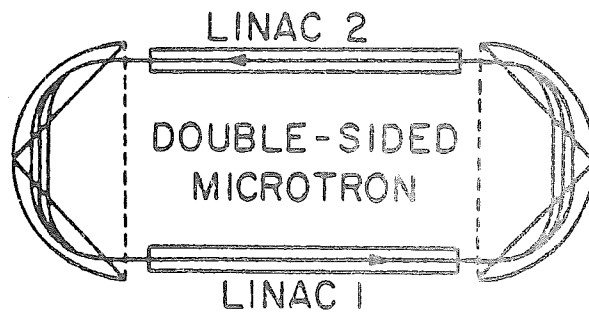
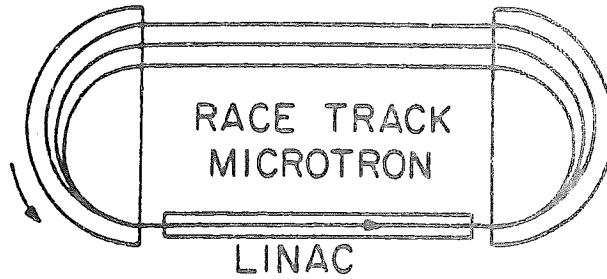
Varying the output energy is relatively simple: electrons can be extracted from any orbit, giving energy variability in steps approximately equal to the energy gain per orbit. Geometries of a microtron beam transport system are possible that make these steps equal to one-half or one-third of the energy gain per orbit. Variation between steps then requires a rather small percentage variation in the excitation of the magnetic elements in the microtron beam transport system and accelerating structure. It is also possible to extract several beam energies simultaneously, by extracting portions of the

beam from different orbits. The macroscopic time structure of the extracted beam is smooth, with a microscopic structure corresponding to the rf acceleration frequency.

To date, one 60-MeV and two 100-MeV pulsed racetrack microtrons have been built and operated successfully. Four CW racetrack microtrons, ranging in energy from 18 to 200 MeV, have also been built and operated successfully, albeit with lower currents than are being considered here. However, because the orbits become very long in multi-GeV microtrons, position tolerances and requirements for the magnetic field quality in the transport system are severe (despite the possibility of steering on each orbit). Therefore, the application of this technique to the multi-GeV energy range is an extension of current accelerator technology and will require a considerable engineering effort.

LINEAR ACCELERATOR/STORAGE RING SYSTEM





EVOLUTION OF THE MICROTRON

IV-B TABULAR COMPARISON OF PROPOSED ACCELERATOR SYSTEMS, COSTS AND STAFFING LEVELS

To facilitate the evaluation of the five proposals considered by the Panel, we include in this section comparative tables. These tables are largely self-explanatory; they were prepared from material that was included in the proposals themselves, provided by the proposing groups during oral presentations or in response to Panel requests, or, where indicated by appropriate footnotes, developed by the Panel on the basis of its own studies and analyses of the proposals. For example, the Panel has concluded in several instances that inadequate provision was made in the proposals for R&D required prior to the initiation of actual accelerator construction. Appropriate cost increases to cover such recommended R&D (discussed in greater detail below) have been estimated by the Panel and added where indicated in the tables.

For each proposal, the construction costs and annual operating costs are summarized in Tables IV-B-1 and IV-B-2, respectively. All cost data are in FY1983 dollars and must be inflated appropriately for "actual-year" dollars. The proposals are shown in alphabetical order throughout, and a 4-GeV future option for MIT-Bates has been incorporated for reference.

In Table IV-B-1, lines 1-9 reflect the construction costs quoted in the proposal; line 10 shows the manpower requirements quoted by each institution. Lines 4a, 6a, and 8a reflect the additional contingency, R&D, and experimental equipment, respectively, recommended by the Panel. These are included in lines 5a, 7a, and 9a, which correspond to the modified total estimated cost (TEC), total project cost (TPC), and the TPC plus experimental equipment, respectively. Line 9a, therefore, is the total cost that must be requested for construction of a particular facility. Note that the relatively high additional contingency in the SURA column reflects the financial needs arising from: (1) creating a new laboratory; and (2) the substantial additional staffing needed for the facility and the related potential time delay.

Table IV-B-2 reflects the annual operating costs of the various proposed facilities. There were numerous discussions between the various groups and the Technical Subpanel, and hence the costs shown here should reflect a fairly accurate and mutually accepted picture. Line 5a (additional capital improvements) has been recommended by the Panel to keep the experimental equipment up-to-date consistent with the standards of a National Facility.

Table IV-B-3 provides estimates of the 15-year total project cost and the initial experimental equipment cost, based on material in Tables IV-B-1 and IV-B-2. There is no **new** information in Table IV-B-3, but the costs have been combined to facilitate comparison.

The tabular comparisons of the accelerators themselves reflect the data presented in the individual proposals. Summaries of the most salient characteristics of the accelerators and the linac-rf systems are given in Tables IV-B-4 and IV-B-5, respectively. To understand the more intricate details, such as future flexibility, variation in parameters, and interrelation of experimental areas, the original proposals should be studied.

Table IV-B-1 CONSTRUCTION COSTS[ⓐ]

Item	Argonne		Illinois		MIT-Bates		NBS		SURA		
	2 GeV	4 GeV	750 MeV	4 GeV	1 GeV	2 GeV	4 GeV	200 MeV [ⓑ]	1 GeV	2 GeV	4 GeV
1. Conventional construction	\$16.2	\$17.0	\$4.5	\$45.1	\$13.0	\$23.9	\$45.1	\$0	\$14.1	\$26.4	\$30.7
2. Accelerator system	48.8	59.4	17.1	57.4	5.6	19.1	57.4	0.2	9.8	22.6	41.1
3. Beam transport system	5.2	7.9	1.7	8.2	2.7	5.0	8.2	0.8	2.6	9.0	9.9
4. Contingency allowed overall	(20%)	(20%)	(20%)	(20%)	(20%)	(20%)	(20%)	(20%)	(20%)	(25%)	(25%)
5. Total estimated cost (TEC) (includes contingency)	70.2	84.3	23.3	110.7	21.3	48.0	110.7	1.0	26.5	58.0	81.7
4a. Additional contingency recommended by Panel	6.0 (8%)	8.0 (9%)	2.5 (11%)	--	2.5 (12%)	10.0 (21%)	--	0	2.5 (9%)	10.0 (17%)	15.0 (18%)
5a. Modified TEC (5 + 4a)	76.2	92.3	25.8	--	23.8	58.0	--	1.0	29.0	68.0	96.7
6. R&D related to construction [ⓐ]	2.2	2.2	1.0	5.2	1.4	3.2	5.2	0	5.0	3.0	10.1
6a. Modified R&D recommended by Panel	10.2	16.0	3.5	--	4.4	8.2	--	0	8.5	7.0	15.1
7. Total project cost (TPC) (5 + 6)	72.4	86.5	24.3	115.9	22.7	51.2	115.9	1.0	31.5	61.0	91.8
7a. Modified TPC (5a + 6a)	86.4	108.3	29.3	--	28.2	66.2	--	1.0	37.5	75.0	111.8
8. Experimental equipment	21.4	21.4	8.0	44.4	9.3	24.4	44.4	3.5	20.2	--	12.3
8a. Modified experimental equipment recommended by Panel	25.0	35.0	10.0	--	10.0	25.0	--	3.5	10.0	25.0	35.0
9. TPC plus experimental equipment (7 + 8)	93.8	107.9	32.3	160.3	32.0	75.6	160.3	4.5	51.7	--	104.1
9a. Modified TPC plus modified experimental equipment (7a + 8a)	111.4	143.3	39.3	--	38.2	91.2	--	4.5 [ⓐ]	47.5	100.0	146.8
10. Man-years needed to complete project [ⓐ]	340	414	251	579	114	290	579	--	141	341	514

ⓐ Cost estimates in FY1983 M\$ (including EDIA).

ⓑ Incremental cost to convert RTM-1 into a nuclear physics research facility.

ⓒ Starting in FY1983.

ⓓ Including R&D effort; excluding contingency.

Table IV-B-2 ANNUAL OPERATING COSTS^①

Item	Argonne		Illinois		MIT-Bates			NBS		SURA	
	2 GeV	4 GeV	750 MeV	1 GeV	2 GeV	4 GeV	200 MeV ^②	1 GeV	2 GeV	4 GeV	
1. Direct personnel cost ^③	\$6.0	\$6.0	\$1.9	\$5.4	\$5.9	\$8.7	\$0.4	\$2.6	\$5.5	\$6.3	
2. Indirect costs	1.5	1.5	1.0	4.3	4.7	7.0	0.3	1.6	0 ^④	0 ^④	
3. Materials and services	3.0	3.0	0.6	2.4	2.7	4.1	0.3	0.7	3.2	3.2	
4. Electric power	1.7	3.6	0.7 ^⑤	1.5	2.0	3.4	0	1.4 ^⑥	1.9	3.6	
5. Capital improvements (AIP/GPP/CE)	2.4	2.4	0.5	3.0	4.2	6.5	0.4	2.9	2.5	3.0	
5a. Additional capital improvements recommended by Panel	1.0	2.0	0.5	0	0	0	0.1	1.0	1.0	2.0	
6. Total operating cost (1 through 5a)	15.6	18.5	5.2	16.6	19.5	29.7	1.5 ^⑥	10.2	14.1	18.1	
7. Direct personnel, FTE ^⑦	153	153	83	180	204	297	--	75	160	184	
8. Indirect personnel, FTE	39	39	8	0 ^⑦	0 ^⑦	0 ^⑦	--	30	0 ^⑦	0 ^⑦	
9. Total operating FTE	192	192	91	180	204	297	--	105	160	184	
10. PhD research-staff (in-house) FTE included in line 9	19	19	10	9	10	22	--	12	30	35	
11. Experimental-support FTE included in line 9	19	19	19	53	59	97	--	27	46	53	

① Cost estimates in FY1983 M\$.

② Incremental cost to operate RTM-1 as a nuclear physics research facility.

③ Including fringe benefits; excluding indirect charges.

④ Included in direct costs.

⑤ Electric power costs will be paid by the institution.

⑥ Number of personnel reporting to the project director.

⑦ Included in direct personnel.

Table IV-B-3 FACILITIES COSTS (IN FY1983 M\$) FOR 15 YEARS

Cost	Argonne		Illinois	MIT-Bates			NBS		SURF	
	2 GeV	4 GeV	750 MeV	1 GeV	2 GeV	4 GeV	200 MeV	1 GeV	2 GeV	4 GeV
Total project cost plus initial experimental equipment (modified) [ⓐ]	111.4	143.3	39.3	38.2	91.2	160.3 [ⓑ]	4.5	47.5	100.0	146.8
Total 15-year operating cost [ⓐ]	234.0	277.5	78.0	249.0	292.5	445.5	22.5	153.0	211.5	271.5
Total 15-year facilities cost	345.4	420.8	117.3	287.2	383.7	605.8	27.0	200.5	311.5	418.3

ⓐ From Table IV-B-1, line 9a.
 ⓑ Not modified; from Table IV-B-1, line 9.
 ⓐ From Table IV-B-2, line 6 (x 15).

Table IV-B-4 ACCELERATOR CHARACTERISTICS

	Argonne	Illinois	MIT-Bates	NBS	SURA
Type of accelerator	Hexatron microtron fed by racetrack microtron	3-Stage cascade racetrack microtron	Linac recirculator and pulse stretcher ring	2-Stage cascade racetrack microtron	Linac recirculator and pulse stretcher ring
Maximum number of recirculations	RTM: 27 Hexatron: 37	RTM-1: 17 RTM-2: 29 RTM-3: 80	Phase 1: 2 Phase 2: 5 Phase 3: 5	RTM-1: 16 RTM-2: 87	2
Duty cycle (beam)	100%	100%	80%	100%	>90%
Output beam energy	RTM: 185 MeV RTM + Hexatron: 500-4000 MeV ^①	RTM-1: 22 MeV RTM-1 + 2: 83.3-183.3 MeV RTM-1 + 2 + 3: 750 MeV ^②	Phase 1: 50-1000 MeV Phase 2: 50-2000 MeV Phase 3: 50-4000 MeV ^③	RTM-1: 15-200 MeV RTM-1 + 2: 200-1000 MeV	500-4150 MeV ^④
Average beam current	Hexatron: 300 μ A	RTM-1 + 2 + 3: 100 μ A	Phase 1: 140 μ A ^⑤ Phase 2: 140 μ A ^⑤ Phase 3: 140 μ A ^⑤	RTM-1 + 2: 300 μ A	Phase 1A: 360 Hz, 278 mA, 120 μ A ^⑥ Phase 1B: 1000 Hz, 200 mA, 240 μ A ^⑥ Phase 2: 720 Hz, 278 mA, 240 μ A ^⑥
$\Delta E/E$	10 ⁻⁴	10 ⁻⁴	10 ⁻³	RTM-1 + 2: 7 x 10 ⁻⁵	<10 ⁻³
Beam emittance (at maximum energy)	Vertical: 0.06 π mm-mrad Horizontal: 0.15 π mm-mrad	0.01 π mm-mrad	0.1 π mm-mrad	RTM-1 + 2: 0.01 π mm-mrad	Vertical: <0.1 π mm-mrad Horizontal: 0.3 π mm-mrad
Microstructure of beam	0.80 or 2.40 GHz	0.82 or 2.45 GHz	2.856 GHz	0.793 or 2.38 GHz	714 MHz
Beams available	3 CW beams with 2 independently adjustable energies from 0.5 to 4.0 GeV and 0 to 100 μ A	Up to 3 CW primary beams of same energy, independently adjustable in current; parasitic beam for tagged-photon experiments	Phase 1 + 2: 1 CW beam; 1 photon beam ^⑥ Phase 3: 2 CW beams of different energies; 1 photon beam ^⑥	RTM-1 + 2: up to 3 simultaneous beams of different currents: 2 beams up to 200 MeV, 1 beam up to 1 GeV RTM-1: 3 beams up to 200 MeV	2 CW beams of same energy from pulse stretcher ring; 1 photon beam ^⑥
Magnetic field in end magnet	RTM: 1.005 T Hexatron: 1.015 T	RTM-1: 0.171 T RTM-2: 0.95 T RTM-3: 1.425 T	--	RTM-1: 1.0 T RTM-2: 1.58 T	--
Number of experimental areas	3	5	9	5 (2 at high energy)	3

① Argonne has also described a 2-GeV option that would have fewer linac sections and klystrons and use less linac and magnet power.

② Lower energies are available by using fewer recirculations.

③ Possible future capability.

④ SURA has also proposed a phased construction program with 2-, 4-, and 6-GeV phases.

⑤ These currents are maximum per beam; the facility current is typically 225 μ A.

⑥ The high-intensity pulsed beam from the accelerator with independent energy and intensity can also be used directly.

Table IV-B-5 LINAC-RF SYSTEMS

	Argonne	Illinois	MIT-Bates	NBS	SURA
Linac structure	On-axis coupled ^① (similar to Mainz)	On-axis coupled ^① (similar to Mainz)	Traveling-wave ($2\pi/3$ mode, approx. constant gradient)	Side-coupled (fabricated by LANL)	Traveling-wave ($2\pi/3$ mode, constant gradient)
Frequency	2.40 GHz	2.45 GHz	2.856 GHz	2.38 GHz	2.856 GHz
Beam aperture	1.2 cm	1.4 cm	~2.0 cm (with protection collimator)	1.0 cm	~2.0 cm (with protection collimator)
Shunt impedance	75 M Ω /m	67 M Ω /m	48-58 M Ω /m	82.5 M Ω /m	53-60 M Ω /m
Accelerating gradient	1.54 MV/m at 52 kW/m ^②	1 MV/m at 22 kW/m ^②	~3 MV/m at 40 mA peak beam current	RTM-1: 1.5 MV/m at ~40 kW/m ^③ RTM-2: 1.25 MV/m at ~56 kW/m ^③	~19 MV/m at 200 mA peak beam current
Accelerator length	RTM: ~4.5 m Hexatron: 3 linacs, each 25 m long	RTM-1: 1.0 m RTM-2: 5.9 m RTM-3: 8.8 m	Phase 1 + 2: 160 m Phase 3: 270 m	RTM-1: 8 m RTM-2: 8 m	171 m (incl. injector)
RF power source	78 50-kW klystrons (CW) ^③	10 50-kW klystrons (CW) ^④	Phase 1 + 2: 12 5.3-MW pk., 100-kW av. klystrons ^④ Phase 3: 21 5.3-MW pk., 100-kW av. klystrons	2 500-kW klystrons (CW) ^⑤	40 40-MW-peak klystrons ^⑥ Phase 1A: 46 kW av. (360 pps) Phase 1B: 128 kW av. (1000 pps) Phase 2: 92 kW av. (720 pps)

① If one of the alternative structures now under development proves to be superior, it will be used.
 ② Approximately 1/3 to 1/2 of this power is dissipated in the cavities; beam loading consumes the remaining fraction.
 ③ Thompson/CSF TH-2075
 ④ Varian VA-938
 ⑤ Varian VKS-8270
 ⑥ Similar to SLAC klystrons but with up to 3.2 times higher average power capability.

IV-C. DISCUSSION AND CRITIQUE OF PROPOSALS

IV-C.1 Argonne National Laboratory

IV-C.1.1 Concept and Theoretical Analysis

The Argonne Hexatron is a modification of the conventional racetrack microtron (RTM) that allows the microtron concept to be extended to energies not previously considered possible. The design permits a very high energy gain per turn (105 MeV) and a large orbit separation (17 cm) without requiring an accelerating mode number greater than 1, long accelerating field wavelengths, or unreasonably high dipole fields in the microtron beam transport system. The proposed design provides the simultaneous capability of two independent extraction energies from the Hexatron plus a third extraction energy whose value is constrained by the energy gain per orbit and the synchrotron tune. The energy of this third beam can assume values between the injection energy and the maximum beam energy, but with approximately a 500-MeV grid. Finally, the geometry of the Hexatron allows it to be assembled in the existing ZGS ring tunnel; this results in a saving in conventional construction costs. A summary of the machine characteristics can be found in Table IV-B-4.

The size of the Hexatron raises questions as to whether currently feasible guide-field and position tolerances are adequate. The orbit dynamics and components of the Hexatron have been the subjects of studies during the past two years; these studies indicate that guide-field uniformity and position tolerances are marginally state-of-the-art. This is a consequence of the Hexatron geometry, which requires strong focusing but allows the dipoles to operate at the modest field of 1.0 T and allows the beam to reach full energy in only 37 orbits at an accelerating mode number of $n=1$.

Given that the required field uniformity, in the absence of steering, scales as N^{-2} (where N is the number of orbits), the fields of the 37-orbit Hexatron, despite its size, will in principle not be appreciably more difficult to trim acceptably than those of a conventional RTM with 80 orbits. The large orbit separation (compared with the dipole magnet gap) means that the dipole-edge treatment aimed at achieving exit angles of 90° may be successful. The results of initial computer simulations and magnet modeling are encouraging. The large orbit separation also allows the installation of steering elements to reduce beam-position error.

The effect of quantized synchrotron radiation emission has received intensive study. This is an important effect above 3.5 GeV and may require the use of a larger-bore accelerating structure with lower shunt impedance; the implications of this requirement are still being evaluated. The Hexatron is designed for a maximum energy of 4 GeV, but it would have serious problems of linac aperture demand above 4 GeV because of emittance growth due to quantized synchrotron radiation emission. However, recent high-power tests with side-coupled linac structures have demonstrated that a larger-bore accelerating structure might be feasible.

There are other areas of concern as well. Position tolerances (specified at ± 0.1 mm) may be met initially, but the question remains as to whether they can be maintained against changes in ambient temperature and settling of the foundations. These alignment uncertainties and synchrotron radiation effects give rise to concern as to whether 1.2-cm-diameter beam apertures will be adequate for all 37 orbits. At the power level of the beam in this machine, the damage that it could do to the expensive accelerating

structures would be impressive if no aperture-defining collimators were used. The large number of corrective elements raises questions of machine control and the attendant question of the need for an adequate algorithm for machine operation. Thus, although it is an innovative design, the Hexatron represents a challenging and difficult engineering project.

Argonne seems to have a good and enthusiastic engineering group, which, however, appears to have limited exchanges with those of other laboratories. They are aware of the most important difficulties of their design and are now trying to assess the magnitude of these problems.

The success of this project depends very strongly on the quality and ingenuity of the engineering staff, as well as on the quality and completeness of the correction schemes for alignment and orbit corrections of the accelerator. Unfortunately, if the necessary tolerances cannot be achieved or if the errors cannot be sufficiently corrected, the performance will suffer substantially.

The first stages of the Argonne proposal consist of a linear accelerator to reach 23 MeV and a racetrack microtron to reach 185 MeV. These are rather straightforward designs and should not pose much of a problem.

The Hexatron design is the portion of the proposal that requires the most theoretical study. The Argonne group has already completed much of the theoretical work and has studied questions of tolerances and correction schemes. The difficulty of achieving the necessary magnetic field tolerances is one of the problems facing the Hexatron designers. Theoretical studies have been performed for field errors of $|\Delta B/B| < 10^{-4}$, alignment errors of $|\Delta x| \leq 100 \mu\text{m}$, and rotational errors of $|\Delta\theta| \leq 400 \mu\text{rad}$. It was found that the resulting orbit distortions of a few centimeters could be corrected down to a few millimeters by means of three measuring devices and three correcting magnets per turn. Studies with errors three times larger suggest that they can be corrected for, especially if a larger linac aperture is chosen. More studies are needed, however, before one can fully determine the limits.

Higher-order optics calculations have also been performed for the case of no field errors for the 220-MeV beam orbit. In general, the theoretical problems are being worked on in the proper order and the group is continuing along the appropriate path to perform the remaining required calculations. In particular, many of the effects have been calculated for the "perfect" accelerator but remain to be calculated for the accelerator when errors are present.

IV-C.1.2 Prior R&D Assessment, Technical

The construction-related R&D costs for this project total \$2.2 M, or 1.7% of the total (4-GeV) construction cost. Included in this amount are PE&D funds for the accelerator and funds for the design of a superferrie magnet-based spectrometer. Although no R&D funds for rf cavity technology are included in the Argonne proposal, ongoing effort in this area is being supported by the joint NBS/LANL accelerator research program. In addition, R&D on sector-magnet design is being supported through separate ANL Program Development Funds. During the period covering FY1980-FY1983, funds have been provided as follows:

Fiscal Year (K\$)	Amount	Fiscal Year (K\$)	Amount
1980	160	1982	600
1981	520	1983	900

It is the recommendation of the Panel that an additional \$13.8 M of R&D funds be used in support of this project. Particular areas to be covered should include:

- RF structures (continuing collaboration with LANL)**
- Model magnet and prototype magnet design**
- Orbit tracking with measured edge fields and error spectrum**
- Extraction techniques to permit continuous energy variation**
- Beam breakup effects with multiple off-axis beams**

IV-C.1.3 Technical Components

Linac structures are required for the 23-MeV injector, the 185-MeV RTM, and the 4-GeV Hexatron microtron. Each of these will use an identical biperiodic on-axis coupled structure that is similar to the Mainz design. The lengths of the linacs are 16 m (including capture, pre-accelerator, and accelerator sections of the injector), 4.5 m, and 3x25 m, respectively. As shown in Table IV-B-5, these structures operate at 2.40 GHz, have a beam aperture of 1.2 cm, and a shunt impedance of 75 M Ω /m. There is some concern that the relatively high rf input power (35.2 kW/m for the accelerating fields and 16.8 kW/m for beam loading) will cause detuning of the accelerator cavities and possible frequency separation of the main and coupling cavities of the on-axis coupled structure.

The Argonne group is also considering the use of a side-coupled structure being developed at Los Alamos; they will use that structure if further tests show that it has characteristics superior to those of the on-axis coupled structure. During recent high-power tests of a 1-cm-diameter side-coupled structure at a power level of 32 kW/m and an accelerating field of 1.6 MV/m, no detuning was observed. The cell-to-cell coupling of 4.7% observed in the Los Alamos prototype is adequate for the 2.06-m sections of the Hexatron design, and no modifications of the proposed rf power distribution system are necessary.

The accelerating structures for each of the three linacs of the Hexatron will consist of 11 2.06-m sections. Space is available to add two cells to each section, thereby decreasing the accelerating gradient and power dissipation per unit length, should this prove necessary.

The rf power to the accelerator structures will be provided by 78 50-kW Thompson/CSF TH-2075 klystrons. These tubes are well-proven commercial models with an efficiency of 62% and a lifetime of over 20,000 hours. In the Hexatron, the output of two such klystrons will be combined to feed each 2.06-m accelerating structure.

Probably the most critical design questions associated with the Hexatron have to do with the six sector magnets. The steel yoke and pole pieces for each of these magnets

weigh 673 tons. Each magnet with its power supply and control system will cost approximately \$2M. The pole edge of each sector magnet is provided with steps for the first 14 low-energy orbits in order to achieve a beam incidence approximately normal to the field boundary; the remainder of the pole edge is straight. This design is intended to avoid strong vertical defocusing forces resulting from oblique incidence, particularly at low energies. Calculations and measurements at Argonne indicate that the effective edge-field contour of the stepped edge is perpendicular to the beam to within 2° .

The magnetic field integral along each beam orbit must be held constant to within one part in 10^4 . Orbit-to-orbit fluctuations of the field integral will induce synchrotron oscillations and increase beam-energy spread. Fluctuations are caused mainly by two factors: (1) errors in the central field strength; and (2) the "softness" of the field edge. Variations in the central field can, in principle, be corrected by means of Purcell filters plus other passive (steel shims, etc.) and/or active (pole-face coils) elements to achieve the desired uniformity. In the Argonne design, the field profile is hardened by the use of magnetic shims along the pole edge and on the inner edge of the pole guard. In addition, magnetic shields are placed between the upper and lower end guards in the regions where the step edges run parallel to the neighboring beam orbits. Measurements indicate that these techniques produce a field that falls off faster than the Enge short-tail edge, for which beam containment has been demonstrated by other calculations.

Despite the apparent success of the sector-magnet design (demonstrated to date by 2-dimensional TRIM calculations and 3-dimensional calculations using steel elements of infinite permeability, as well as by measurements made on a one-step, 2/3-scale-model magnet), the complete achievement of the design field distribution remains to be demonstrated. Argonne has recently begun further studies of the magnet's properties using the Rutherford Laboratory program TOSCA, which performs 3-dimensional magnetostatic field calculations using steel elements with variable permeability. In addition, a 3-orbit prototype of the magnet is being built and will be ready for testing in May, 1983. The results are expected to demonstrate conclusively whether or not the sector-magnet design is satisfactory for its intended use in the Hexatron.

IV-C.1.4 Conventional Facilities

The accelerators, auxiliary equipment, and associated experimental areas would be housed in existing buildings at Argonne. Most of these facilities were used in connection with the now-dismantled ZGS accelerator. Replacement cost of these facilities has been estimated by Argonne to be in excess of \$50 M. Their value to the proposed project is undoubtedly less than this amount, because some of the facilities could be built at reduced cost if they were to be designed for the specific needs of the new project. Nevertheless, the availability of these facilities is a great asset to the Argonne proposal.

The principal cost of conventional facilities for the proposed project is for modifications to the existing facilities to make them suitable for housing the Hexatron and the RTM, experimental equipment, and data collection rooms. Three separate experimental areas are planned, each suitable for electron beams of $100 \mu A$ in intensity and 4 GeV in energy.

In addition to the buildings, approximately 50 MW of power is available at nearby substations, and 50 MW of water-cooling capacity is also available. These utility capacities are far in excess of the needs of the proposed project (~ 14.5 MW). It is estimated that the existing air-conditioning capacity is sufficient for the Hexatron. Ample radia-

tion shielding is also available in the ZGS ring building, the walls of which are constructed of 3.5-ft-thick concrete. Three overhead cranes of 20-ton, 20-ton, and 50-ton capacity are available in the ring building. A control room and many cable trays also exist.

Other required conventional-facilities work entails the construction of beam-line tunnels from the Hexatron to the three experimental areas. The total cost of all conventional-facility modifications and new construction (including EDIA and contingency) is \$17.0 M in FY1983 dollars.

IV-C.1.5 Special Situations

A very important "special situation" at Argonne is the availability of numerous buildings and facilities as a result of the dismantling of the ZGS accelerator. These facilities can be used for the proposed project, following necessary modifications that can be made at a small fraction (~15%) of the cost of completely new facilities.

A further asset for Argonne is the availability of a trained design staff and a project management team that is already in place and functioning. Numerous user support services are available, including machine shops, a plastics shop, electronics services, engineering services and graphic arts, computing services, library services, rigging services, an occupational health and safety staff, and a multidisciplinary research staff. Among the general site services provided are fire protection, paramedics, plant security, grounds maintenance, a travel office, and a health and medical office.

Argonne is a half-hour from O'Hare Airport, which provides frequent service to every major airport in the country. The Laboratory has a cafeteria and a visitors' lodging facility that has 112 rooms and apartments on-site.

IV-C.1.6 Capability Assessment

The Argonne group includes a number of senior accelerator physicists and engineers having, collectively, considerable experience. Expansion to the planned level of construction manpower should thus be straightforward. In addition, the project management structure is in place, with H.E. Jackson designated as Project Director and R. Kustom as Associate Project Director.

Besides the present project staff, Argonne National Laboratory has experienced accelerator personnel presently engaged in various areas; this additional staff may be needed, because the Hexatron constitutes a significant technical challenge. The ability to interface with future user group could be strengthened. It appears that the Laboratory management is fully committed to this project and will take the necessary steps to maximize its chances for success.

Further work is in progress on the mechanics of beam extraction from the Hexatron. Basic numerical studies have been carried out that show the feasibility of continuous energy variation (by discrete small steps) of the extracted beam.

Attention is being given to the possibility of regenerative beam breakup, and known scaling laws are being used to compare with operating microtrons elsewhere. In particular, recent experimental tests carried out in Mainz indicate that regenerative beam breakup should not be a problem for the beam current levels contemplated for the Hexatron. Assuming that the construction commitment is received by January 1, 1985,

there remains a period of 18 months to complete the essential preconstruction R&D work. This is adequate for refining responses to remaining design and technical questions and to prepare for Title I design work.

Support structures for the Hexatron construction project are fully in place, including not only procurement, library, and general laboratory housekeeping organizations, but also substantial shop facilities (mechanical, electronics, plastics) and a superconducting technology group experienced in magnet construction (of direct relevance to spectrometer magnet construction).

The stated duration of construction, 4.5 years, reflects a realistic schedule that includes the period of time available for completing pre-construction R&D work. The group is ready to take on this project from both organizational and skilled-personnel points of view.

IV-C.2 University of Illinois

IV-C.2.1 Concept and Theoretical Analysis

This system consists of three racetrack microtrons (RTMs) operating in cascade. Energy gains — variable at each stage — are limited to factors of less than 10, and the mode number of each stage is $n=1$. The energy variability of the three stages allows a considerable range of output energies with virtually no retuning of the last stage. Although only one output energy can be obtained at a time, the output beam can be split into three components with high efficiency and can thus serve three experimental halls simultaneously. Another (independent) beam with an energy that is variable between 83 and 183 MeV could be obtained with the addition of a second rf beam splitter between the second- and third-stage microtrons. A summary of the machine characteristics can be found in Table IV-B-4.

Orbit dynamics studies have been carried to an adequate stage of completeness. All components of the system have been studied, and in some cases modeled, either at the University of Illinois or at other laboratories. No technological weakness were found. This is a carefully worked out, conservative design that should achieve its goals. One disadvantage of this design, however, is that it does not allow for energy expansion without considerable redesign or the use of additional microtron stages.

The Illinois group has benefitted from its extensive experience in the design and operation of racetrack microtrons and from close contact with the Mainz and NBS/LANL groups. In making the transition from their present 80-MeV microtron using a superconducting linac to the 750-MeV cascaded microtron of their proposal, they have chosen to incorporate in their design many of the subelements developed at Mainz and NBS/LANL.

IV-C.2.2 Prior R&D Assessment, Technical

There are several areas on which the Illinois group should place R&D emphasis. The work in progress on linac structures will have to be extended substantially. Fortunately, the group should be able to rely at least partially on the results of LANL R&D studies in this area. Further work in particle tracking should also be undertaken, with inclusion of the full spectrum of errors.

Planned R&D efforts are broken down as follows:

Task (man-years)	Effort
Linac fabrication	10
RF separator system	5
Microtron magnets	2
Microtron optics	5
Spectrometer design	$\frac{2}{24}$

Funding for the above construction-related R&D effort is not part of the University of Illinois proposal. The intent is to fund the work (24 man-years, costing \$960 K) through the utilization of some of the laboratory's present operating budget.

In terms of the total construction budget of \$35.8 M, the \$1.0 M for R&D (2.8% of the total cost) is too low. We suggest that a more realistic assessment of R&D costs would raise them to at least 9.8% of the construction cost, or approximately \$3.5 M. In addition to placing emphasis on the topics described above, the R&D efforts should include work on the accelerator rf and control systems.

IV-C.2.3 Technical Components

All three stages of the 750-MeV RTM would use room-temperature, on-axis-coupled accelerator structures similar to those used in MAMI-1 and MAMI-2 at Mainz. These well-proven structures have a shunt impedance of $67 \text{ M}\Omega/\text{m}$ and provide an accelerating gradient of 1 MV/m when powered at a level of 15 kW/m. Altogether, the accelerator requires about 20 m of on-axis-coupled structure, mainly in modules about 2m in length. If a superior accelerator structure results from any of the R&D programs now under way at various laboratories, the improved structure could be used; however, the Mainz structure would fully satisfy the beam specifications of the proposed accelerator. Included in the 20 m of on-axis structure required for the cascaded microtron system are a 2-MeV capture section and a 2.5-MeV preaccelerator section that combine to inject a 4.5-MeV beam into the first microtron stage. Table IV-B-5 gives a summary of the linac-rf system characteristics for the proposed accelerator compared with those for the other proposals being considered.

Radio frequency power for the linac structures will be provided by 10, 50-kW CW klystrons (Thompson/CSF TH-2075), each of which will supply power to a single 2-m linac module. These are well-proven commercial tubes with high efficiency ($\sim 62\%$) and long lifetime (over 20,000 hours); they are a good match for the proposed application.

Because of its high cost and critical performance requirements, the power supply system for the Thompson/CSF TH-2075 klystron is one of the most important subsystems of the accelerator. Each of the 10 klystrons requires a 25-kV beam voltage at 3.2 A. With the help of a commercial supplier, the University of Illinois group has developed a preliminary design of the power supply system in which each power supply module will supply three klystrons. Each klystron will be connected to the power supply through a series regulator that will provide 0.1% regulation, current limiting, and fault protection. This design appears to be well conceived and cost-effective. A detailed design study, in collaboration with the Argonne group, is currently in progress.

Other important accelerator systems include the temperature regulation system for the linac, the beam diagnostic devices, and the computer control system. Conceptual designs of these systems have been completed and seem quite adequate for the intended purposes. Much detailed design remains to be done, however.

IV-C.2.4 Conventional Facilities

The University of Illinois proposal includes requests for the following new buildings and site improvements:

Item	Cost (FY1983 K\$)
Site development	582
Accelerator vault	1096
Annex building for cooling, power distribution, and klystron power	644
New experimental hall	1143
Beam transport tunnel	242
Modifications to existing experimental hall	70
	<u>3777</u>

The above costs were estimated by architectural and engineering consultants and include EDIA costs but not contingencies; these estimates appear to be reasonable.

IV-C.2.5 Special Situations

The University of Illinois has agreed to contribute an estimated \$2 M toward the construction of the proposed facility by limiting its annual collection of indirect costs (for the 5-year period of construction) to the amount received in 1979. In addition, the University has a policy of not including electric power costs as a direct charge to research programs; this policy will save about \$750 K/year in operating costs. Finally, the Illinois group intends to provide \$8.8 M of the total construction cost and \$960 K of the R&D cost by redirecting funds from the operating budget of their present facility during the construction of the new facility.

The physical plant of the existing Nuclear Physics Laboratory (NPL) would be available for the proposed program. Its estimated replacement value is \$10.25 M in FY1983 dollars.

Additional available facilities and equipment include the NPL machine shop and electronics shop, related Physics Department facilities, various equipment items from MUSL-2, data acquisition computers (worth approximately \$400 K), electronics pool equipment (worth \$500-750 K), and existing experimental equipment.

For specialized operations or temporary overloads beyond the resources of the facilities listed above, the new laboratory would have access to various shops within the College of Engineering and other departments of the University.

In addition, a University network of five computers is maintained by the Computer Services Organization and would be available at normal University rates to researchers at the proposed accelerator. The University also has a large library system, including several branch libraries; a nuclear research library is maintained in the NPL site.

Through its indirect budget and/or state funds, the University provides various services and facilities including a business office, a print shop, maintenance of buildings and grounds, janitorial services, utilities, security, fire protection, emergency medical care, safety services, and conference planning and facilities.

The Illinois group is planning two additions to the accelerator facility for user-laboratory, set-up, and office space. The added space would come to 19,000 ft² at a total cost of about \$900 K. It is likely that the University will contribute a significant fraction of this cost.

Housing, travel facilities, motels, and restaurants are plentiful and convenient to the laboratory. Moreover, the University has agreed to make several of its nearby houses available at modest cost to users for extended visits or to user groups for short visits.

IV-C.2.6 Capability Assessment

Because the cascaded microtrons proposed here do not constitute a significant extrapolation of known technology and because considerable experience exists locally in the construction of experimental hardware, detectors, electronics, etc., there should be little problem in carrying out the construction objectives. A core group of accelerator physicists and nuclear physics experimentalists is in place; with this, enhancement of the staff to the planned level for construction should be straight-forward.

Until recently the preconstruction project management was carried by Professors P. Axel and L. Cardman. The unfortunate death of Professor Axel leaves a leading position unfilled. University search procedures that will result in the appointment of a leading nuclear experimentalist are already under way. Professor Cardman will continue to carry the responsibility for the technical direction of the preconstruction R&D and will subsequently provide the technical direction for construction and operation of the new facility.

Because the design of the cascaded microtrons makes use of linear accelerator structures with modest gradient values (1 MV/m), proven on-axis-coupled accelerator cavities can be used. Collaborations with Chalk River and LANL are in progress, however, and more efficient structures with higher acceleration gradients may be used if appropriate. This issue will certainly be resolved by the time construction begins. Other R&D issues are of a "routine" preconstruction nature (rf separator, microtron magnet, microtron optics, and spectrometer studies) and do not involve critical construction issues.

The basic support organization, in terms of shops, procurement, general laboratory housekeeping, etc., is well established at the Nuclear Physics Laboratory. Consequently, when construction begins there should be no delays associated with the peripheral but essential support structure.

A concern of the Panel is that the existing group has limited experience in managing a project of the magnitude being proposed here. Although the present staff is enthusiastic, bright, and energetic, they are too few in number. The University of Illinois proposes to add 20 people, including seven permanent staff scientists, to the laboratory during the construction phase. An additional eight persons would be added when the new facility becomes operational. The University is committed to maintaining the nine tenured and tenure-track positions currently held by experimental nuclear scientists in the Physics Department. Also, the nuclear theory group at Illinois has been augmented by the recent offer of an incremental tenure-track position.

The proposed time scale for construction of this project is 5 years. Based on the present staffing levels, the proposed manpower increments, and the present state of readiness to begin this construction project, it appears that this time scale is realistic.

IV-C.3 Massachusetts Institute of Technology - Bates Laboratory

IV-C.3.1 Concept and Theoretical Analysis

This proposal describes a phased system development based on the existing MIT-Bates 400-MeV, 1.8%-duty-cycle linac and the 720-MeV single-turn recirculator (soon to be upgraded to 462 MeV and 840 MeV, respectively). A further upgrade of the rf system (requiring additional operating funds to refurbish all the klystrons and switchtubes) is being considered that could increase the maximum energy of the recirculated beam to 1080 MeV (unloaded). In Phase 1, the linac (after its energy upgrade) will be used to inject into a 300-m circumference stretcher ring. At this point the system will be capable of providing 300-1080 MeV CW electron beams to the experimental areas now in use at the Bates Laboratory.

For Phase 2, four additional recirculator paths are to be built. Each pass of the five-pass recirculator system travels in its own return transport line. The lengths of these lines are closely matched to the injected-beam pulse length so that the recirculation through the linac is "head-to-tail", in contrast to both the present recirculator scheme and a microtron, where all passes are present in the linac simultaneously. Beams can be switched on a pulse-to-pulse basis (1000 Hz), either to the present recirculator for subsequent transport to the existing experimental areas or to the new recirculator and then to the pulse stretcher ring. Characteristics of the proposed accelerator are summarized in Table IV-B-4.

The beam actually makes five passes through the linac. Thus, for example, at a nominal energy gain of 0.4 GeV, it will be possible to provide 2.0-GeV electrons to the stretcher ring. The system is expandable in energy by the addition of a 4-GeV storage ring and enough additional linac accelerating structures and rf power to bring the single-pass energy up to 828 MeV (fully loaded).

The design of this system is at present largely conceptual, although the existing single-pass recirculator represents a substantial R&D effort toward the design of the proposed five-pass recirculator. Only modest amounts of R&D on the stretcher ring have been done. It is therefore difficult at this time to make more than general comments and point out possible problem areas. The most serious potential difficulty involves the question of whether the linac will be free from beam-breakup instabilities when operating in the head-to-tail recirculation mode fully loaded. It is not yet possible to calculate this with any certainty. However, empirical tests and use of the Helm-Loew-Panofsky scaling law suggest that the beam-breakup threshold for 2-GeV operation will be above 40 mA.

The proposed three-turn injection scheme inherently leads to a larger transverse phase space in the stretcher ring. However, the use of a properly designed one-third-integer extraction scheme should minimize the loss of beam quality in the external beam. Open-loop operation of the extraction system is proposed, but this slow extraction system may have to include feedback in order to achieve satisfactory intensity-versus-time behavior. This technique has been demonstrated on proton machines, but on much longer (three orders of magnitude) time scales. The time delays inherent in the resonant growth of particle motion that are to be exploited for slow extraction restrict the bandwidth of such servo loops to at most a few kilohertz, thereby limiting the efficacy of the feedback system.

The effects of the various transverse and longitudinal instabilities that traditionally plague high-current electron storage rings have not yet been analyzed. These depend quite sensitively on the details of the vacuum chamber envelope and the rf cavity system, which are not available at this time. It is reasonable to state, however, that the high-frequency rf system now proposed (chosen to have the same frequency as that of the linac) will exacerbate any tendency toward longitudinal and transverse instabilities. The instabilities can limit stored beam current and degrade beam quality, thus reducing the performance of the ring as a beam stretcher. In the area of ring instabilities, the MIT-Bates group has relied to a certain extent on the theoretical work of the SURA group. This is clearly only an approximation for those aspects where their design differs from the SURA design.

The MIT-Bates group has designed its low-energy stretcher-ring lattice around surplus Princeton-Penn Accelerator magnets; it is not clear what constraints this implies.

The effects of nonlinear elements in both the transport system and the stretcher ring have been studied in the absence of errors. The effects of errors on the particle dynamics have not been studied, either with or without nonlinearities.

The Bates group plans to use a 2.856-GHz rf system for the stretcher ring; therefore, coupled-bunch instabilities, higher-mode losses, etc., will be considerably different than for the 717-MHz system of SURA.

The success probability of this proposal will be difficult to assess until the design is finished. However, it is probably lower than that of SURA. For example, the average current at 2 GeV might be lower than the 100 μ A specified, but it should be easy to reach several tens of microamperes.

IV-C.3.2 Prior R&D Assessment, Technical

In the MIT-Bates proposal, the construction-related R&D costs are \$1.4 M for Phase 1, \$3.2 M for Phase 2, and \$5.2 M for Phase 3. In terms of the construction costs for the three phases, these amounts correspond to 4.1%, 3.9%, and 3.4%, respectively. This level of R&D is insufficient for a project of this degree of difficulty, and the R&D funds should be increased to \$4.4 M in Phase 1 and \$8.2 M in Phase 2 to provide adequate studies of recirculation techniques (including beam breakup) and stretcher-ring design optimization. It will be necessary to add staff to support the increased level of R&D that the Panel suggests. Phase 3 is not well enough defined at this time to provide a basis for an R&D estimate by the Panel.

IV-C.3.3 Technical Components

The existing MIT-Bates accelerator utilizes a traveling-wave structure operating in the $2\pi/3$ mode at 2.856 GHz. To combat beam breakup, the various sections of the accelerator were designed with different HEM₁₁ resonant characteristics along the machine in order to reduce the coherent length of the transverse deflecting mode. Thus, a constant $2\pi/3$ phase shift per cavity in the TM₀₁ accelerating mode was maintained, but the HEM₁₁ resonant frequencies were varied by suitable selection of the iris aperture and the diameter for each cavity. In this manner, a structure with an approximately constant gradient characteristic was achieved that has a high starting current for beam breakup. Because of the dimensional variations, the shunt impedance also varies and has a range of values between 48 and 58 M Ω /m in the accelerator structure. Parameters of the system are given in Table IV-B-5.

The present Bates accelerator has a maximum single-pass energy of about 400 MeV when powered by 10 4-MW peak (100-kW average) klystrons. Beam recirculation has been used to increase the maximum energy to about 720 MeV. The maximum energy will be further increased under present funding to approximately 840 MeV (unloaded) by adding another modulator and two more klystrons.

The mean time between failures (MTBF) of the klystrons has been about 60,000 hours over the last few years, which is excellent. In estimating operating costs, MIT has assumed a more conservative MTBF of 30,000 hours.

In Phase 2, the beam would be recirculated so as to pass through the accelerator five times and thus reach an energy of up to 2.5 GeV at low currents and 2.0 GeV at 100 μ A average current.

In Phase 3, the accelerator length would be increased by 360 ft by adding nine SLAC-type 40-ft girder assemblies, each of which would be powered by an added klystron. The resulting single-pass energy of the accelerator would be increased to 980 MeV unloaded or 830 MeV at 40 mA peak current. With five passes, the maximum output energy would be 4.82 GeV unloaded or 4.07 GeV at 40 mA.

Although the Bates accelerator undoubtedly has a high cumulative beam-breakup threshold, more tests are needed to determine both the maximum achievable value of the beam-breakup scaling variable and the appropriate value of the exponent, n , in the scaling equation that indicates how strongly beam breakup depends on the beam pulse length.

Considering the pressures due to ongoing operations and research programs, it is clear that the present staff would have to be augmented if any part of the new program were undertaken. MIT-Bates proposes an increase of 25 in project staff in FY1984 and an additional staff increase of 39 for Phase 1, if approved. They further propose an increase of about 4 indirect staff members in FY1984 and an additional increase of 5.5 for Phase 1. The Panel agrees that increases of this general magnitude are needed if the proposed program is to move ahead.

IV-C.3.4 Conventional Facilities

Conventional construction costs total \$45.1 M for all three phases of the Bates program and amount to approximately 29% of the total construction cost. (These estimates were prepared by the firm of W.B. Merry and Associates, the engineer of record for the recirculator construction recently concluded.) A construction contingency of 10% was included in the base estimates, which were then further increased to include EDIA (10%) and contingency (15%).

Conventional construction to be accomplished during Phase 1 consists principally of the South Hall ring complex, including the ring tunnel, the beam switchyard, the internal target area, the tagging annex, the utility building, the data assembly building, the personnel-utility passageways, and the warehouse. In addition, a research and laboratory building would be constructed. Total cost of conventional construction for Phase 1 is \$13.0 M, including EDIA and contingency.

The Phase 2 conventional construction would upgrade the South Hall ring from 1 GeV to 2.5 GeV and would provide a 2.5-GeV recirculator for the linac. Total conven-

tional construction cost for this phase, including EDIA and contingency, is estimated to be \$10.9 M.

The Phase 3 conventional construction would provide for accelerator extension to higher energy, conversion of the recirculator from 2.5 GeV to 4.0 GeV, and a high-energy pulse-stretcher ring. The cost of conventional construction for this phase, including EDIA and contingency, is estimated to be \$21.2 M.

IV-C.3.5 Special Situations

MIT has agreed to waive indirect cost charges on the salaries of personnel engaged in the proposed construction project. This would amount to a saving of \$731 K for Phase 1, \$1373 K for Phase 2, and \$2572 K for Phase 3; the total waived for all three phases would be \$4676 K.

The replacement cost of the existing Bates Laboratory, accelerator, and research equipment is estimated to exceed \$50 M in FY1983 dollars. During the construction period and later during the operating period, additional laboratory, office, shop, and other logistical support space will be available, as well as facilities on the MIT campus.

The extended Bates Laboratory would be operated by MIT as a National Facility and identified as the Bates National Accelerator. Responsibility for the Bates Laboratory and the Laboratory for Nuclear Science has been delegated by MIT to the Dean of Science, who has established two advisory committees: the Bates Policy Advisory Committee and the Bates Management Advisory Committee. The former includes several members from outside MIT.

The Bates Users Group, which was instituted soon after the existing accelerator's completion, was formally incorporated in 1981 with the formation of a Bates Users Corporation structured in accordance with the laws of the Commonwealth of Massachusetts.

The Director of Bates would be advised by three groups: the Director's Advisory Committee, the Program Advisory Committee, and the Technical Advisory Panel.

IV-C.3.6 Capability Assessment

The management structure for the MIT-Bates proposal has been planned, but the Director and other key staff members have not yet been identified. It is planned to separate the management staff of the construction project from that of the ongoing operations and research staffs. Although key management personnel are capable and experienced, the present management structure has not been adequate to the simultaneous demands posed by routine operation, upgrading of the existing facility, and preparation of a proposal for the new facilities under discussion here, at a level of detail that would permit the Panel to assess it properly.

It is simply evident that the MIT group is not adequately staffed at the present time both to carry forth a design study for the proposal prior to construction authorization and to handle the day-to-day demands of their present facility. It was stated, for example, that with present manpower no design work toward the construction proposal will be carried out for the next half-year. If MIT is to maintain even its present level of research activity and machine reliability, quite apart from successful completion of the

upgrading program that has already been approved, the Panel strongly recommends the strengthening of **both** management and operational groups.

The stated duration for Phase I construction is three years. This is conditional on the existence of a 15-FTE staff to carry out preconstruction R&D. If this additional effort can be acquired only upon construction approval, a four-year construction period should be assumed for the Phase I construction. Successful achievement of stated performance parameters will depend upon the addition to the Bates Laboratory staff of a number of accelerator scientists. Unfortunately, the inability of such scientists, in the past, to attain normal academic status at MIT will make attraction of the most able candidates more difficult than might be the case elsewhere.

Points of major strength for the Bates Laboratory at the present time are, however, its internal groups of outstanding experimentalists, experienced in electromagnetic physics, and leading nuclear theorists as well as its ability to interface with the national experimental users community; in recent years it has been a leading laboratory in the field of experimental nuclear physics.

IV-C.4 National Bureau of Standards

IV-C.4.1 Concept and Theoretical Analysis

The racetrack microtron (RTM) proposed by the National Bureau of Standards is an extension of an R&D project already under way to develop a 200-MeV RTM. It is proposed to build a second RTM -- using technologies developed for the first stage -- capable of reaching 1 GeV. The mode numbers for the first and second stages are $n=2$ and $n=1$, respectively. The second stage requires 87 orbits to reach 1 GeV at the design value of 9.5-MeV energy gain per orbit. Five simultaneous beams at two energies -- three at 200 MeV and two at the second-stage extraction energy -- would be available. The second-stage extraction energy is variable only in steps corresponding to the energy gain per orbit. A summary of machine characteristics can be found in Table IV-B-4.

All components of the first stage are designed, and, except for the accelerating structure, most are under construction. A preaccelerator section, recently tested at LANL, has exceeded its design goals. It is expected that all components for the second stage will be adequately modeled on RTM-1 and will thus require minimal R&D. Orbit-dynamics calculations have been carried out in great detail for RTM-1 but to a lesser extent for RTM-2.

The overall concept of this system is quite straightforward. However, there are some areas that need attention. Because of its higher mode number, the first-stage accelerating structure operates at 1.5 MV/m. In order to keep the shunt impedance high, the beam apertures in the structure are 1 cm in diameter. This will require careful alignment of the second stage if the same structure is used.

The dipole magnets in the RTM-2 beam recirculator system are to be operated at a gap field of 1.6 T. This is a high value, considering the required field accuracy of $\Delta B/B=10^{-4}$. In principle, the field can be trimmed adequately at one excitation to develop a successful scheme; some R&D will be required to accomplish this.

It is planned to excite the accelerating structure of RTM-2 with one 500-kW klystron; this has the virtue of simplicity. However, the tube selected for this use has not yet been made in large quantity, and operating experience is lacking with regard to service lifetime at full power. Also, phase control at the input ports of the accelerating structure must be carried out at high power levels.

Orbit calculations have been carried out for RTM-2, taking synchrotron radiation into account. Emittance growth due to quantum fluctuations appears to be small, and hence the excellent beam quality is preserved. None of the concerns described above will prevent the machine from reaching its performance specifications.

IV-C.4.2 Prior R&D Assessment, Technical

The present NBS proposal does not include any request for construction-related R&D. However, R&D support is included in the joint NBS/LANL accelerator research program under which RTM-1 is being built. The total cost of the joint NBS/LANL program is approximately \$11 M, of which \$6 M is the cost of the accelerator.

The Panel feels that an additional \$3.5 M (9% of RTM-2 construction costs) is needed for this project. Topics that should be stressed include: (1) orbit tracking with a

full spectrum of errors and (2) linac rf structures (in collaboration with LANL). We note that amounts of \$370 K and \$2345 K are requested for RTM-1 and RTM-1+2 operations, respectively, for "experimental apparatus modifications, improvements, and replacements."

IV-C.4.3 Technical Components

Present plans call for both stages of the NBS Cascade Microtron System to use the side-coupled linac structure that is currently under development at LANL. This structure has an effective shunt impedance of $80 \text{ M}\Omega/\text{m}$ at 2.38 GHz, a beam aperture of 1.0 cm, and no interfering rf modes. The preaccelerator section of RTM-1 has been fabricated with a design cooling capacity of 28 kW/m at a gradient of 1.5 MV/m. The first high-power tests have obtained an effective shunt impedance of $82.5 \text{ M}\Omega/\text{m}$ and a gradient of 1.6 MV/m at 31 kW/m. Table IV-B-5 gives a summary of the rf system characteristics for the proposed accelerator.

Accelerating structures for both RTM-1 and RTM-2 consist of a pair of 4-m-long side-coupled structures. The RTM-1 structure will operate at a gradient of 1.5 MV/m, whereas the RTM-2 structure will operate at 1.25 MV/m.

Radio-frequency power at 2.38 GHz will be provided by two Varian VKS-8270 klystrons, one each for RTM-1 and RTM-2. Power from each klystron will be split into two equal parts by a high-power splitter and will feed two 4-m side-coupled accelerator structures. High-power phase shifters will also be provided in the waveguide system. The VKS-8270 klystron was designed about 10 years ago for use in the NASA satellite program. Only a few tubes (~10) have been built, so their lifetime is uncertain. NBS has discussed this with Varian and is counting on a lifetime of 10,000 hours; this would require that each tube be replaced about every 2-1/2 years.

If the 200-MeV RTM-1 program is to meet the goal of starting physics research by July, 1985, some additional funding will be necessary to supplement NBS-provided manpower. It is estimated that an additional 7 man-years of design/engineering effort will be needed in FY1984 to ensure that the research equipment is ready to go when the beam is available.

IV-C.4.4 Conventional Facilities

The 15-200 MeV program with RTM-1 will be carried out in three existing experimental areas. Building modifications and additions to permit three low-energy experiments to take place simultaneously are estimated to cost \$48 K, including contingency and EDIA.

The high-energy program (200-1000 MeV) will require a new building to house RTM-2 and two new experimental areas and associated data collection rooms. These will be built adjacent to the present laboratory at an estimated cost of \$14,022 K, including contingency and EDIA. Together, these additions will permit five experimental programs to be run simultaneously (three electron scattering and two tagged-photon experiments).

The new reinforced concrete building is approximately rectangular, with one side attached to the existing accelerator wing. Its lower floor is 34 ft below ground level. The total floor area of the addition is approximately 35,000 ft².

Modifications associated with the 200-MeV program include installation of new beam lines and rearrangement of shielding walls to create Measurement Room 3 at the site of the present linac injector. The 1000-MeV program also requires structural changes to the present building to improve utility access, to install a new fire-suppression system, to improve equipment-handling capability, and to relocate the present RTM klystron power supply.

IV-C.4.5 Special Situations

NBS would provide manpower for the construction project having a value of \$2415 K in Phase 1 (200 MeV) and \$2645 K in Phase 2 (1000 MeV). In addition, NBS would make a direct contribution of \$830 K during Phase 1 for beam transport and building modifications to bring the 200-MeV beam from the accelerator to three existing experimental areas. During Phase 2, NBS would make a direct contribution of \$2010 K for modifications of the existing building, installation of 200-MeV beam lines, removal of the old NBS linac, and site preparation for the new building.

Existing structures and facilities that would benefit the new program include: the 200-MeV RTM-1, the building that houses it, and the associated experimental areas; existing beam transport magnets, power supplies, and vacuum systems; existing experimental apparatus, such as the NBS electron scattering spectrometer; and general campus facilities, such as the library, cooling tower, central computer, grounds and access roads, cafeteria, electric power substation, and machine shops. Replacement costs for these structures and facilities are estimated to exceed \$27 M.

NBS would contribute \$2210 K (62%) of the RTM-1 operating costs and \$4290 K (47%) of the RTM-1+2 operating costs. The indirect budget includes the cost of electricity and other utilities based on NBS-wide averages. Although the new microtron facility would clearly use more than its share of electricity, NBS management has agreed that the project will not be charged for the "excess" usage.

IV-C.4.6 Capability Assessment

At the present time, the National Bureau of Standards plans to complete construction of a 200-MeV RTM. They then propose to construct related experimental hardware for this RTM, a cascaded 1-GeV RTM, and additional experimental facilities for use at the 1-GeV electron beam energy. The 200-MeV RTM now under construction is a modest extrapolation from existing racetrack microtron technology (the 175-MeV RTM at Mainz is in an advanced stage of being commissioned), although it makes use of a somewhat higher gradient (1.5 MV/m) standing-wave accelerator structure. Development of the CW rf structure is being carried out in collaboration with LANL, and full-power tests of a side-coupled accelerator structure section have been successful. Consequently, no particular design problems are in evidence for the injector microtron.

The 1-GeV RTM is a scaled-up design from the RTM-1 device, with a larger number of traversals (87 instead of 16). The threshold current for regenerative beam breakup has been calculated to be about 40% above that for the RTM-1 accelerator that will serve as its injector. With earlier completion of the injector unit, regenerative beam-breakup-threshold studies will be carried out, the results of which will be used to guide the choice of final tune for RTM-2. Consequently, RTM-2 is expected to operate well below the beam-breakup threshold. With construction approval anticipated by January 1, 1985, and continuation of the present R&D effort, this project will be ready for construction from a technical point of view.

An explicit management structure for this project has not yet been provided by NBS. Although the present personnel are very experienced, we would consider it prudent to add some senior staff to enhance the depth of project direction.

NBS has proposed that an external organization (i.e., not directly under NBS) be formed, and supported by DOE/NSF, to provide user support services. Properly set up, such an organization could provide effective user support and might add to the flexibility of the support structure. It would be important, of course that NBS shop facilities be made available to users for experimental support.

The 4.5-year projected construction period appears reasonable. We would expect NBS to be ready to begin construction by January 1, 1985. The availability of support facilities and staging areas for accelerator and experimental hardware assembly is an asset for construction. Planned manpower over the duration of the construction period appears to be well projected.

IV-C.5 Southeastern Universities Research Association

IV-C.5.1 Concept and Theoretical Analysis

The Southeastern Universities Research Association (SURA) proposes a linac and single-pass recirculator/beam-stretcher ring system. The linac is to be a 2-GeV pulsed machine with single-pass head-to-tail recirculation; it would produce a 4-GeV beam having a pulse length and intensity that allow single-turn injection into the stretcher ring. The charge stored in the ring -- extracted uniformly during the time interval before the next injection cycle -- would result in a beam current of 240 μ A (design specifications) with a duty cycle of about 90%. Characteristics of the proposed machine are summarized in Table IV-B-4.

The ring and injector designs are well matched to their purpose. Schemes for injection and extraction are probably as good as can be proposed now, considering the present state of the art. Extensive particle dynamics calculations have been carried out for the linac, recirculator, and stretcher ring and give confidence in the basic design. However, no component design or modeling has yet been done. Before construction can begin, much R&D must be carried out on critical items, such as the ring accelerating cavities, injection and extraction hardware, magnetic elements, control systems, and vacuum systems.

A more serious problem is the lack of an existing klystron that meets the average power demands of the linac operating at its design specifications in energy, current, and duty cycle. Professional opinion is divided as to the time it would take to develop such a klystron. This uncertainty requires that the performance of the system be downgraded to 120 μ A until the design and testing of an appropriate klystron are accomplished.

As pointed out earlier, slow extraction has been a standard procedure at proton accelerators for some time; however, the relevant beam-spill times have so far been measured in seconds rather than milliseconds, as is proposed here. A sophisticated spill-control system must be developed.

Most of the known instabilities that occur in high-current electron storage rings have been considered and found to be tolerable. However, coherent longitudinal coupled-bunch instabilities are expected to be present because the beam is to be injected in highly compressed bunches. Present theory is not capable of predicting precisely the probability of severity of such instabilities. In some storage rings these instabilities constitute an intensity limit; in others they do not. It should be kept in mind that no electron storage ring has achieved the very high injection efficiency or the very large circulating beam specified here. Transverse deflecting modes in the accelerating cavities have not been studied, because the cavities are as yet undefined.

None of the above problems will keep the machine from working, but they may well delay the system from achieving its beam-intensity design goal. Substantial R&D in these areas remains to be done.

The design utilizes a number of parts that either have been tested or are being tested at other laboratories. The SURA group will profit from this work if they are able to put all of these parts together and make them work as a unit. They are trying to push the state of the art in some areas. SURA has some excellent and enthusiastic accelerator physicists who keep in contact with their colleagues around the world. At the present, however, little in-house engineering or technical help is available to them.

The probability of reaching the full design capabilities of the accelerator at turn-on is uncertain. However, the probability of success at reduced capabilities (200 μ A at 1 GeV, 100 μ A at 4 GeV) is quite high, assuming that SURA can augment its staff with high-quality personnel.

An electron pulse-stretcher prototype has been built at Sendai, Japan (SSTR), but significant differences between the SURA and SSTR designs make it difficult to use SSTR results to predict the actual performance of the SURA machine. Most of the design differences incorporated into the SURA proposal are to alleviate problems found by SSTR, such as injection losses and coupling resonances crossed by the beam.

Theoretical calculations for the SURA design are well-advanced. This group has spent more than four years performing the calculations, in consultation with many accelerator physicists around the world.

IV-C.5.2 Prior R&D Assessment, Technical

The SURA construction-related R&D amounts to \$10.1 M for the 4-GeV project. This amount corresponds to 7.4% of the construction budget. The Commonwealth of Virginia and the SURA universities have promised to provide \$6,460 K of R&D funds. Particular aspects of R&D to be covered include:

Klystron development

High-duty-cycle modulator development

Beam breakup in the linac (note that the specified intensity is four times that at SLAC)

High-repetition-rate, fast-injection kickers

Stretcher-ring design (including internal target options)

Stretcher-ring cavity development (including parasitic mode studies)

Stretcher-ring beam instabilities

Resonant extraction studies (including extraction efficiency, time structure, and tolerances)

Extracted-beam parameter studies (including emittance, momentum spread, and stochastic emittance growth due to synchrotron radiation)

IV-C.5.3 Technical Components

SURA proposes to use 40 SLAC-type accelerator sections for its linac structure. Each of these sections is 3.05 m long and is of the traveling-wave, constant-gradient type with an attenuation parameter $\tau = 0.57$ Np and an operating frequency of 2.856 GHz. Parameters for the system are given in Table IV-B-5. The value of τ for the structure may need to be further optimized, because SURA plans to use higher beam currents and higher rf power per unit length than SLAC currently uses. This optimization may lead to the adoption of a somewhat lower value of τ . Other types of structures, including standing-wave structures, will also be studied before the final design is selected. Other important parameters of the present SLAC structure are: a shunt impedance of 57 M Ω /m; a Q of 13,200; and a filling time of 0.83 μ sec.

Each of the 40 accelerator sections will be supplied with power by a 40-MW (peak) klystron designed to operate at a pulse length of 3.2 μ sec and a pulse repetition rate of 1 kHz. The resulting duty cycle (0.32%) is 3.2 times that of the present SLAC klystron. This matter has been discussed with klystron experts at other laboratories and in indus-

The major conventional facility items are: accelerator housings; beam switchyard housing; end station A, counting house, and beam dump; end station B, counting house, and beam dump; tagged-photon end station and counting house; access and fan buildings; accelerator control building; support facilities; AC power and distribution system; facility cooling system; and site preparation.

Cost estimates for the above items contain the following factors:

Contractor job and bid contingency	15%
EDIA	10%
Overhead and profit	15%
Contingency	15%

Building and facility construction costs were compiled by the firm of Hayes, Seay , Mattern and Mattern, which has considerable experience in planning large structures in the Southeast, including tunnels and subway systems.

The item "support facilities" mentioned above in the listing of conventional facilities covers the cost of rehabilitation work in the two large buildings that have been made available to SURA. These buildings are the Virginia Associated Research Center (VARC) and the Space Radiation Effects Laboratory (SREL).

IV-C.5.5 Special Situations

SURA appointed a site committee to evaluate six sites for the proposed accelerator facility. The SURA Board of Trustees reviewed the committee's report and selected the Newport News, Virginia, site, primarily because of the availability at that site of the VARC and SREL buildings.

The VARC building (35,000 ft²) contains offices, laboratories, classrooms, a machine shop, a technical library, a cafeteria, an electronics shop, and storage areas. The SREL building (70,000 ft² floor area) consists of a 130 x 300 x 49-ft-tall high-bay area and a two-story support area. The latter includes offices, conference rooms, laboratories, electrical and mechanical equipment rooms, refrigeration and pump rooms, and a control room with raised computer flooring. The value of these facilities to the proposed laboratory has been estimated as \$10.2 M, including \$1.0 M for the existing library.

Land for the proposed laboratory (150 acres), including space for future expansion, will be made available by the City of Newport News. The value of the land is estimated to be \$0.3 M.

A proposal has been made to the Commonwealth of Virginia for direct support of senior staff positions in the proposed laboratory in the following amounts:

Period	Amount (K\$)
1983/84	160
1984/85	332
1985/86	569

The Governor of Virginia has recommended (and the Legislature has approved) \$160 K for this purpose in his budget for 1983/84.

During the period 1980-1982, the 23 SURA universities have contributed approximately \$600 K in direct and indirect costs toward the development of the National Electron Accelerator Laboratory proposal and the organization of SURA. Continued support of 17 SURA faculty members who will participate in the accelerator and equipment design has also been pledged by the SURA universities.

IV-C.5.6 Capability Assessment

SURA has proposed the construction of the accelerator at the Newport News site formerly occupied by SREL. Except for the impressively large cyclotron building and the VARC laboratory building, this is in essence a "green site" requiring not only the construction of a National Electron Accelerator Laboratory but also a broad spectrum of related facilities that constitute the standard major laboratory infrastructure.

The SURA consortium has brought together a group of collaborators who produced a very substantial design study for the 4-GeV linac/stretcher ring machine. This group has benefited from interactions with respected accelerator scientists elsewhere and has worked closely with the Stanford Linear Accelerator Center.

Present staff members are bright and enthusiastic but have limited experience in accelerator design and construction; they need to be strongly reinforced by professionals from other laboratories if this project is approved.

As mentioned previously, a number of technical issues require further attention. These are not crucial design issues, and most could be resolved with adequate R&D effort before construction begins. However, the current absence of adequate engineering support will limit the pace of the R & D.

The klystrons used for the design of the linear accelerator do not exist, and an unrealistically short development time has been assumed by the SURA group for their production. For this reason, it should be assumed that construction will commence using klystrons with an average power capability (46 kW) equal to that of the SLAC klystrons. The machine would then gradually be upgraded by the subsequent replacement of these klystrons with newly developed, higher-average-power klystrons.

The consequent parameters of the linac/stretcher ring are then as follows:

Parameter	Value	
	Phase 1A	Phase 1B
Linac repetition rate	360 Hz	1000 Hz
Maximum beam energy	4 GeV	4 GeV
Peak intensity	278 mA	200 mA
Average intensity	120 A	240 A
Average klystron power	46 kW	128 kW

This approach constitutes an acceptable and sensible phasing of the construction, eliminating potentially serious delays and permitting the eventual achievement of the original design parameters at acceptable cost.

Essential to the linear accelerator system is early development work on the high-duty-cycle modulators. Beam breakup in the linear accelerator structure should also be of concern, because the maximum beam current in the linac is four times that at SLAC. On the other hand, even with the double-pass design, the effective accelerator length is only 10% of that of SLAC, and the beam pulse length is 75% as long as that at SLAC.

The basic stretcher-ring design is in hand, and its structure has been optimized for fast single-turn injection in vertical-acceptance phase space and slow half-integral resonant extraction from the horizontal phase space. Both modes of beam manipulation are established techniques for proton machines.

It is desirable that computer simulation studies be carried out on the resonant extraction process with relevant component "noise" spectra, in order to optimize extraction efficiency and beam time structure and minimize sensitivity to resonant-growth-driving-term errors. These studies should be done before finalizing the detailed structure of the lattice and the overall resonant-extraction component distribution around the stretcher ring. It is a distinct advantage that extraction takes place from a zero-dispersion straight section of the stretcher-ring lattice, thereby eliminating time-dependent phase space migration of the extracted beam.

The possible beam instabilities that could prevent the stretcher ring from reaching its design intensity were comprehensively assessed. It was correctly realized that the transverse instability due to the high-Q rf cavity could limit the beam current. The required damping of the parasitic modes of the rf cavity by a factor of several thousand is not necessarily straightforward, and early R&D work on the cavity is essential. Furthermore, the longitudinal coupled-bunch instability should be of concern; this could be driven either by the impedance spectrum of the distributed ring elements or, more likely, by the narrowband parasitic impedance spectrum of the rf accelerating cavity. Again, early development work on the rf cavity is needed, and an analysis to assess beam-instability thresholds with a measured rf-cavity "damped" impedance spectrum will be desirable in due time.

Further analytical work is also required to determine the extracted beam parameters (ϵ , $\Delta p/p$) that result from the half integer resonant extraction process, taking into account the stochastic growth of the beam due to quantized synchrotron radiation emission.

With the assumption that the facility is initially downgraded in intensity to the 120- μ A level (Phase 1A), there are no crucial design issues that should either prevent a normal transition from preconstruction R&D work to Construction Title I design work by January 1, 1985, or, from a technical point of view, prevent the project from reaching its design goals in due time. A crucial issue at present, however, is the lack of adequate staff to carry forward a vigorous R&D and construction program.

The stated duration of construction is 4 years. However, there is no adequate allowance in the detailed construction schedule for a buildup of staff and support structure. Therefore, a construction schedule of 4-1/2 years should be assumed.

Construction management is not in place at this time. The SURA consortium is in the process of attracting senior project management and is ready to appoint a project director upon approval of the project. The success of the present proposal will indeed depend critically on the choice of this person and his ability to attract a core group of experienced accelerator scientists and engineers.

V - RECOMMENDATIONS:

As noted previously, and in agreement with the Barnes Subcommittee, the Panel recommends that the highest priority for new accelerator facilities in the electromagnetic field be accorded to one having a maximum energy of at least 4 GeV and high duty factor.

V-A - Argonne and SURA

That being the case, we begin our detailed discussion of our recommendations by considering the two fully developed proposals for such facilities before us, namely, those from the Argonne National Laboratory and from the Southeastern Universities Research Association.

It is a measure of the strength of the electromagnetic physics community in this country that two quite different proposals of this scope, magnitude and quality are available for consideration. The decision between them has been a difficult one. The Technical Subpanel, after a very careful, independent analysis of both designs -- as discussed in Section IV above -- has concluded that both designs are feasible ones and that either could very well form the basis for an extremely powerful national facility. In the Subpanel's considered opinion both designs fall short of the originally proposed specifications -- that from Argonne in terms of maximum achievable energy and that from SURA in terms of maximum achievable current. Other questions have been raised concerning both designs in Section IV, but it is the opinion of the Panel that given the normal duration of pre-construction time and the normal R & D that would be expected to continue, in parallel with construction, these can be resolved satisfactorily.

Our decision between the two proposals then depends upon the relative weightings that we ascribe to the different problems facing the two groups of accelerator designers and to other considerations quite apart from these technical ones.

The fact that the SURA group has pulled together the SURA consortium of over twenty universities and that these in turn have pledged five new Tenure Commonwealth professorships, 25 new tenured or tenure-track experimental nuclear physics faculty positions and at least 5 new tenured or tenure-track theoretical nuclear physics faculty positions, should their proposal be approved, has weighed substantially in their favor. Such a combination of collaborating universities and new permanent positions in nuclear physics constitutes a very substantial increment to the total U.S. university involvement in nuclear physics and goes a long way toward providing assurance that there will be the continuing flow of active young scientists required to exploit fully the kind of major new facility that we discuss herein. In the case of Argonne, the University of Chicago has pledged to add two new tenured appointments in nuclear physics to its Physics Department and to arrange adjunct appointments for a number of the permanent staff at Argonne in both nuclear physics and nuclear chemistry in the corresponding university departments.

Important, also, has been the recognition that the SURA design could readily be extended in energy to 6 GeV, or above, should the physics encountered in this new region make such an extension desirable, while the ANL design could not. Although we cannot, with any degree of certainty, tell at this time how important or necessary the higher energies may be, experience has taught us that the option of obtaining them should not be given up lightly. Moreover, we have noted that having constructed the injector for

the 4 GeV stretcher ring, the SURA group would have already available an ideal injector for a 1 GeV or smaller ring which could be added to the facility, at something resembling the cost of a single experiment, to provide CW beams simultaneously in the lower energy range should the national program in electromagnetic physics eventually require it.

And, thirdly, although the Panel has not been unanimous on this point, there is a strong majority belief that the SURA design is a more conservative one once it is agreed, from the outset, to downrate the beam current specifications to more nearly meet present klystron power capabilities. Target beam power limitations convince us that such downrating, at least initially, will not compromise the experimental programs. A number of the Technical Subpanel members still hold significant reservations about the potential beam loss in the ANL accelerator from beam centering errors and quantum fluctuation phenomena at the higher energies as well as about the geometric stability of the large dipoles and other accelerator components to the accuracy required for successful long term operation.

With these, and a large number of lesser considerations in mind the Panel then **recommends:**

That the proposal of the Southeastern Universities Research Association (SURA) for the construction of a linac — stretcher ring accelerator system capable of providing high duty factor beams throughout the energy range from 0.5–4.0 GeV be accepted and that this facility be constructed and designated the National Electron Accelerator Laboratory (NEAL).

Obviously it is a matter of substantial concern that the SURA group has neither the management nor the accelerator construction teams in place nor, realistically, would it have been possible to expect this prior to a decision on their proposal. The Panel is convinced, however, that the ultimate success of this venture depends critically upon the selection and attraction of a strong, dynamic Director at the earliest possible time and the establishment of an accelerator construction team drawn from among the world's most able practitioners. We consider the SURA decision to utilize the five Commonwealth Professorships in attracting the Director and four senior accelerator scientists to be a very wise one.

If this new Laboratory is to fulfill its proper function in the national nuclear physics enterprise, it is essential that its operation and management be truly national in scope and that it draw upon the entire community both for planning and execution of its program. That being so, and because the Panel considers it mandatory that SURA involve the entire community formally and as soon as possible, it **recommends**

That SURA management, in consultation with DOE and NSF, appoint a National Advisory Board (NAB) as soon as possible and that the members of this Board be engaged in all major decisions affecting the structure and future of the National Electron Accelerator Laboratory.

And both because we believe that it is essential to involve the community as soon as possible and because we believe that the SURA group will need detailed assistance from this community in the development, in timely fashion, of experimental facilities for use with the accelerator complex, the Panel further **recommends**

That very soon after formal approval of NEAL, its management, with the advice of its National Advisory Board, announce a formal solicitation of experimental proposals and the creation of a Program Advisory Committee (PAC).

Our reason for what may seem a somewhat premature recommendation is that our experience suggests that external user groups are much more apt to become actively involved in , and take responsibility for, the construction of major pieces or systems of research equipment if they have been formally assured of their subsequent place in the scheduling to use this equipment. Although the tradition of user design and construction of such major equipment is much more highly developed in elementary particle physics there is a rapidly growing number of examples in nuclear physics as well e.g. the spin spectrometer at HHIRF, the 180° spectrometer at Bates, the HRS and EPICS spectrometer systems at LAMPF, etc. As is common practice in particle physics and in these examples in nuclear physics, the Panel believes that the optimum arrangements involve subcontracting via the host Laboratory (here NEAL) rather than direct independent funding of the user groups by the funding agencies.

It also bears emphasis that included in the DOE FY1984 Congressional Budget Request is the new electron source, planned by Arnold *et al.* of American University, for installation at the Stanford Linear Accelerator Center (SLAC) specifically with the intent of making that facility available for nuclear physics research for a fraction of its time — currently estimated at about one month per year. While we recognize that time for nuclear physics research on the SLAC facility will always be severely limited, and in competition with elementary particle physics utilization, we nonetheless **recommend:**

That potential users of NEAL be encouraged to develop proposals for utilization of SLAC for consideration by the appropriate Program Advisory Committee, and that DOE/NSF give high priority to provision of the necessary support for those experiments that are accepted, in order that a significantly larger fraction of the U.S. electromagnetic physics community gain access to, and experience from, experimental studies with higher energy electron beams that have hitherto been available to it.

We have addressed, in preliminary fashion, the experimental equipment requirements ancillary to a facility such as NEAL in Appendix VII-A to this report.

Finally, because the Panel believes that convenient access is of major importance to a national facility that will be as unique as NEAL, because it also believes that there are significant advantages in terms of general intellectual ambience, cultural activities, access to libraries and laboratories in widely diverse fields, possible joint use (perhaps even only initially) of facilities and services such as purchasing, personnel, security, health etc, at a site in the vicinity of a major university, and because it understands that the SURA Board was far from unanimous in its selection of the Newport News site proposed for NEAL, it **recommends**

That SURA and NEAL management consider the possible advantages of relocating NEAL to provide improved access to one or more major university campuses and to one or

more major airports, providing that this can be accomplished without significant increase in the total project cost.

Having made these recommendations it is obvious that the Panel does **not** recommend construction of the proposed GEM facility at Argonne. But the Panel wishes to take this opportunity to comment on the excellence of the ANL proposal. The Hexatron is an imaginative new development in accelerator technology and ANL's proposed use of its surplus ZGS facilities to permit a cost-effective proposal is exemplary. Argonne has a very dedicated, able group of scientists and engineers already in place and these, together with the presence of established management and support structures were factors that strongly favored Argonne.

V-B. - University of Illinois

The University of Illinois has a long and very distinguished tradition in electromagnetic physics and an enviable reputation for the education of leaders in this field. It has suffered a grievous loss in the death of one of its leading physicists, Peter Axel, but is fortunate in having a dynamic group of young researchers led by Larry Cardman that is more than capable of carrying forward the Illinois tradition.

The Panel was much impressed by the proposal prepared by the Illinois group and the presentation of it. We have no doubt that the Illinois group, given their performance in recent years, could, if given the opportunity, move expeditiously to produce the facility that they have proposed.

It is thus with regret that the Panel has concluded that it is **not** possible within a coherent overall national plan for nuclear physics — or indeed for electromagnetic physics — to move forward to the construction of a facility of national scope at the University of Illinois given our decision, above, to recommend construction of the SURA 0.5-4.0 GeV facility.

At the same time, the Panel considers it of great importance that the University of Illinois continue its tradition of excellence in both research and education in this field. To that end we are delighted to learn of the NSF decision, already in place, to fund Illinois for acquisition of microtron dipole end magnets identical to those under construction for the NBS/LANL 200 MeV machine at NBS. This presently approved upgrading of the Illinois facilities, possibly with the further substitution of room temperature linac cavities for the superconducting ones now in use, could result in a CW facility with energies up to a few hundred MeV which could support a very rich spectrum of experimental activities. The Panel, of course, also anticipates that the Illinois group will include very active exploitation of the higher energy SURA facility in their longer range plans.

V-C - Massachusetts Institute of Technology

For more than the past decade, the Bates Laboratory at MIT has been one of the major world centers for electromagnetic physics. This has reflected a unique combination of dedicated, skilled experimentalists who, perhaps more than any others, have demonstrated the potential of truly high resolution measurements with electrons and of equally dedicated, skilled nuclear theorists who have been interested in the electromagnetic physics in detail while ranging broadly over much of theoretical physics.

The Panel considers it essential that this tradition be maintained. It is important not only that MIT experimentalists continue to do the kind of pioneering experiments in electromagnetic physics for which Bates has become justly world famous but also that the MIT theorists, who interact with a much broader national and international community, retain their active interest in, and input to, electromagnetic physics.

It was thus, with considerable disappointment that the Panel learned that the MIT group had not found it possible to carry through a detailed design for a 4 GeV system which would have been considered in parallel with those from Argonne and from SURA. As originally proposed to us, MIT had intended to engage in a phased approach first implementing its currently funded upgrading program to yield a maximum energy of ~ 840 MeV and higher reliability at low duty factor; then adding a stretcher ring to obtain high duty factor at this — or a slightly higher energy ~ 1 GeV; then moving up to 2-2.5 GeV and finally to 4 GeV. Only conceptual design work has been completed on the later stages of this progression.

Having decided that the time was ripe to move to 4 GeV and to recommend construction of the specific facility proposed by SURA, the Panel now concludes that it would **not** be desirable within the overall national program in nuclear physics for MIT — Bates to plan on significant increase in energy beyond its currently approved upgrading to ~ 840 MeV.

At the same time we recognize that the MIT planning for increase of the duty factor of their facility at this energy was understandably designed as an integral phase of a larger, more ambitious plan directed eventually to 4 GeV and is thus not necessarily optimized for CW operation at 840 MeV.

We would urge the MIT-Bates group, therefore, to complete their currently approved upgrading so that their present research program can be extended to the higher energies to be available and benefit from the higher reliability that the upgrading will provide.

We sense that the demands of the ongoing research program, the current upgrading, and the planning that went into the current proposal have overloaded the management and accelerator groups at Bates and would urge that, as a matter of high priority, these groups be strengthened. Given such internal strengthening, we believe that an optimized design for high duty factor operation of the Bates facility at its upgraded energy will emerge naturally in the course of a few years. We suspect that such an optimized design will be substantially less costly to build and to operate than that included as Phase I of the presently available proposal.

As noted at the outset of this section, MIT-Bates has been one of the leading world centers in electromagnetic physics for more than the past decade; the Panel believes that it has the potential to retain this role in the future. We believe, too, that MIT physicists can and should play important roles in the planning for, and execution of, the NEAL facility.

V.-D. - National Bureau of Standards

The National Bureau of Standards also has a record of accomplishment in electromagnetic physics, over several decades, of which it can be justly proud; included among its achievements is the education of a large number of leading scientists in the field.

Through the currently-in-place, DOE-funded, cooperative program between NBS and LANL, very important contributions have been, and continue to be, made to the technology of electron accelerators. The 200 MeV CW microtron facility has provided, and will continue to provide, an important test bed for new ideas in this area.

Given the continuing and strengthened activities at both MIT and the University of Illinois, and its decision to recommend construction of the SURF 0.5-4.0 GeV facility, the Panel does **not** recommend expansion of the NBS facility to 1 GeV as proposed. Rather the Panel strongly encourages the Department of Commerce to continue to operate the 200 MeV facility as it has NBS facilities in the past, welcoming collaborators from the external scientific community involved in experimental programs with NBS staff. We see it as entirely reasonable that such collaborators, as in the past, would request support for their collaborative activities from NSF or DOE but we do not recommend the establishment of formal mechanisms whereby NSF/DOE would support general user activity through NBS nor do we recommend NSF/DOE provision of major research instrumentation at NBS except insofar as this may evolve naturally as a component of some ongoing collaborative research program.

VI ACKNOWLEDGEMENTS

The Panel wishes to express its appreciation to the many people who have worked long and hard to develop such excellent proposals for new facilities for new electromagnetic physics. In particular, we wish to express our special thanks to Larry Cardman, Peter Demos, Harry Holmgren, Harold Jackson and Sam Penner, the spokesmen for the five proposing groups, for the patience and good humor they have managed to retain in the face of repeated questions, questionnaires, visits, requests for data and the like; they have made our task much easier.

G.E. Brown met with the Panel, at its invitation, on one occasion for discussions of aspects of electromagnetic physics and we are much indebted to him, as we are to all those who have forwarded unsolicited comments and suggestions during the Panel's deliberations.

We would also wish to express our appreciation to Jim Leiss, Enloe Ritter, Bill Rodney and Harvey Willard who, on behalf of the sponsoring agencies, spent long hours with us and provided us with a wealth of fact and insight. Special thanks go to John Erskine who has performed yeoman service in coordinating all Panel activities and in producing its report on an almost impossible schedule.

And, finally, the Panel Chairman, on behalf of his fellow Panel members, wishes to take this occasion to express a special note of thanks to the Technical Subpanel and its Chairman who have spent an enormous amount of time and effort in developing the complete and detailed technical understanding of the five proposed accelerator systems without which the Panel simply could not have functioned responsibly.

VII. APPENDIX

VII-A. EXPERIMENTAL EQUIPMENT AND USER ASPECTS

VII-A1 General Comments

The clarity with which the proposed facility reveals new phenomena will depend as much on the quality and adequacy of the experimental equipment as on the capabilities of the accelerator itself. It is essential that substantial funding be provided for the equipment to carry out the broad-ranging experimental program addressed by this facility. It is also clear that a substantial effort -- involving all prospective users of these facilities -- will be required to determine the optimum mix and design of the experimental facilities.

For all of the proposals considered here, planning for experimental equipment is less advanced than that for the accelerators themselves. In the main, plans have been carried only far enough to fix the scale and/or layout of experimental areas so they could be reasonably costed. At best, conceptual designs are available; in many cases cost estimates are based on a simple, sometimes large, scaling or earlier designs. Nor are the specified arrays of equipment generally complete, except possibly those for the 1000 MeV facility proposed by the National Bureau of Standards.

This approach can be understood and defended. We are truly entering a new realm of experimentation with energy and beam power increased by a factor of ten and duty cycle by a factor of one hundred. It would be surprising if we could anticipate all of our experimental needs in detail. Furthermore, straightforward extrapolation of earlier spectrometer designs will not necessarily be cost-effective; yet there are no working superconducting spectrometers appropriate to the needs of the proposed research. Nor does one have sufficient experience with large solid angle (4π) photon detectors in this energy range to attempt a cost-effective design.

Nevertheless, it is necessary to have an estimate of total equipment costs, at least through the first five years of operation, so that it is possible to assess rationally the probably cost of the project and its impact on our overall scientific effort. Implicit in this remark is the realization that total equipment costs will be a substantial fraction of the overall cost of the facility.

Although it is difficult to make a detailed estimate at this time, a first approximation has been obtained by combining large items from the various proposals: this yields (see Table A-1) an estimate of \$35 M. About one-half to two thirds of this amount should be expended within one year of the completion date of the accelerator, and the remainder during the next three to five years. Substantial uncertainties in the estimate involve the questions of the need to build a high-resolution coincidence-pair spectrometer (included here) or a storage ring for internal target studies (not included), as well as questions relating to the design and cost of 4π detectors. The resolution of these questions and the refinement of the estimates necessarily awaits a final decision on the part of the funding agencies.

The Panel emphasizes again the importance of providing adequate experimental equipment funds early in the project so that the essential research and development work can be completed in a timely fashion. Equally crucial is the early formation of a strong user group to involve the national nuclear physics community in the design and construction of this equipment.

Table A-1

**BASIS OF EQUIPMENT COST ESTIMATE
(for a 4 GeV research program)**

Experiment types: High resolution
 Moderate resolution
 Moderate resolution/photon monochromator

Equipment Item	Total Cost (M\$)
(1) Computers (on-line and analysis)	1.3
a) VAX 11/750 (4) = 1.0	
b) VAX 11/780 (1) = 0.3	
(2) Spectrometers	25.7
a) Photon monochromator	1.6
b) High-resolution spectrometer pair	7.0
c) Moderate-resolution spectrometer pair (2)	6.8
d) Cryogenics	1.9
	<u>17.3</u>
EDIA + contingency (at 49%)	8.4
(3) Targets	1.0
(4) Polarized targets and recoil polarimeters	2.0
(5) Miscellaneous detectors	1.0
(6) 4π detector(s)	3.0
(7) Electronics	<u>1.0</u>
TOTAL	35.0

In the remainder of this appendix we will summarize briefly the experimental equipment requested by those groups submitting proposals for a high duty cycle, high energy electron accelerator. Where relevant, we will also comment here on the means of dealing with users suggested by each facility.

VII-A.2 Argonne National Laboratory

Argonne has proposed a capital equipment construction budget of \$21.4 M to outfit the three target areas that receive concurrent beams of independently controlled energy and intensity. Each target area is approximately 24 m in diameter. The experimental equipment consists of a photon monochromator, a high-resolution spectrometer pair, a moderate-resolution spectrometer pair, associated cryogenic facilities, and three data acquisition computers of the VAX 11/750 class. Main characteristics of the spectrometers are summarized below:

SPECTROMETER	p^{\max} (GeV/c)	$\Delta p/p$	$\delta p/p$	Ω (msr)
High Resolution Spectrometer A	1.9	10^{-5}	+5%	> 20
High Resolution Spectrometer B	1.1	10^{-4}	$\pm 10\%$	> 30
Moderate Resolution Spectrometer A	4.0	10^{-3}	$\pm 10\%$	30
Moderate Resolution Spectrometer B	2.0	10^{-3}	$\pm 10\%$	30

The Enge split-pole magnet concept would be used for the photon monochromator to provide tagged photons with an energy resolution of $\Delta E/E \leq 1.5-5.0 \times 10^{-4}$ without dispersion matching. A superconducting dipole will be used to bend the emerging electron beam into a below-grade beam dump. The distance between radiator and target is 8.0 meters and the photon beam spot on target is ≤ 1.0 cm, FWHM. A moderate resolution spectrometer pair can be used in conjunction with the monochromator.

The Panel concludes that costs for the spectrometers have been estimated carefully, and that considerable thought has been given to their general characteristics. However, no ancillary experimental equipment is requested in the proposal. Argonne expects that items such as cryogenic and other special purpose targets, very large γ , π^0 and neutron detectors, focal plane detectors, Cerenkov detectors, polarized sources, etc., will be provided by users.

The proposed Hexatron facility offers a user-friendly environment. A Program Advisory Committee with a national membership would review proposals and provide rankings and recommendations for scheduling; in addition, a visiting committee would be formed to review annually the facility operations. Argonne has considerable experience in operating user facilities, such as those associated with the ZGS, and has developed a detailed infrastructure for this purpose.

Extensive shop facilities exist at Argonne, and the operating budget allocates \$875 K for support of 25 experiments annually (\$35 K each). In addition, the proposed operating budget would provide 19 engineering and technical staff people for experimental support. At present, there are relatively few experimentalists on the Argonne staff conducting research in electromagnetic physics, so that the in-house impetus for equipment development must come primarily from researchers with various other backgrounds. Argonne staff members have considerable experience with large magnetic spectrometers, however, which will be invaluable.

Argonne management has stated its intention to reprogram its current LAMPF effort toward the Hexatron, and to add personnel to achieve an in-house complement of 19 experimentalists working at the facility. These 19 scientists would be funded by a separate DOE medium energy physics contract, but would be available for consultation and assistance to outside users of the facility.

VII-A.3 University of Illinois

The experimental equipment listed in the Illinois proposal includes two magnetic spectrometers and photon facilities, with a total cost of \sim \$5.4 M.

In detail, the proposal discusses a 750 MeV/c spectrometer to be used mainly for the detection of scattered electrons. With a 30 msr solid angle and $\pm 10\%$ momentum

acceptance, this spectrometer is expected to yield a momentum resolution of $2-5 \times 10^{-4}$. For the detection of pions, a large aperture pion spectrometer is proposed. This QQD spectrometer is intended as a flexible device that can be transported to the pivot when it is needed as coincidence detector. The QQD configuration chosen is expected to give a 10 msr solid angle momentum acceptance of $\pm 15\%$ and a 5.3 m flightpath. Tracing the detected pions through the spectrometer by software analysis should permit a momentum resolution of $\pm 0.5\%$.

For the production of photons, both a tagged photon facility using a split-pole spectrometer and an untagged bremsstrahlung facility are proposed. The former aims at a $\pm 40\%$ momentum bite for the tagging electrons, and an intrinsic resolution of 2×10^{-4} . This facility, when employed using off-axis production of photons, is expected to produce gamma radiation of appreciable (50%) polarization.

For the detection of photons and neutral pions, a spectrometer of two NaI(Tl) detectors (9" x 12") is proposed. This pair of crystals is expected to yield an energy resolution of 2-5 MeV, depending on π^0 energy, and a fairly large (2msr) solid angle.

Extensive experimental equipment, which is already in use in conjunction with the lower energy facility now at Illinois, will be available for the detection of photons and giant resonance decay products. Two large data acquisition computers and an extensive pool of nuclear electronics are also available.

The Illinois laboratory is now primarily a university oriented research facility. Provisions have been made for the use of the new accelerator by a diverse community of outside users, in a way similar to what now occurs at IUCF. The strong tradition of electromagnetic physics research at Illinois represents a definite asset to the development of new apparatus and research programs.

VII-A.4 Massachusetts Institute of Technology - Bates Laboratory

For phase II the Bates proposal discusses experimental equipment, including three magnetic spectrometers, amounting to $\sim \$19$ M. These spectrometers are proposed as an addition to the high resolution spectrometer ELSSY and the medium resolution spectrometers MEPS, OHIPS, and BIGBITE and related detectors and computers presently in use.

In detail, the spectrometers discussed include a spectrometer scaled up from the present BIGBITE, which would serve both as a spectrometer with large energy acceptance used in deep inelastic single arm experiments, and as one arm of a coincidence pair. For the investigation of $(e, e' X)$ coincidence experiments ($X=p, d, \alpha, \pi, K$) a pair of high resolution spectrometers is discussed. These spectrometers, apart from the higher maximum momentum, would be similar to the presently used spectrometer pair at NIKHEF.

SPECTROMETER DESIGN OBJECTIVES

SPECTROMETER	Pmax (GeV/c)	$\Delta p/p$	$\delta p/p$	Ω (msr)
Large acceptance (BIGBITE) QQD	2	5×10^{-3}	+12%	2-3
High resolution QDD	1	$< 1 \times 10^{-4}$	+1%	6
High resolution QDD	1	5×10^{-4}	+5%	17
K-spectrometer	2	2×10^{-4}	+5%	20

For use at 2 GeV, the photon tagging system now already in use would be upgraded by adding a second magnet. This system aims at an energy resolution of 1-2 MeV.

A second photon tagging system is planned using the high intensity electron beam circulating in the stretcher ring. A combination of quadrupole, ring dipole, septum magnet and two additional dipoles would permit the tagging of photons over a large energy range. For electron beam energies of 1-2 GeV, this system is expected to tag photons down to 10% of the circulating electron-beam energy, with an energy resolution of 2-3 MeV.

For (γ, K) and ($e, e' K$) experiments both good energy resolution and short flight path are desirable. As a state of the art spectrometer of this type, the Bates proposal discusses a 2 GeV/c spectrometer with 2×10^{-4} momentum resolution, 20 m flight path and 20 msr solid angle.

In addition, the Bates proposal includes for gamma radiation detection a 16" x 20" NaI(Tl) and a 30 cm x 30 cm BGO detector. A number of cryogenic targets as well as a polarized H source, the beam of which is to be used as internal target in the stretcher ring, are proposed. To run this equipment, a significant upgrade of the present computer facilities, by 3 PDP 11 and 2 VAX-type computers, is envisaged.

The Bates laboratory at present is a facility used approximately 50% by outside users. Beam time is allocated by the director based on recommendations of a Program Advisory Committee which currently has two-thirds of its members from outside the MIT community. Bates has developed considerable experience with the operation of a user facility and in providing outside users with the needed infrastructure. In addition, the expertise of the MIT group would greatly facilitate the development of new apparatus and the early startup of new programs.

With the proposed long-range expansion program of Bates, the laboratory intends to change its relation with the Laboratory for Nuclear Science and MIT, in order to become a more independent national facility. The overall performance of Bates will be monitored by the Dean of Science, who is assisted by a Policy Advisory Committee and a Management Advisory Committee. As the laboratory expands into a national user facility, the membership of the Policy Committee will evolve so as to assure that the interests of the user community are represented. The Program Advisory Committee will operate in the future in its present form.

VII-A.5 National Bureau of Standards

The National Bureau of Standards has proposed equipping its facility with a substantial array of experimental equipment having a total value of \$3.5 M for Phase 1

(RTM-1) and \$16.6 M for Phase 2 (RTM-2), or a total value of \$20.2 M. The proposed operating budget includes \$0.37 M/year (\$2.3 M/year) during Phase 1 (Phase 2) for modifying, improving and replacing equipment.

Phase 1 equipment, to be housed in three experimental areas, includes magnetic spectrometers (a photon-tagging facility; a large acceptance large solid angle QDD electron spectrometer of moderate resolution; a low energy, 43-137 MeV/c, general purpose spectrometer; a DD spectrometer with Ge detector; and a 180° scattering system); non-magnetic spectrometers (a BGO gamma-ray detector; π^0 spectrometers; and detectors for neutrons and charged particles including fission fragments); and three on-line minicomputer systems (PDP-11 type). For Phase 2, two more experimental areas will be constructed and furnished with additional equipment including magnetic spectrometers (a photon-tagging facility; a pair of QDD spectrometers for coincidence measurements with large solid angle and high resolution, $\Delta p/p=10^{-4}$; charged-pion and neutron detectors; forward-angle electron spectrometers; a beam swinger for out-of-plane measurements; and a magnetic 4π detector); non-magnetic spectrometers (mainly a BGO crystal ball covering about one-third of 4π ; two on-line minicomputer systems (PDP 11); and a minicomputer (VAX type) for data analysis.

The accelerator is to operate as a national user facility, with NBS reserving less than 20% of the total beam hours for a single 200 MeV beam line, corresponding to perhaps 5% of the capacity of the facility, for mission-oriented research.

All proposals for research in nuclear physics, including those of NBS staff, will be subject to peer review by a Program Advisory Committee (PAC) consisting of outside users and NBS personnel. User activities would be supported by a non-NBS organization, denoted for present purposes as User Services (US). User Services would be funded by DOE/NSF and might operate under the aegis of a university, consortium of universities or a management group of associated universities. The Director of US would be from outside the NBS and would be responsible for purchasing, hiring technical personnel, negotiating contracts, etc. Physicists and technicians would be available to provide liaison with users, and to provide detailed assistance with equipment. The Director of US, and the NBS Research Coordinator would appoint the PAC. The Research Coordinator would be responsible for outside user liaison activities and scheduling of beam time.

VII-A.6 Southeastern Universities Research Association

The table below lists the preliminary designs, costs and locations of the spectrometers requested in the SURA proposal. Costs for these total \$8.48 M. The high-resolution spectrometer is not part of the current proposal but is an anticipated future addition. Also requested in the initial experimental apparatus are counting equipment, \$1.3 M; electronics, \$1.35 M; and a computer, \$1.2 M, making a total request of \$12.33 M.

SPECTROMETER DESIGN OBJECTIVES

Spectrometer	<u>In Proposal</u>		<u>Future Addition</u>
	<u>Moderate Resolution Spectrometers</u>	<u>Large Acceptance Spectrometer</u>	<u>High Resolution Spectrometer</u>
Number	(2)	(1)	(1)
Maximum Momentum (GeV/c)	4.0	8.0	1.5
Momentum Acceptance (%)	10	5	4
Solid Angle (msr)	10-20	5	3
Range of Angular Rotation (degrees)	15-165	20-160	25-155
Resolution ($\Delta p/p$)	10^{-3}	10^{-3}	10^{-2}
Cost (M\$)	1.61 (ea.)	2.65	2.61
End Station	A, Tagged photon	B	B

The SURA consortium has emphasized that these spectrometer designs may change as they are reviewed by the future user community and has stated its intention to involve users closely in this effort. End station A may receive beam from either the linac or the pulse stretcher ring; as noted in the table it is anticipated to be the location of a moderate-resolution spectrometer and a future high-resolution spectrometer. End station B, which receives beam only from the stretcher ring, is expected to house a moderate-resolution and a low-resolution (large acceptance) pair suitable for coincidence experiments. The tagged-photon facility, adjacent to the stretcher ring, is planned to contain a moderate-resolution spectrometer.

A Program Advisory Committee with broad national and international membership would review requests for laboratory resources and beam time, while an in-house staff of experimentalists, engineers, and technicians would be available to assist outside users. The current extensive involvement of several SURA physicists in ongoing research with electron accelerators indicates that the requisite expertise will be available.