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Origins and History of the Los Alamos Meson Physics Facility

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by

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CONTENTS

ORIGINS AND HISTORY OF THE
LOS ALAMOS MESON PHYSICS FACILITY

by

M. Stanley Livingston, Consultant

ABSTRACT

This monograph presents a history of the Los Alamos Meson Physics Facility (LAMPF) from initiation of preliminary plans and proposals in 1962 to the present. It includes the year-by-year story of the actions of the Atomic Energy Commission, the United States Congress, and the Bureau of the Budget relative to funding the project. It also discusses the discovery, subsequent interest, and proposed applications of the pi-meson.

INTRODUCTION

The purpose of this study is to search out the origins of the concepts involved in the design and development of the Los Alamos Meson Physics Facility, and to write the history of the LAMPF project. This search for historical origins quickly leads to an awareness of many facets of the story, each of which deserves a separate survey; yet each is incomplete in itself and has meaning only as a part of the whole. The procedure used here is to treat the several areas of interest in separate chapters or sections, as indicated in the Contents, although the reader will note many cross linkages.

The most pertinent historical sequence is the story of the local group that conceived and carried out the project at Los Alamos. This includes the series of preliminary plans and trial proposals that started in 1962, the responses from the Atomic Energy Commission, and the impact of the several advisory panel studies. This basic sequence is presented in Chap. 1.

A sequence of fundamental importance, but of a more formal nature, is the year-by-year story of the actions of the Atomic Energy Commission, the United States Congress, and the Bureau of the Budget relative to funding the LAMPF project. The actions of the Joint Committee on Atomic Energy are of particular significance in this sequence. These negotiations and decisions and their eventual results are described as a running story in Chap. 2.

C. F. Powell and his associates at the University of Bristol in England discovered the pi-meson (or pion) in photographic emulsions exposed to cosmic rays at high altitudes in 1947. Further studies showed that the pi-meson was a strongly interacting particle of short lifetime (2×10^{-8} sec) that decayed into a weakly interacting particle called the mu-meson (or muon). The muon was the original meson, discovered in 1932 in cosmic rays by Carl Anderson; it is also unstable, decaying into an electron (and two neutrinos) with a lifetime of 2×10^{-6} sec.

The first observation of pi-mesons in the laboratory was by A. L. Gardner and C. M. G. Lattes, in 1948, using a 400-MeV proton beam from the 184-in. synchrocyclotron at the University of California Radiation Laboratory. For the next ten years synchrocyclotrons in several laboratories in the United States and abroad (of several hundred MeV energy) were used for the study of production cross sections and basic properties of pi-mesons and their decay products. Proton intensities from synchrocyclotrons were initially low and the research was limited in scope. At an early stage, it became clear that pi-mesons were highly efficient in the production of other nuclear interactions; their use as incident projectiles for meson-induced interactions became a further goal. However, to exploit this field properly would require much higher intensities of mesons and so much higher intensities of accelerated protons than were available from synchrocyclotrons.

The growing awareness of the importance of the research field of meson physics was a basic contributing factor and provided the external pressure that made the LAMPF proposal successful. Of particular interest is the story of the competition between the several laboratory groups that designed and requested support for high-intensity meson-production facilities, and the reasons why the task was assigned to the Los Alamos Scientific Laboratory (LASL). This part of the story is told in Chap. 3.

Another aspect of the history of this field is the evolution of the concept of the "meson factory" as a research facility. A meson factory is a very high-intensity accelerator of intermediate energy (less than 1 GeV) which produces intense beams of secondary radiations, primarily pions. Such a facility is expected to provide new tools for the study of nuclear structure and to open new fields of research. Our knowledge of nuclear structure has increased steadily with the continuing study of meson-produced interactions. The scientific motivation has also strengthened as machines have been developed to produce ever higher intensities. Scientists in many institutions have become interested in meson research and have started planning experiments that will become possible only with really intense meson beams. An important aspect of LAMPF history is this rapidly growing scientific interest which came from the cross-fertilization of ideas between scientists from many institutions.

Other parts of the story include the origins of the important technical features that made the LAMPF proton linac a practical answer to the needs. This part of the history starts with basic features developed at other linacs and briefly described in Chap. 3; again, it shows the importance of collaboration between workers in different laboratories. Details will interest experts in this engineering field. For example: How were modern linac structures such as the side-coupled cavity developed from their elementary origins? And who first recognized the necessity of a change in the type of accelerating structure and the frequency of acceleration above 100 to 200 MeV?

Within the LAMPF laboratory, the origins of some of the technical developments are not always clear and assignment of individual credit may be questionable. To the extent that memories and laboratory records allow, such technical contributions are identified in this study and are described in Chap. 4. However, much of the credit still remains to be shared jointly by the entire LAMPF staff including the many engineers, technicians, and machinists. Each had his part in perfecting the thousand-and-one details which have made the completed accelerator successful.

The administrative and organizational practices are discussed in Chap. 5. The changing structure of the Divisions and Groups within LASL, and the responsibility assignments to leading members of the staff are also described. For completeness, a list of the staff involved in the construction of LAMPF during 1971 is given in Appendix A.

The planning for the scientific use of the facility, including new administrative arrangements to expedite cooperation between LAMPF and the university scientists, is treated as a separate part of the study and is discussed in Chap. 6. Included is the story of the growth of interest and support for a biomedical facility to explore opportunities for treatment of human tumors with meson beams. It is hoped that this procedure of describing the various aspects separately will result in a readable account of the story of this important new research facility, LAMPF.

CHAPTER 1

ORIGIN OF THE LAMPF PROPOSAL

Long before LAMPF was proposed and funded as a major new research facility, the seeds from which it would grow were germinating within the Los Alamos Scientific Laboratory. Although LASL was originally established as a mission-oriented Laboratory and was funded primarily through the Division of Military Applications of the Atomic Energy Commission, a tradition had become established of the importance of basic research to the ultimate goals of the Laboratory. The Physics Division supported many programs in basic atomic and nuclear research and in the development of instrumentation for this research. Most staff members of the Physics, Theoretical, and other scientific Divisions had advanced degrees and research training, as did many members of the applied science Divisions. Staff interest in new research fields and associated design studies were generally supported by the Administration. This readiness to support fundamental research projects at LASL was known of and approved by AEC officials as authorized DMA policy.

One area in which Los Alamos scientists became interested was nuclear and particle physics based on high-energy accelerators. During the period 1954 to 1957 a group of LASL scientists and outside consultants made preliminary design studies for two machines: a 2-GeV spiral-ridge FM synchrocyclotron and a 12-GeV proton synchrotron. The design effort continued at a rather low level for two to three years. The staff members most actively involved were D. Nagle, H. Argo, F. Ribe, A. McGuire, and F. B. Harrison, supported by J. M. B. Kellogg, Physics Division Leader. However, there were no strong spokesmen to argue for and to promote the projects, the LASL Administration was lukewarm, and the design studies were terminated without results. In retrospect, it seems that such high-energy machines, which are useful primarily for research in high-energy particle physics, were considered inappropriate to the Los Alamos mission by Administrative and AEC Staff. So this accelerator design program faded away into the files.

The recorded story of LAMPF started in 1962 when Louis Rosen sent a memorandum[1] to Kellogg suggesting a program for future physics facilities at the Los Alamos Scientific Laboratory. The significant feature of Rosen's memorandum was its emphasis on the scientific importance and the growing feasibility of the "meson factory," a very high-intensity accelerator of energy 500 to 800 MeV, with which a program of studies of nuclear physics could be launched using secondary beams of pi-mesons as probes. This memo pointed out the need for updating the LASL facilities and suggested that the Atomic Energy Commission be "forcefully apprised" of the potential importance of a meson facility at Los Alamos. Rosen's interest had been indicated earlier that year when he attended a Conference[2] on sector-focused cyclotrons at Los Angeles in April. One of the papers, by Prof. Roy Haddock of UCLA, was on "The Role of the Pion Factory in Elementary Particle Physics." Another, by Lloyd Smith of the Lawrence Radiation Laboratory at Berkeley, was on a "Comparison of Accelerator Types" for use as meson factories.

The memorandum was only one example of the continuing urge at LASL to develop new physics opportunities. Rosen's interest was paralleled by other scientists in the Laboratory who joined with him in studies of the scientific opportunities and in the engineering design problems. Several staff members wrote letters in direct support of Rosen's proposal: Kellogg transmitted Rosen's memo to the Director, Norris Bradbury, with his enthusiastic approval; Charles Critchfield of the Theoretical Division sent a supporting memo to Kellogg; Prof. Hans Bethe, an important early member of LASL and a continuing consultant to T Division, wrote in support to Bradbury; and Richard Taschek, Alternate P-Division Leader, indicated his interest in a letter to J. C. Severeins of the AEC Research Division. At an early stage, Leona Marshall (Libby) suggested that Rosen enlist Nagle, also of the Physics Division. Nagle left his studies of the

Mossbauer effect and became Rosen's chief supporter and the first local expert on accelerator technology.

The first order of business was to decide which type of accelerator to use. Several LASL scientists, including Nagle, John Marshall, R. Taschek, E. Knapp, D. Hagerman, and others visited other laboratories in this country in which high-intensity machines were being studied. During the summer of 1962 teams of LASL staff members visited and talked with experts at Berkeley (R. L. Thornton), Oak Ridge (R. Livingston), Yale (R. L. Gluckstern), MURA (D. W. Kerst), UCLA (J. R. Richardson), Argonne (A. V. Crewe), and also Stanford and Princeton. Potential scientific users at LASL and several visiting scientists were consulted. From all these investigations the conclusion was the same–that a proton linac was probably the most satisfactory type, even though it was expected to be the most costly. The linac was favored by an impressive majority of potential users because of its superior beam quality, high intensity, and ease of extraction.

Others at Los Alamos joined in the effort. Knapp, Hagerman, and McGuire became active in design planning, L. Marshall studied the optimum energy range, and several members of the Theoretical Division contributed to the discussion of the scientific use. During this period of planning, the activities in accelerator design were considered a normal and proper part of the Physics Division program, and were conducted in a rather informal manner. On September 1, 1962, Taschek was named Leader of the Physics Division. However, before he left for his new assignment in the Director's Office, Kellogg made plans to organize a new Group (P-11) to formalize the growing linac design group. On this same date Rosen became Alternate Physics Division Leader. He reduced his research activities on polarization in nuclear interactions and became increasingly active in planning for the research use of the new facility. Rosen left the technical planning and design to others but his enthusiasm and leadership attracted other members of the Physics Division to join the design study group. The LASL Administration and the local AEC representatives were fully informed and were very helpful during this phase of planning for a meson facility.

This intense activity brought immediate visible results. By December a preliminary version of a Proposal[3] had been prepared by 19 members of the LASL staff and 3 consultants. The Proposal included a discussion of the scientific motivation and described a proposed study program for utilizing mesons and other secondary radiations. It included design criteria of the accelerator (based in large part on Yale Report Y-6), descriptions of necessary buildings and facilities, and manpower and cost estimates. An important appendix was a report by William B. Brobeck Associates on a comparison of particle accelerators for meson production, which gave relative characteristics, yields, and costs. Again it was concluded that the proton linac offered the best performance, although at the highest initial cost. The basic characteristics of the linac described in the initial proposal are shown in Table I. Many features in this list of parameters were retained, essentially unchanged, in the final design.

By the start of 1963 many members of the LASL staff had become interested or involved in the planning for a meson facility. This was recognized within the Physics Division by the formation on February 1 of a new Group, P-11, with Nagle as Group Leader, to coordinate the planning. Among the more active members of the Group were Nagle, Knapp, Hagerman, and McGuire. They became an informal "steering committee" and met frequently to discuss the technical studies and to coordinate the engineering aspects of the planning. T. Putnam became a member of this steering committee when he transferred to Group P-11 in April 1964; and McGuire left the Laboratory in January 1965. For two years after its formation, P-11 group members wrote more than 20 technical papers on various aspects of linac design; the results of their studies are also recorded in quarterly Progress Reports.[4] A sampling of the topics studied illustrates the

TABLE I

LINEAR ACCELERATOR CHARACTERISTICS (from Preliminary Proposal, December 28, 1962)

Proton energy	750 MeV
External average beam current	1000 μA
Overall length	1820 ft
Radio frequency	200 MHz below 200 MeV 800 or 1200 MHz above 200 MeV
Rate of energy gain	0.5 MeV/ft
Total peak rf power	85 MW
Total average rf power	4.7 MW
Macroscopic duty factor	5.0%
Injection energy	750 keV
Total accelerator power	28 MW
Beam loading	18%

Drift-tube (Alvarez) design is used below 200 MeV and iris-loaded waveguide (Hansen) design is used above this energy.

Focusing is accomplished by quadrupole magnets in the drift tubes and between waveguide sections.

Triode amplifier tubes are used at 200 MHz and coaxitrons at 800 Mhz or klystrons at 1200MHz.

coverage and identifies most of the LASL staff members active in design.

a. Beam dynamics calculations - Hagerman, Milich, and Visscher.
b Radiofrequency structures calculations - Hoyt.
c. RF structures, experimental - Hagerman, Knapp, Schlaer, and Furnish.
d. RF amplifier study - McGuire, Furnish, and Freyman.
e. Experimental area - McGuire, Whetstone, Logan, and Marshall.
f. Beam blow-up in a linac cavity - Gluckstern and Butler.
g. Accelerating structures - Potter, Knapp, and Lucas.
h. Electron analog tests - Brolley, Emigh, and Mueller.
i. An 805 Mc amplifier - Hagerman, Doss, Freyman, and Parker.
j. RF phase and amplitude control - Jameson and Turner.
k. Electrical behavior of long linac tanks - Nagle.
l. Tests on a cloverleaf cavity - Knapp, Parker, Doss, Freyman, and Schlaer.
m. Digital computer for linac control - Putnam, Jameson, and Schultheis.
n. Linac error analysis - Butler.

A presentation, in the form of an outline of the initial proposal, was given by Rosen to the High Energy Panel of the AEC General Advisory Committee and the President's Scientific Advisory Committee in January 1963, and was later published as a LASL report.[5] One of the next steps was a study of the work schedule, organization, and budget requirements[6] for the project, reported in April 1963. In August, the LASL Administration submitted to the AEC a Schedule 44, Construction Project Data Sheet, entitled "Los Alamos Meson Physics Facility," estimated at a cost of $47,142,000. Other reports followed rapidly, although some were only restatements of the basic proposal for special purposes. Two papers presented by Rosen and Nagle at a Meeting of the Association of Rocky Mountain Universities on December 18, 1963, for the purpose of discussing prospects for collaboration, were published as a LASL report.[7] As of this date, the planning activity was still being referred to internally as LAMP (Los Alamos Meson Project). The acronym "LAMPF," coming from the title of the Schedule 44, came into general use during the following year.

For the record, it should be noted that this design activity was an authorized part of the Physics Division program and was supported by funds allocated by the Division of Military Applications (DMA) of the Atomic Energy Commission. The major expenditures during the early years before AEC Research Division funds became available were for salaries of staff and technical personnel diverted into the design study. The total funds provided by the DMA during FY 1963, 1964, and 1965 were estimated to be $2,380,000. When Research Division funds became available, most of the salary budget was transferred to the new account. However, some DMA support continued in the form of LAMPF overhead absorbed by LASL, Engineering Department support, and General Plant Projects. During FY 1966 to 1971, inclusive, such supporting funds continued at a level of approximately $900,000 per year.

The Schedule 44 submission brought the first official response from the AEC Division of Research. A meeting that included Los Alamos representatives L. Rosen, P. Franke, D. Hagerman, and D. Nagle was held on October 25, 1963, in Paul W. McDaniel's office to discuss the various aspects of research, development, planning, and the associated costs and schedules for the proposed Los Alamos Meson Physics Facility. The project was tentatively included in the budget of the Division of Research for the coming fiscal year (FY 1965).

This was only nominal AEC recognition of the existence of the new program. It was clear that the Research Division required further backing by the Commissioners and general support by the scientific community before the LAMPF project could be funded. With an estimated budget of about $50,000,000, it was the most costly scientific facility yet proposed in the field of basic nuclear research. Competing proposals for meson factories had been received by the AEC from several other institutions. The Research Division proceeded to survey the mood of leading scientists. Also, McDaniel appointed an ad hoc committee of scientists from the Southwest and Rocky Mountain areas, chaired by G. A. Kolstad of the Research Division, to study the problem of a regional scientific facility at Los Alamos for the study of medium-energy pion physics and to advise the AEC on the scientific and technical merits of the proposal.

The report[8] of this "Kolstad Committee," which was issued on March 17, 1964, recognized the unique features of the proposed Meson Facility and suggested that it would make an important contribution to the scientific and educational growth of the Southwest and Rocky Mountain regions, as well as becoming a major spur to the scientific strength of the Los Alamos Scientific Laboratory. It was considered at that time to be a regional form of a national laboratory that would involve many local universities in a previously undeveloped form of cooperation with Los Alamos. The report was highly complimentary and recommended that funds be appropriated to implement the proposal at the earliest possible date. The Committee also recognized that security regulations at LASL would need to be examined and probably modified to minimize possible handicaps.

Meanwhile, in late 1962 the General Advisory Committee (GAC) to the AEC and the President's Scientific Advisory Committee (PSAC) established an Advisory Panel to "review the status of high–energy accelerator physics and to make recommendations as to the future program in this field." This joint GAC/PSAC Panel held a series of meetings and hearings during the winter and the AEC published their Report[9] in April 1963. The "Ramsey Report," named for the chairman of the Panel, Prof. Norman F. Ramsey of Harvard, made several recommendations concerning high-energy accelerators, including a 200-GeV proton synchrotron designed at the Lawrence Radiation Laboratory and a 12.5-GeV high-intensity fixed field alternating gradient (FFAG) accelerator proposed by the MURA group at Madison. The report did not consider high-intensity machines of less than 1-GeV energy, stating that a 12.5-GeV machine would serve most of the needs for a high-intensity accelerator in the field of elementary particle physics.

The Ramsey Panel Report did not include the needs for lower-energy accelerators to support nuclear structure physics. In addition to the AEC, the National Science Foundation and the Department of Defense supported programs in this field, and the responsible staff members were aware of the growing pressures for additional facilities. Among these pressures was the expanding interest in accelerators of very high intensity with energies below 1 GeV - the "meson factories." By early 1963, there were four groups proposing to build such facilities: Yale (with Brookhaven), Oak Ridge National Laboratory, University of California at Los Angeles, and the Los Alamos Scientific Laboratory.

In December 1963, the Administration made a policy decision against building the MURA very high-intensity FFAG accelerator for 12.5-GeV protons. This decision implied that the subject of meson factories needed to be studied further.

In late 1963, Donald F. Hornig, Director of the Office of Science and Technology, established an Advisory Panel on Meson Factories, chaired by Professor Hans A. Bethe, to consider the usefulness of high-intensity accelerators for nuclear structure research and the needs for this type of facility. The Panel met on December 4-5, 1963, and at several successive times. The "Bethe Panel Report"[10] was issued in March 1964 and made a series of specific suggestions. They proposed that only one meson facility be built; it should have variable proton energy up to a maximum between 500 and 800 MeV; it should be built in a National Laboratory; and it should support the scientific needs of a well-organized group of "user" universities. The report commented on the relative merits of the several types of machines, and made it clear that the proton linac was preferable for several reasons, including intensity, variable energy, and ejection efficiency. A disadvantage of the linac was its small duty cycle. Although there was no definite choice indicated, the several specific recommendations pointed strongly toward the LASL proposal for a proton linac as the leading contender. Because of its importance in the decision-making process of awarding the meson factory to Los Alamos, the members serving on this Panel are listed in Ref. 10.

One of the administrative anomalies discussed in the Bethe Panel Report concerned the budgetary arrangements for supporting this medium-energy high-intensity research field. It was not included in the high-energy particle research budget and had not yet been recognized as part of the low-energy research field of nuclear physics. The Bethe Panel suggested that the Low-Energy Nuclear Structure budget should be substantially increased to include at least one meson factory.

At the April 2-4, 1964, meeting of the AEC General Advisory Committee, the LASL proposal for a meson factory was presented by Rosen, Nagle, and Taschek. The GAC also had the report of the Bethe Panel available and concurred with the general recommendations. However, they had not been briefed on the other meson factory proposals, and were concerned with the impact of funding such a costly proposal as LAMPF on the national program of support for low-energy nuclear physics; in consequence, they did not make a specific recommendation for LAMPF.

However, in April the AEC Research Division made $500,000 of Construction, Planning, and Design funds available to LASL to define the scope, design the basic characteristics, and develop reliable estimates for the LAMPF project. These funds were for design planning only and carried no assurance of future support. The funding did allow LASL to increase the design effort (the personnel applied to LAMPF averaged 15 during FY 1965) and to employ an architect-engineering (A/E) firm to develop cost estimates.

A policy decision made by the AEC in May 1964 stated that medium-energy physics utilizing high-intensity radiations from particles accelerated to energies of up to 1000 MeV constituted an important area of research that was germane to the needs and interests of the AEC. This intermediate-energy field was to be supported by a budget separate from low-energy nuclear physics and high-energy particle physics.

With the report of the Bethe Panel it had become clear to members of the Oak Ridge Accelerator Division that their proposal for an "Mc^2 Cyclotron" was not favored in the meson factory competion. A. Weinberg, Director of ORNL, wrote to McDaniel recommending consideration of a new type of accelerator, the separated orbit cyclotron (SOC), and urging that the AEC not commit funds for a meson factory until the SOC could be evaluated and a second ORNL proposal could be prepared.

This was the situation at the July 6-8 meeting of the GAC. McDaniel discussed the policy of dividing accelerator physics into three categories, with meson facilities in an intermediate-energy class. He also expressed concern with the divided opinion of the scientific community, as he had sampled it, in view of the expected funding limitations for accelerator-based physics. For these and other reasons, the GAC recommended that the meson facility not be included in the FY 1966 budget.

The engineering and cost study of the LAMPF proposal,[11] which had been authorized by the AEC, was completed by September 2, 1964, and was transmitted to the Division of Research. In addition to supporting the local model study program, $500,000 was used to obtain the services of several commercial firms: Radio Corporation of America and Continental Electronics performed parallel studies and made cost estimates of the radio-frequency power systems; Edgerton, Germeshausen and Grier, Inc., made a study of the control system; and Giffels and Rossetti, Inc., produced an architect-engineering study of the buildings and site requirements with the help of Brobeck and Associates on the machine components. From these studies a final cost estimate was developed and presented to the AEC in a Schedule 44 dated October 30, 1964, for a total of $55,000,000. This became the base cost-estimate figure during future negotiations. The time schedule for construction was estimated as six years.

CHAPTER 2

AEC AND CONGRESSIONAL ACTIONS ON LAMPF FUNDING

The winter of 1964-65 was a period of great uncertainty regarding future prospects for funding the LAMPF proposal, or even continuing the design study. The President's budget for FY 1966 did not provide any funding to continue the meson facility program. In November 1964, Bradbury provided information on the LAMPF proposal and its prospects to the Hon. Clinton P. Anderson, U.S. Senator from New Mexico. On Senator Anderson's advice, copies were sent to the other members of the Joint Committee on Atomic Energy and its staff. In January 1965, Bradbury talked with McDaniel about his concern over the future prospects for the project. Bradbury's stated first preference was for full authorization for construction by Congress in FY 1966; his second preference was for authorization for detailed design at about $4 million plus about $2.5 million for research and development (R&D) in FY 1966; a third and minimal possibility was a line item of $500,000 for further progress on Title I design plus $2.5 million for R&D. When a Santa Fe newspaper reported on January 25 that LAMPF was not in the President's budget and requested comment from LASL, Bradbury's comment was "We seem to have lost the battle, but we have not yet lost the war. ... If we do not make it this year, we will certainly increase our efforts to get it in next year."

Special open hearings were held on March 2-5, 1965, in Washington before the Subcommittee on Research, Development and Radiation of the Joint Committee on Atomic Energy (JCAE) on the subject of High-Energy Physics Research. About 40 physicists testified and the complete testimony was published in a Congressional Report[12] released June 29. Among other reports, Rosen described the purposes, plans, and status of the LAMPF project. At the conclusion of the discussion, Glenn Seaborg testified that the AEC regarded the Bethe Report as AEC Policy, and that it was only a matter of timing as to when the meson factory could be financed in competition with the numerous other items competing for the budget. In response to a question by Chairman Holifield, he replied that there was no money for further design of the LAMPF project in the FY 1966 budget.

The Joint Committee on Atomic Energy continued hearings on the AEC Authorization Legislation for FY 1966 on March 10. The new category called Medium Energy Physics was described by McDaniel. It had a budget of $7.5 million, but it did not include any item for LAMPF. However, when the report of the Authorization Legislation was released by the JCAE, it carried an item of $9 million for Medium Energy Physics, an increase of $1.5 million. This increase was described as a reallocation of $1 million from the weapons program and $500,000 from High Energy Physics. The Committee specified that $2 million of the funds for Medium Energy Physics were to be utilized for R&D in advanced design studies for the proposed LAMPF project. The Committee also recommended construction funds of $1.2 million for partial A/E work for this facility under a new plant and capital equipment authorization. The Committee stated its expectation that the FY 1967 authorization bill should include funds for construction of the LAMPF facility, currently estimated at $55,000,000.

The House Appropriations Committee approved the $9 million budget for Medium Energy Physics but did not approve the $1.2 million for partial A/E for the LAMPF facility; however, the Committee on Appropriations of the Senate restored this cut. The final Appropriation Bill for the AEC for FY 1966, as approved by both houses of Congress and signed by the President, provided the $1.2 million in construction funds for LAMPF A/E work as well as the $2 million for advanced design studies (R&D) specified by the JCAE.

In November 1965, an article published in the LASL magazine, The Atom, described the progress in the linac design. In particular, it reported the new accelerator cavity scheme which had been developed – the side-coupled cavity – and which promised to increase efficiency and reduce tuning troubles. It was reported to be a significant advance in the evolution of linacs and was expected to reduce future linac costs. This article was noted by a member of the Joint Committee staff, Colonel Jack Rosen, who inquired of the AEC whether this might reduce the cost estimate for the LAMPF facility. This caused some confusion for the AEC budget planners and required a letter from Bradbury to the JCAE explaining that the new development would make a better machine and allow the duty cycle to be increased, but would probably not reduce the cost. Incidentally, it may be noted that later utilization of the idea by commercial firms did demonstrate the advantages of side-coupled structures for electron linacs of 4- to 12-MeV energy.

At this point it might be assumed by an inexperienced observer that the battle over the funding for LAMPF had been won and that construction support was assured. This was not the case, as the story told in the remainder of this chapter will attest. There was also a disconcertingly long delay (to the LAMPF staff) in the authorization for spending of the funds that had been appropriated. The Congressional Appropriation Bill for the AEC for FY 1966 was not passed and signed by the start of the fiscal year, but, as has become common in recent years, was delayed by pressure of Congressional business until September. Next, a financial plan for disbursement of the appropriated funds had to be prepared by the AEC and approved by the Bureau of the Budget (BoB).

From information received later from AEC representatives,[13] it seems that questions concerning the justification for the LAMPF project had arisen within the Bureau of the Budget. Charles L. Schultz, Director of the BoB, was concerned with the construction funding of $55 million planned for the FY 1967 budget. He had noted the $4 million authorization by the National Science Foundation to Columbia University for increasing the intensity of the Nevis synchrocyclotron, and wondered whether this might provide an acceptable substitute for LAMPF. He questioned the necessity for the 800-MeV energy of LAMPF, having been informed that $10 million could be saved by reducing energy to 500 MeV, with only minor changes in scope. He also questioned the need for the continued support for design of the ORNL Separated Orbit Cyclotron. Answers to these and other questions were provided by the Division of Research and by Chairman Seaborg, who strongly supported the program for LAMPF. The authorized funds of $1.2 million in construction funds for A/E work and $2 million in operating funds for FY 1966 were finally allocated to LASL in January 1966. Although these funds were restricted to design activities and no assurance was given of full construction funding, this date is generally taken to be the start of the definitive design phase of the LAMPF project.

Meanwhile, design activities had not been allowed to lose momentum at LASL. A new Division of Medium Energy Physics (MP Division) was formed in July 1965 with Rosen as Division Leader and Nagle and Tesche as Associate Division Leaders. A primary purpose was to continue with the design and development of the meson facility. With the Congressional authorization, the AEC felt justified in allowing LASL to anticipate funding to maintain progress. By February 1966, a contract had been negotiated with Giffels and Rossetti, Inc., of Detroit, for the A/E work on the major portion of the LAMPF building complex. A 6000 square foot "mock-up" addition to the P-Division building was nearing completion to house waveguide prototypes, an 800-MHz power amplifier, controls and other components of a test system. A 40-cell prototype of the waveguide (Model B) was in progress. The rf systems were also in an advanced stage of development. By February the MP Division had a staff of 61 with 18 persons from other LASL divisions contributing to the effort. General agreement existed within the project that the desired beam quality could be achieved throughout the linac without requiring unduly severe electrical and mechanical tolerances.

The President's Budget for FY 1967, when submitted to Congress, included $3 million of construction funds to continue A/E work, and $2.9 million in operating funds under Medium Energy Physics for continued R&D for LAMPF. The JCAE agreed to this continuation of support for design and again postponed full authorization for construction to the following year. In due course these budget items were acted upon favorably by the Appropriations Committees, passed by the Congress, signed by the President, and allocated by the Bureau of the Budget.

During the remainder of calendar 1966 and on into 1967, the design activities for LAMPF continued. The limitation to design activities only was liberally interpreted by the AEC to include full-power prototype development, site clearance, and many other related activities that could only be justified on the assumption that authorization of construction would follow. This was clearly the intent of the Joint Committee and of the AEC. For example, the site preparation was extended to include bulldozer excavation of the entire linac tunnel and experimental area region, and was included within the $3 million of A/E work.

On September 10, 1966, Vice-President Humphrey visited Los Alamos and was given a briefing about the meson facility. It became known that President Johnson had indicated his support for the LAMPF project. In October 1966, LASL was host to the International Conference on Linear Accelerators, which brought together many of the world's foremost experts in the field.

In preparing the FY 1968 budget, the AEC Research Division requested funding of $50.3 million for the remainder of the construction cost. However, the final version of the AEC budget request to the BoB did not include any construction funds for LAMPF and the item did not appear in the President's Budget submitted to Congress. Hearings on the AEC Authorization Legislation for FY 1968 were held by the JCAE in February 1967, at which Rosen was again invited to testify. Rosen informed the Committee of the status of LAMPF design progress and of the increasing scientific interest. He also discussed the potential use of negative pion beams for radiation therapy of deep-seated tumors. In the report by the JCAE on these hearings there is stated: "The Committee recommends approval of the full amounts requested by the Commission for operating expenses and plant and capital equipment obligations proposed for this subprogram (Medium Energy Physics) in the coming fiscal year." This included the authorization of new obligations of $50.3 million for the meson physics facility at Los Alamos.

However, the House Appropriations Committee, in its report to the Congress, recommended a reduction of $39.9 million in the request for LAMPF to convert the financing to an annual appropriation basis instead of the full funding proposed in the budget estimates. This represented a major change in Congressional policy regarding the funding of line items of this type. All previous accelerator installations had had construction costs authorized in full. The Appropriations Committee stated that because of the large construction cost involved, it would be desirable for Congress to review construction cost and progress annually. This recommendation was accepted by the House and the Senate and the bill was approved by the President. So the LAMPF budget authorized for FY 1968 included only $10.4 million for construction.

Physical construction (Title III) actually began in the early spring of 1968. Acting on the expectation of a $10.4 million construction budget, the LAMPF staff had obtained bids for several of the buildings on the site and for several long-delivery items of materials and equipment. Then in November 1967, the Bureau of the Budget requested from the AEC an analysis of the impact of a nine-month deferral in the start of construction. This was in anticipation of the FY 1968 Public Works Appropriation Bill, which was awaiting the President's signature and which called for a freeze on spending of new construction funds. With heavy hearts, a reduced program of construction was prepared and submitted by LAMPF planners. After considerable discussion and negotiations, a revised total of $3.7 million was allowed and allocated for the fiscal year.

An important event in this year was the first operation of the Electron Prototype Accelerator on December 21, 1967, which operated as planned and confirmed the validity of basic concepts and design criteria for the 800-MHz waveguide system. A long-delivery order was placed for copper-clad steel for the tanks of the Alvarez-type linac to provide the first 100 MeV. A contract was awarded in January 1968 to J. R. Brennand Co. for construction of the Equipment Test Laboratory, the first building on the LAMPF site.

The groundbreaking for this first building of the LAMPF complex was held on February 15. Due to inclement weather the ceremony was transferred on short notice to the platform of the auditorium in the LASL Administration Building. Senator Clinton P. Anderson, Chairman Glenn Seaborg of the AEC, and Louis Rosen wielded gold-plated shovels in a box of earth brought from the site. Also present at the ceremonies were Congressman Thomas Morris; AEC Commissioners James T. Ramey and Gerald Tape; and General Manager R. E. Hollingsworth, President Charles J. Hitch, and Vice President Emeritus Robert Underhill of the University of California; University of California Regents Edwin Pauley, Elinor R. Heller, John Canady, and Theodore Meyer; Dr. A. Ray Chamberlain of Colorado State University representing Associated Western Universities, Inc., and from LASL the Director, Norris Bradbury, and many members of the staff.

The authorization for FY 1969 followed a pattern similar to earlier years. The final action of Congress, with the approval of the President, resulted in an appropriation of $18.7 million in construction funds. In summary, by June 30, 1968, approximately $7 million in construction funds had been committed and another $7 million of authorized funds was being held in reserve by the BoB. The new funds for FY 1969 raised the authorized total to about $33 million, or 60% of the estimated cost.

Then in September 1968, a serious threat occurred when the Bureau of the Budget withheld $26 million of capital funds (authorized for LAMPF by Congress and requested by the AEC) that had not yet been allocated. Later information shows that Mr. Charles J. Zwick, Director of the BoB, acting under restrictive orders from President Johnson, was concerned about continuing the LAMPF project in future years and questioned whether or not construction could be pursued of both LAMPF and the 200-BeV accelerator in Illinois. This action by the BoB soon became known in Los Alamos where it caused acute dismay at the administrative level. Bradbury protested strongly to the AEC. The Commissioners were also seriously concerned and requested reconsideration by the BoB. Fortunately, this effort was successful and the BoB agreed to release the FY 1969 funds for LAMPF. The good news was received at LASL on October 10, 1968. Bradbury and Rosen and others concerned were greatly relieved and heartened.

LASL requested $15.3 million for FY 1970 to maintain the construction schedule. However, the President's Budget allowed only $5 million for LAMPF. On request, Rosen estimated the impact on the project of a one-year deferment of $10.3 million of construction funds to be a six-month postponement of completion date and an increase in cost of about $1 million. Strong letters of protest from Bradbury and the LAMPF Policy Board were transmitted to the AEC. The JCAE held hearings on the AEC Authorizing Legislation for FY 1970 in April 1969, where McDaniel testified and gave a status report on LAMPF. Rosen was present at the hearings and was again asked by Chairman Holifield to comment. Despite all efforts, the final action by Congress and the President was to provide only $5 million in construction funds for FY 1970.

This result called for a restudy of LAMPF priorities and schedules, with the purpose of trying to maintain the date of June 30, 1972, for initial operation of the accelerator, even though some of the research support facilities might be delayed. It was found that some of the funds allocated to contingency had not been required and could be reassigned to construction. It still seemed possible to meet the initial operation date under revised priorities, although less essential items would be postponed and the total cost for completion would be increased by $1 million.

The President's Budget to Congress for FY 1971 included $10.5 million in construction funds, leaving a balance of $6.7 million to reach the revised total estimate of $56 million. In the JCAE hearings on the AEC Authorizing Legislation for FY 1971, McDaniel testified that these amounts would, hopefully, enable the LAMPF staff to produce an initial beam by the summer of 1972 and to complete all construction by the summer of 1973. Rosen was in attendance and discussed the LAMPF status and plans for a Biomedical Facility. The final action by Congress and the President was for $10.5 million in construction funds for FY 1971.

Rolling with the punches had become so customary that there was a feeling of great relief at LASL when the FY 1972 construction budget for LAMPF of $6.7 million was announced - sufficient to complete construction of the facility. This amount was listed in the President's budget announced in late 1970; by late 1971 it was passed by Congress and signed into law. The $56 million total included a $1 million increase due to postponement of scheduled needs for FY 1971, but otherwise was the same amount estimated at the start of the project in 1965 - an admirable record. By early 1971 the most important unfunded items were the Biomedical Facility and housing for the beam assigned to classified weapon's research, neither of which had been included at the start.

This period of political promotion and financial juggling was in retrospect an exciting and successful one. The record related above will change some preconceived ideas about the monolithic momentum of the Atomic Energy Commission.

The importance of the Joint Committee in influencing the funding process stands out over that of any other arm of government, including the Congress. Certain individuals contributed significantly to forwarding the LAMPF project over its successive hurdles. The two members of the Joint Committee from New Mexico, Senator Clinton Anderson and Representative Thomas Morris, served as watchdogs to guard the LAMPF budget time after time. Senator Anderson used his high prestige for direct approaches to the President on several occasions. Representative Morris was influential through his membership on the House Appropriations Committee. The Chairman of the JCAE for several terms during the period of LAMPF funding was Representative "Chet" Hollifield, and he proved a good friend and supporter. Two members of the JCAE staff were also extremely helpful in expediting approvals of LAMPF budget items and in keeping the LASL staff informed: Mr. John Conway had a legal background and Col. Jack Rosen was a military officer with a Master's Degree in Physics who handled the technical problems. Later, Col. Rosen transferred to the AEC as assistant to Commissioner Tape where he continued his activities in support of LAMPF until his untimely death in 1970. The JCAE really took an interest in the fate of the Los Alamos meson project; they rescued it from Congressional and Bureau of the Budget attacks year after year. In a speech at the National Accelerator Conference in 1969, Representative Hosmer of the JCAE spoke of "forcing the meson on a reluctant administration." In recalling the history of LAMPF, it is well to recognize the understanding and foresight of those dedicated members of the Joint Committee and their staff who watched and cared for the fledgling LAMPF and brought it through to full stature.

CHAPTER 3

ACCELERATORS FOR MESON FACTORIES

A. Early Linear Accelerators

The linear accelerator provides a method of obtaining high-energy particles by use of repeated small pushes. The concept is as old as the child's swing and must have occurred to many inventors in the days before the technology that was required to implement it was developed. The earliest written proposal was by Ising[14] in 1924, but it was premature due to the rudimentary state of the electrical art, and did not result in a working model.

The concept that made the linear accelerator a practical possibility was resonance of the moving particles with an alternating radio-frequency electric field. In 1928, Wideröe* described[15] the resonance principle and a working prototype of a two-step linear accelerator. A radio-frequency voltage was applied to an arrangement of three cylindrical electrodes in line such that the particles were accelerated on crossing each of two successive gaps between electrodes, emerging with an energy equivalent to twice the applied voltage. The length of the tubular electrode, the voltage and frequency of the applied rf and the type of ions (Na^+, K^+) were chosen to allow the ions to be accelerated while crossing each gap, and to be shielded by the central "drift tube" during the decelerating half cycle of the radio frequency (rf).

Ernest O. Lawrence of the University of California was inspired by Wideröe's paper to invent, in 1929, the magnetic resonance accelerator that later gained fame under the name "cyclotron." While the cyclotron was being developed, David H. Sloan, a student working under Lawrence's direction, constructed a much improved version of Wideröe's linear accelerator for mercury ions. A set of 30 drift tubes of increasing length (to match the increasing ion velocity) were connected alternately to two bus bars. The capacitance of the drift tubes was resonated with an inductive coil at a frequency of 7 MHz and powered by a homemade 20-kW power oscillator tube. The limitations of the drift-tube system and oscillator and the low frequency restricted the type of particles in resonance to heavy ions. With this arrangement, Sloan and Lawrence[16] were able to accelerate Hg^+ ions to 1.26 MeV in 1931. Later, Sloan and Coates[17] accelerated Hg^+ ions to 2.85 MeV using an improved apparatus and bombarded a number of targets; no nuclear events were observed, only x rays characteristic of the materials. Still later, Kinsey[18] built a linear accelerator for Li^+ ions at energies up to 1 MeV, also with negligible scientific results.

These early resonance accelerators were not able to accelerate protons, or other light ions, due to the limitations of the rf technology of the time. As a result, they were not useful for nuclear studies or disintegrations and were abandoned in favor of the cyclotron.

B. Drift-Tube Accelerator

At LAMPF the first 100 MeV of acceleration is produced in a drift-tube-type linear accelerator, similar in many respects to other linacs presently used as injectors for high-energy accelerators such as AG proton synchrotrons.

Luis W. Alvarez of the University of California Radiation Laboratory proposed, in 1946, to build a linear proton accelerator to be driven by existing rf power oscillator tubes developed for radar systems and designed to operate at about 200 MHz, which were then available as war surplus. The accelerator consisted of a long cylinder resonant at this frequency, with an array of 45 drift tubes of increasing length (to match particle velocity)

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*In 1972 Rolph Wideröe, this ingenious and versatile inventor, is still active in the laboratory of the Brown-Boveri Company in Zurich.

mounted along its axis. The loaded cavity operated in the 2π mode, a modification of the TM_{010} mode. Protons were preaccelerated to 4 MeV in a horizontal electrostatic generator before injection into the linac. The resonant cylinder was formed of shaped copper sheet mounted within a steel vacuum chamber and was water cooled; both the copper cylinder and the enclosing vacuum chamber were formed in two halves that were split along a horizontal center line and could be opened to service and align the drift tubes. The first linear accelerator[19] of this type was completed at Berkeley and protons were accelerated to 32 MeV in October 1948. The Alvarez linac has been described as the successful fusion of the resonant acceleration principle (Ising, 1924; Wideröe, 1928; Sloan and Lawrence, 1931) with the high-power rf techniques developed for radar during World War II.

In the ensuing 20 years there have been major improvements in the engineering techniques used for construction, and the output energy has been increased to 200 MeV. But the basic principle of the drift-tube linac and the basic arrangement of structures for acceleration have been retained without significant modification except for the addition of post couplers. Engineering improvements have been the result of work in many laboratories and have involved a great deal of consultation and cooperative effort in which individual credit is difficult to assign. The most significant of these modifications are listed.

a. Improvement of mechanical tolerances in construction.
b. Improvement of rf properties of materials and joints.
c. Use of improved pumps, seals, and vacuum-conditioning techniques.
d. Use of automatic temperature controls to stabilize frequency.
e. Use of quadrupole lenses in drift tubes for focusing.
f. Use of copper-clad steel in tank construction.
g. Use of post couplers to change operation from 2π to $\pi/2$ mode.
h. Radiation "hardening" with ceramic insulation.

A listing[20] of the major Alvarez-type linacs built or under construction by 1971 is given in Table II.

C. Studies at Harwell

There seems to be no doubt that the first recorded plans for a medium-energy, high-intensity proton linac intended to produce quantities of pi-mesons were developed in England in the early 1950's by a group of scientists and accelerator experts mostly from the Atomic Energy Research Establishment (AERE) at Harwell.[21] The earliest record of interest in this field is a letter[22] dated November 21, 1950, from T. G. Pickavance at Harwell to W. Walkinshaw (then at T.R.E.) requesting consideration of a proton linac to boost the energy of the extracted beam of the Harwell synchrocylotron (175 MeV) by 100 MeV to be able to produce pi-mesons through the p + p interaction. Walkinshaw's answer raised the difficult problem of adequately focusing the diverging emergent beam from the synchrocyclotron.

Pickavance continued his interest in a meson-producing linear accelerator for the Harwell accelerator program. For example, he wrote to D. W. Fry at Harwell on September 5, 1951, citing the meson yields expected from a 400-MeV proton linac with 1-μA intensity, and describing some of the possible meson physics studies.[23] This letter stimulated Fry to call a meeting[24] on October 23 to discuss alternative possibilities for future accelerators in England. The conceptual design of a 450-MeV proton linac and the techniques available for focusing the beam in the linac were also discussed.

This activity by the Harwell accelerator experts resulted in a meeting of top British physicists from AERE and the Universities, called by Sir John Cockcroft in June 1952, to discuss British accelerator policy and the possibility of joining in the European effort (which was to become CERN). British policy was formed from this and subsequent meetings. Initially the policy was to join the European program to build a multi-GeV proton synchrotron at Geneva, and also to build a 600-MeV proton linac at Harwell to provide pi-mesons for British scientists. A memorandum[25] prepared in early 1953 describes the status of British accelerator policy at that time and gives staff requirements and cost estimates.

The first design study[26] for the Harwell proton linear accelerator (PLA) was prepared by L. B. Mullett in April 1953; the first engineering drawings were dated December 1953. Many of the early technical studies involved focusing problems, including use of grids, foils, electrostatic lenses, axial conductors, and magnetic focusing with solenoids. Another series of studies was on the use of dielectric disk loading for waveguides to match particle velocity. By 1953 it became clear that "strong focusing" by the use of quadrupole magnetic lenses of alternating polarity, as discovered and published[27] in the United States in late 1952, would allow much higher beam currents, some hundreds of times more intense than those available from synchrocyclotrons.

By 1954 there were 50 persons working on the PLA at Harwell. A decision was made to construct a 50-MeV first section of the Alvarez design as a prototype and to gain experience. Design efforts were then turned to studies of structures for linacs at higher energies. Detailed design on the PLA continued until 1956, when a decision

TABLE II

LISTING OF ALVAREZ-TYPE PROTON LINACS[a]

Machine	Year Completed	Output Energy (MeV)	Frequency (MHz)	Focusing	No. of Drift Tubes	No. and Type of Tanks
Alvarez, Berkeley	1948	32	202.5	grids	45	1-liner
Kharkov 1, USSR	1950	20.5	139.4	grids	50	1-liner
Bevatron, Inject I	1953	10	202.5	grids	42	1-liner
Univ. Minnesota	1955	10	202.55	grids	41	3-liner
		40			37	
		68			24	
PLA, Harwell	1959	10	202.56	grids	41	3-liner
		30		quads	40	
		50		quads	26	
CERN-PS, Inject	1959	10	202.56	quads	41	3-liner
		30			40	
		50			26	
AGS, Inject I	1960	50	201.06	quads	124	1-copper clad
Nimrod, Inject	1961	15	115	quads	48	1-liner
Bevatron, Inject II	1962	19.3	199.3	quads	73	1-copper clad
ZGS, Inject	1963	50	200	quads	124	1-copper clad
ITEP-PS, Inject	1966	6	148.5	quads	18	2-liner
		24			33	
Serpukhov, Inject	1967	38	148.5	quads	93	3-liner
		73			41	
		100			26	
AGS, Inject II	1971	200	201.25	quads	295	9-copper clad
200 GeV, Inject	1971	200	201.25	quads	295	9-copper clad
LAMPF, Inject	1971	100	201.25	quads	165	4-copper clad

[a]Taken in part from *Linear Accelerators,*[20] North Holland Publishing Company, Amsterdam, 1970.

was made to terminate the PLA at 50 MeV and to cancel the plans for 600 MeV. This action was taken when it was decided to build a proton synchrotron for 7 GeV (Nimrod) at Harwell. A final design report[28] on the 600-MeV linac was published in 1957.

Walkinshaw first pointed out that the shunt resistance of the Alvarez-type drift-tube linac decreased with increasing particle velocity, requiring excessively high rf power. It was expected that a different structure would be more suitable for high energies. One type of structure suggested at Harwell was an iris-loaded waveguide, another was a series of coupled resonant cavities.

One of the most significant contributions of this Harwell study was made by Peter Dunn on resonant loop coupling between cavities. He appreciated the significance of a double-periodic system, i.e., pillbox cavities and resonant coupling loops, and worked out equivalent circuit equations.[29] Also, Adlam[30] worked on an external coupled cavity that might be considered the precursor of the present LAMPF side-coupled cavity. However, at that time the costs of waveguide fabrication were a cause of concern, and Dunn's loop coupling was favored as probably less costly. Later, Alan Carne did some work on X-bar and Clover-leaf structures for waveguides, which was also known and utilized during the design of LAMPF.

D. Studies at Yale and Brookhaven

Activity directed toward the design of a high-intensity proton accelerator at Yale was initiated by Professor Vernon Hughes in early 1959.[31] On his recommendation, in the late summer of 1959, the Physics Department voted in favor of a high-intensity accelerator to be used for meson physics. The facility was to be located at Yale and was intended to complement rather than compete with the facilities at Brookhaven National Laboratory. A small design effort was immediately started in the Physics Department and included the services of R. L. Gluckstern, E. R. Beringer, M. S. Malkin, and G. Wheeler, all having just completed the Heavy Ion Linac at Yale. It is hardly surprising that they showed small enthusiasm for cyclotrons and quickly turned their attention to the proton linac. The Yale designers were also strongly encouraged toward a linac by John P. Blewett of Brookhaven, who had designed the 50-MeV linac injector for the Alternating Gradient Synchrotron (AGS). They chose an initial goal of 750-MeV energy and 100-μA average current. Their studies soon showed that the linac had an inherent capability of even higher current, and they raised the announced goal to 1-mA average. This caused a frantic effort by the cyclotron proponents at ORNL and UCLA to show that cyclotrons could also produce a 1-mA external beam.

At the Second International Conference on Sector Focused Cyclotrons, held at UCLA in April 1962, the battle between cyclotrons and linacs was formally joined, with a survey report by Lloyd Smith that discussed the relative merits of different machines. Smith concluded that the proton linac was the strongest candidate (although it was the most costly). By 1963, at the Third International Conference of Sector Focused Cyclotrons and Meson Factories, in Geneva, the linac occupied a significant place on the program.

Meanwhile, the Yale studies matured and the first formal design report of the linac meson facility,[32] known as "Y-6," was issued in 1962. This proposed to use an Alvarez-type linac with shaped drift tubes operating at 200 MHz for the first 200 MeV, and an iris-loaded waveguide at 800 or 1200 MHz to accelerate from this energy to 750 MeV. The total length was 550 m. This report was used as the basis for the initial Yale request for support from the Atomic Energy Commission. It is also fair to say that the first LASL proposal for a linac meson factory (December 1962) was based largely on Yale Report Y-6.

By the end of 1962, there were four meson factory proposals receiving serious attention from the U.S. Atomic Energy Commission. These were: ORNL (H^+ cyclotron); UCLA (H^- cyclotron); Yale (linac) and LASL (linac). Yale thought it wise to strengthen their relative position in the competition by combining forces with Brookhaven. At Brookhaven, John Blewett was strongly urging a new injector of much higher intensity and higher energy for the AGS. For a time, the Brookhaven and Yale groups considered a facility at the AGS in Brookhaven that would provide a high-intensity beam for injection during the short injection pulse and would serve as a meson factory for the remainder of the time (95%). This effort failed to become a practical proposal, largely due to lack of official support from the Brookhaven Administration and the AEC.

By 1964, following publication of the "Bethe Panel" study of meson factories for the Office of Science and Technology, it was clear that there would be no meson facility at Yale. The AEC instructed the Yale design group to terminate its work by September 1964. The final report[33] of the design study is Yale Internal Report Y-12; the estimated cost was $59.3 million.

The Yale group made a major contribution toward establishing the linac as the most suitable accelerator for a meson factory. Had it not been for their efforts a cyclotron might have been built. When a LASL group visited Yale in 1962, the Yale staff were extremely helpful with their information and advice. Substantial technical contributions also came from the Yale group. They made the first calculations showing the feasibility of very high currents in a linac. They justified the separation of the linac into two structurally different components as early as November 1960, one with drift tubes operating at 200 MHz and the other with a waveguide structure resonant at 800 (or 1200) MHz. Yale followed Harwell's lead in developing the π-mode standing-wave waveguide instead of a traveling-wave waveguide. Much of the early thinking which led LAMPF to the choice of a linac was done at Yale. Many features of the eventual LAMPF machine design bear a striking resemblance to Yale Report Y-12. It is well to recognize the debt owed by the LAMPF project to this earlier work of the Yale linac study group and to their generosity in advice.

E. High-Intensity Cyclotrons

The invention of the cyclotron by Ernest Lawrence in 1930 was followed by a decade of standard cyclotron development (with uniform magnetic field) at Berkeley and many other laboratories. This stage is best represented by the classic "60-in." cyclotron that attained the relativistic energy limit (for protons and deuterons) of 20-25 MeV. This size of machine was widely copied and used for nuclear studies up to this energy. In 1938, Thomas[34] pointed out a method of increasing the relativistic energy limit based on the use of azimuthal variations in the magnetic field to maintain axial focusing; for various reasons his proposal was not utilized at that time.

The next phase was the rapid development of the synchrocyclotron following the end of World War II, proposed independently by E. M. McMillan at Berkeley and V. Veksler in Moscow. The synchrocyclotron was based on the synchronous stability available with frequency modulation, which provided much higher proton energies, but at quite low intensities (0.1- to 1.0-μA average). About 10 large machines were built, mostly for energies of 400 to 700 MeV.

During 1950-1952, the Thomas cyclotron concept was revived by McMillan at Berkeley, and the theoretical aspects analyzed by D. Judd, as part of the Materials Testing Accelerator (MTA) program of the AEC-supported Radiation Laboratory of the University of California, to develop a source of very high-intensity protons. This work was done under security restrictions with potential for the production of fissionable material in the event the U.S. were denied foreign sources of uranium. Supporting theoretical work and model studies were carried on at the Oak Ridge National Laboratory, and were also classified. Then in 1952 the principle of "strong focusing" using alternating magnetic gradients was discovered at Brookhaven.[27] The AG principle was extended to fixed-field alternating gradients (FFAG) by the Midwest University Research Association (MURA) group at Wisconsin, where an important concept was the spiral-ridge synchrotron. The generalization of this concept to cyclotrons was straightforward, and it became clear that the spiral-ridge cyclotron was essentially an extension of the Thomas radial-sector machine.

Design studies for conversion of existing cyclotrons to azimuthally varying field (AVF) were undertaken from 1953 onward at several laboratories, including LASL, ORNL, and UCLA. For the next decade, a great deal of effort was applied to the development of AVF cyclotrons, also called isochronous or sector-focused (SF) cyclotrons, with much higher intensities than were available from synchrocyclotrons, although generally at lower energies. In a conference on sector-focused cyclotrons held at Sea Island, Georgia, early in 1959[35] a tabulation by R. J. Burleigh in the Conference Proceedings lists 15 machines either operating, under construction, or in the design stage. Most were for proton energies below 100 MeV; one was a design study (at AERE Harwell) for 240 MeV; another was a very preliminary engineering study for a 400-MeV size machine sponsored by the University of Florida.

F. Studies at Oak Ridge

The first accelerator group to apply serious design efforts to high-intensity cyclotrons of the medium-energy range (0.5 to 1 GeV) was at the Oak Ridge National Laboratory, led by Robert S. Livingston. This interest followed directly from their earlier classified studies of the Thomas cyclotron. It also utilized their experience with electromagnetic separators for uranium isotopes (Calutrons) and with two large standard cyclotrons: the "86-in." cyclotron was brought into operation in late 1950 and became an effective tool for basic nuclear research and for isotope production, operating at proton energies up to 23 MeV; the "63-in." cyclotron was designed expressly to accelerate heavy ions (N^{3+}, N^{4+}, etc.) and opened this new field of research.

Active interest and extensive theoretical design studies on an AVF cyclotron of very high intensity started at ORNL in late 1954. The initial design[36] took the form of a three-spiral-sector magnet of 76-in.-diam pole capable of accelerating protons to 75 MeV and heavier ions to other appropriate energies. The scientific motivation for the development of the 75-MeV "ORIC" was for basic research in nuclear physics and chemistry, the production of neutrons and induced radioactivities, and the study of heavy ion atomic physics; there could be no expectation of the production of mesons at this energy. However, early ORNL studies also included two electron analogue models, one to study the resonance behavior of particles in AVF magnetic fields, and an ambitious model (Electron Analogue II) for a possible 850-MeV cyclotron. Note that this analogue study for 850 MeV was first described in 1954.

With the completion of ORIC in 1960, the major design effort went to the "Mc^2 Isochronous Cyclotron." This effort was based on the desire to build a high-intensity cyclotron of the highest practical energy, which was conceived to be for an energy (900 MeV) just below the proton rest-mass equivalent; the rest-mass energy was believed to be a technical limit. It was for this purpose that Electron Analogue II was built and studied; these studies showed that all resonances could be avoided or crossed up to the mc^2 limit (for electrons). With this favorable prediction, design and engineering studies on the Mc^2 Cyclotron continued, with a status report in 1962 and a formal proposal[37] in 1963. The magnet was to be an eight-sector spiral-ridge type, with four fixed-frequency rf cavities located in valleys between the ridges. The design intensity of the 810-MeV external beam was 100 μA. The expected yields of pions, neutrons, neutrinos, etc., were calculated and a typical program of research was described. The total budget for construction was estimated to be $42,7000,000.

Robert Livingston and his staff organized the first of a series of conferences on sector-focused cyclotrons held at Sea Island, Georgia, on February 2-4, 1959. At this conference, most of the papers dealt with machines having energies below 100 MeV, and there was no mention of linacs as potential competitors to high-intensity cyclotrons. A second conference[38] on sector-focused cyclotrons was held at UCLA, Los Angeles, in April 1962. By this date (three years later) the goals had changed. Several multihundred-MeV machines were described; the term "meson factory" had been invented and was used in the titles of several papers presented at the conference. A paper by Lloyd Smith compared the merits of the several accelerator types as meson factories; he concluded that the best accelerator seemed to be the proton linac, but admitted that laboratories with cyclotron experience would probably still argue for a cyclotron. The stage was set for LASL to enter the scene.

By 1964, with the report of the "Bethe Panel" on meson factories, it seemed probable that the Mc^2 Isochronous Cyclotron Proposal was in difficulties and was not the obvious front runner. A major criticism was the known beam loss during acceleration and ejection and the risk of buildup of unacceptable levels of radioactivity in the chamber. The ORNL group offered a counterproposal of a Separated Orbit Cyclotron (SOC) following the design[39] developed by F. M. Russell in 1962 while present at Oak Ridge as a visiting scientist from the Rutherford Laboratory. The SOC was to be formed of a helical spiral of magnets in which the beams were spatially separated on each turn. It might be described as a linac wrapped up into a spiral having the advantage of easy ejection of an emergent beam. The engineering design of the SOC was not yet as well developed as that for the Mc^2 Cyclotron, and the proposal was informal. The initial proposal was a letter from A. Weinberg, Director, ORNL, to Paul McDaniel in June 1964 claiming advantages for the SOC and asking for postponement of a decision on the LAMPF meson factory until the SOC could be evaluated. (The SOC had not been considered by the Bethe Panel.) However, this second ORNL proposal came too late to be considered, and the AEC support for LASL was not diverted.

It is of interest to observe some of the comparative material developed during this period of competition for a meson factory. As an example, Table III, published in the

TABLE III

THREE TYPES OF HIGH-INTENSITY ACCELERATORS (MESON FACTORIES) BRIEFLY COMPARED [a]

	SOC (ORNL)	Yale Linac	Mc^2 Cyclotron (ORNL)
Proposed final energy	1,000 MeV	750 MeV	810 MeV
Upper limit	> 10 GeV	> 10 GeV	810 MeV
Proposed mean current	1.0 mA	1.0 mA	100 μA
Upper limit	10 mA	1.0 mA	1.0 mA
Extraction efficiency	100%	100%	80%
Extracted beam quality	Good	Good	Probably good
Microscopic beam structure	5%	1.4%	5%
Macroscopic beam structure	100%	5%	100%
Energy spread in beam	0.1%	0.1%	0.1%
Cost of machine per watt of beam	$16	$24	$120
Machine cost for 1 GeV at 1 mA	$16 x 10^6	Extrapolated to $24.2 x 10^6	Not possible
Machine cost for 810 MeV, current as proposed	Interpolated to $13.8 x 10^6	$18.5 x 10^6	$14.5 x 10^6
Variable energy capability	Yes	Yes	No

[a]Taken from ORNL-3431, January 1963.

ORNL Report, reproduces the characteristics of three machines. Note the claims (not well justified) for a much higher beam intensity (10 mA) for the SOC than for the linac or the Mc^2 Cyclotron. Also note that the cost estimate for the SOC is lower than for the other types, although no significant engineering design effort had been applied.

G. Studies at UCLA[40]

Another group to study the design problems of cyclotrons of the high-intensity medium-energy range, specifically aimed at the production of mesons, was at the University of California, Los Angeles, under the direction of Prof. J. Reginald Richardson. This interest was stimulated by earlier experiences in the Materials Testing Accelerator (MTA) group at the Radiation Laboratory in Berkeley, including work on the "Thomas" cyclotron under security restrictions. Richardson, along with Kenneth MacKenzie and Byron Wright, had built and operated electron models of the Thomas cyclotron and developed extraction efficiencies of up to 90%.

When Richardson left Berkeley and went to UCLA, he considered plans for a relativistic cyclotron of energy up to 250 MeV and approached the Atomic Energy Commission for design support as early as 1952. This approach was discouraged because the MTA project was still classified. The matter was dropped until after the Thomas cyclotron work was declassified in 1955, in time for the Geneva Conference on the Peaceful Uses of Atomic Energy. Also, by this time the MURA group had introduced spiral-ridge focusing for fixed-field accelerators as an extension of the concept of alternating gradient focusing.

The UCLA group decided in 1957 to build a 50-MeV proton cyclotron of the spiral-ridge design, which occupied much of their efforts for the next four years. However, they continued their interest in a higher-energy cyclotron to be used primarily as a source of pions for high-energy particle research. By the summer of 1958, they had formulated plans for a design study aimed at an energy of 400 MeV (thought at that time to be limited by the $\nu_r = 3/2$ resonance) and with high intensity (10 μA) compared with the output of existing synchrocyclotrons.

In the fall of 1958, Richardson and his associates (including MacKenzie and Wright) made the first of a series of proposals to the Research Division of the AEC for support of a design study. The AEC was interested, as indicated by the late Commissioner John Williams in the spring of 1959 when he said that he favored "the best damn pion producer that it is possible to build." However, a series of delays ensued in funding the proposed study of the design for a meson factory. The official proposal[41] from UCLA was dated July 1960, but support funds were not allocated until June 1, 1962.

The laboratory at UCLA was host to the second "Conference on Sector-Focused Cyclotrons" in April 1962, which was attended by many of the most experienced and able accelerator designers in the U.S. and abroad. Most of the papers dealt with technical problems of isochronous cyclotrons that included several design studies for machines in the multihundred-MeV energy range which could produce mesons. Prof. Roy Haddock of UCLA presented a paper on "The Role of the Pion Factory in Elementary Particle Physics." Incidentally, it seems that Prof. Richardson initiated the use of the term "meson factory" for high-intensity machines in the multihundred-MeV energy range, and it was used frequently in discussions at this conference.

In 1963, Richardson conceived and suggested the use of H^- ions in a sector-focused cyclotron for a meson factory and reported the concept in a UCLA report.[42] The advantage of accelerating H^- ions in a cyclotron is that it solves the problem of beam extraction; stripping foils can be used to produce H^+ ions (protons) that then emerge from the magnetic field. Also, the energy of the extracted proton beam can be varied by changing the position of the stripping foil. The major limitation is electric dissociation of the H^- ions in the magnetic field, which increases with magnetic field and with beam energy. Beam loss due to dissociation produces radioactivity in the accelerator that could result in serious maintenance problems for energies above about 500 MeV. After further study and demonstration of H^- ion acceleration in the 50-MeV machine, Richardson made a revised proposal[43] to the AEC in 1964. This proposal was one of the competitors for support considered by the Bethe Panel to have some significant advantages, primarily variable energy, a high duty cycle, and relatively low cost. However, the Bethe Panel recommended that government support go to a facility at a National Laboratory, so the UCLA proposal was discounted. Richardson shifted his interest to assist in the design of the TRIUMF facility, which is described in the following section, at the University of British Columbia. He is presently Director of that facility.

H. Low-Intensity Meson Facilities

Three laboratories have been funded to build meson-producing accelerators in the medium-energy range with considerably lower beam intensities (0.03 to 0.1 mA) than the design intensity of the LAMPF machine. These are located at Vancouver, in Zurich, Switzerland, and at Columbia University.

TRIUMF

The Tri-University Meson Facility (TRIUMF) is a research facility for medium-energy nuclear physics under construction at the University of British Columbia, Vancouver, for nuclear scientists in three West Coast universities in British Columbia and the University of Alberta. The accelerator is a 500-MeV H^- ion cyclotron with an ejected proton beam of 0.1-mA average, based on designs initiated and developed by J. R. Richardson at UCLA. The proposal[44] was accepted and approved by the Canadian Atomic Energy Control Board in 1967 and the scheduled completion date is 1972.

A tabular listing of parameters included in the proposal is reproduced in Table IV, and compares the TRIUMF characteristics with those of other meson factory proposals as of 1966. Note that the average current is less than 10% of that listed for LAMPF, and the energy is 500 MeV compared with 800 MeV. These parameters were chosen to reduce cost and operational radioactivity hazards in order to achieve a meson "workshop" at an early date.

TABLE IV

COMPARISON OF MESON FACTORIES AND WORKSHOPS[a]

	H^- Cyclotron		Ring Cyclotron	Linac	
	TRIUMF 1966	UCLA 1964	ETH Zurich	Los Alamos	ING[e]
Energy (MeV)	500	600	510	800	975 MeV
Energy variable (MeV)	200-500	200-600	No	200-800 (in steps)	(in 2.63 MeV steps)
Energy resolution (full width)	0.3%	0.3%	0.4%	0.4%	—
Duty factor macrostructure	100%	100%	100%	6-12%	100%
Average current (mA)	0.1[c]	0.2[b]	0.08	1.2	65
Beam emittance (cm mr)	0.2	0.2	$\lesssim 3$	1	—
Average rf power (MW)	0.83	1.3	0.24	6.1	90
Overall size of accelerator (ft)	50 diam	70 diam	43 diam	2600 long	4940 long
Polarized protons[d] per second	1.2×10^{11}	1.2×10^{11}		2.4×10^{10}	
Simultaneous multiple beams	yes	yes	no	no	no
Cost of accelerator[f] (millions of dollars)	6.3	7.7	7.6	21.6	
Cost of project[f]	16.7	23.2	22.9	59.4	110

[a]Taken from TRIUMF Proposal,[44] University of British Columbia, November 1966.

[b]Current rating 0.6 mA from 200 to 550 MeV and 0.2 mA at 600 MeV.

[c]Current rating at 500 MeV; higher currents possible at slightly lower energy.

[d]For comparison purposes, a polarized source strength of 2×10^{12} proton/sec is assumed in each case.

[e]The ING project has research aims beyond those of a meson factory. The figures quoted for ING are for the Basic Machine discussed.

[f]All costs are in 1966 Canadian dollars (= 1.08 x U.S. dollars). Estimates prior to 1966 are escalated at 4% per annum. The estimates do not include contingencies.

Swiss Institute for Nuclear Research

Another medium-energy meson research facility under construction is the "ring-cyclotron" at the Swiss Institute for Nuclear Research (SIN) in Zurich. Design studies and plans have been in process at the Electro Teknical Hochschule[45] for several years. The new laboratory is being built at the nearby village of Villigen and is planned for completion in 1973. A recent status report is given in the CERN Courier.[46]

The significant feature of the design is the use of a low-energy injector cyclotron to produce 100 μA of protons at 72 MeV. This injector is a spiral-sector isochronous cyclotron provided by Philips of Eindhoven. The major advantage is separation of the chief beam-loss region (at low energies) from the main high-energy machine and hence the reduction of radioactivity buildup. The emergent beam from the injector is focused and deflected through a shielding wall into the main ring accelerator; injection and capture efficiency approaches 100%.

The isochronous ring accelerator developed at Zurich will accelerate protons from 72- to 585-MeV energy. It consists of eight spiral-sector magnets arranged in a ring with a 2-m inner radius at injection and a 4.5-m outer radius. Four rf cavities resonant at 50 MHz provide acceleration at a rate of over 2 MeV per turn; this gives an orbit separation of 8 mm at peak energy. An emergent beam is ejected between sectors. Tests on a prototype and calculations predict 90 to 95% ejection efficiency. A major problem of a positive ion cyclotron is the low efficiency of ejection and production of undesirable radioactivity by the spilled beam. At the modest intensities planned for this machine, the radioactivity buildup is expected to be kept within manageable values.

The emergent beam is brought to an experimental hall to feed two primary target stations. One will have a thin target serving as the source of three pion beams and a nucleon beam; the other will have a thick target and will be the source of four pion beams (one to be used for medical purposes) and a muon beam using a 10-m superconducting solenoid channel. A polarized ion source and a polarized target are also planned.

Columbia University

The 385-MeV synchrocyclotron at the Nevis Laboratory of the Columbia University Physics Department has been used for research on medium-energy physics since 1950 with an internal circulating beam of about 0.4 μA. Ten or more other synchrocyclotrons throughout the world, of 300- to 700-MeV energy and similar intensities, have also explored this research field. In recent years, significant new research results in this field have been increasingly difficult to obtain due to low intensities. Funds for support are in short supply and several synchrocyclotrons have been closed down.

At Columbia, a proposal[47] for rebuilding the cyclotron as a sector-focused machine of 10 to 100 times higher beam intensity and higher energy was approved and funded by the National Science Foundation (NSF) in FY 1966, and reconstruction is in progress. The status was reported at the Particle Accelerator Conferences[48] in 1969 and 1971. Two modifications combine to raise the space charge limit that had restricted intensities in the early synchrocyclotrons: strong focusing and a high vertical oscillation frequency (ν_z) are obtained by using spiral-sector focusing with three-fold symmetry; and the frequency of modulation is increased to 300 Hz, which involves higher rf voltage and increases the macro duty cycle to 50%. Additional excitation coils near the magnet gap and shorter pole separation at the periphery provide the higher energy. The expanded facility should be in operation in 1972 at 550-MeV energy with an average emergent beam of up to 30 μA, capable of producing meson intensities sufficient to extend research into a variety of new programs.

I. Intense Neutron Generator

The most ambitious plan to date for a medium-energy very high-intensity accelerator was the Intense Neutron Generator (ING) proposal at the Chalk River Laboratory of the Atomic Energy of Canada, Limited (AECL), for a proton linac of 975-MeV energy operating on a 100% duty cycle at an average current of 65 mA. This major research facility was intended to provide a source of secondary neutrons with an intensity (10^{16}/cm^2) exceeding that of any available nuclear reactor. It would also have been the world's highest intensity source of pions, muons and neutrinos, although its purpose was much broader than that of a meson factory. A technical proposal[49] was published in 1966, and was under study for two years by committees of the Canadian Science Council and government officials. The proposal was turned down by the Government of Canada in the spring of 1968, and the project is now in abeyance.

The ING project had its origin[50] in the long-term interest of W. B. Lewis in the use of nuclear spallation reactions for the production of energy. Preliminary studies of the yield of neutrons from high-energy protons were made at Chalk River as early as 1952 (when the MTA project was being started at Berkeley). The problem was revived in 1963 by the late Lloyd Elliott, who initiated a study of the physics of neutron production. The first studies were performed by G. A. Bartholomew, J. D.

C. Milton, and E. W. Vogt, who concluded that spallation by high-energy protons should be an effective technique.

Various accelerators were considered initially, with primary interest in the Separated Orbit Cyclotron (SOC) proposed by Russell[39] of the Rutherford Laboratory. Design studies continued at Chalk River through 1966, with increasing concern over the escalating cost estimates for the SOC. The technical problems of the ING proposal were largely associated with the very large rf power requirements and with the anticipated high levels of radioactivity.

In 1966, a delegation visited Los Alamos and was impressed with the potentialities of the LAMPF developments, and from that date the planning was changed to a linac based largely on LAMPF designs but operating on a 100% macro-duty-cycle. The detailed development was curtailed by limitation of design funds, so the engineering design has not been completed.

CHAPTER 4

TECHNICAL DEVELOPMENTS AT LAMPF

A. Design Specifications

The group of LASL staff members who were attracted, in the summer of 1962, by the dream of a meson factory at Los Alamos had one thing in common – a desire to renew the quality and vitality of nuclear physics research at Los Alamos. The initial goal was to define the scope and criteria of the project and to prepare a preliminary proposal. Most of the group were research scientists and theoretical physicists, intrigued with the new fields of research that would be opened by the very high-intensity beams of mesons and other radiations; some contributed by planning new experiments and estimating yields. Teams from LASL visited existing accelerator laboratories and studied the potentialities of the several possible types of accelerators as meson producers; they quickly chose the proton linac as the most desirable machine. Still others with engineering experience studied problems of site development, buildings, facilities, and power requirements, and then prepared plans and cost estimates. An *ad hoc* "steering committee" organized this interest into a study program that produced the Preliminary Proposal[3] of December 28, 1962. In the following year a Schedule 44 was submitted to the AEC as the official request for support.

There were no linac experts at Los Alamos in 1962 and only a few who had experience with other accelerators. It is not surprising that the technical characteristics of the linac presented in their Preliminary Proposal were taken directly from Yale Report Y-6. But this situation was to change remarkably in the next few years. The small LASL design group entered at full speed into a program of basic analysis, model studies, and prototype development that brought them to equivalence with more experienced linac laboratories within a relatively short time.

At the time the LASL group entered the linac design competition, they found general agreement on the techniques to be used for proton energies of up to 100 MeV. The "classical" Alvarez drift-tube structure operating in the 2π mode at 200 MHz was by far the most efficient structure and had adequately high shunt impedance. There was also general agreement that triode power amplifier tubes were acceptable as power sources at 200-MHz frequency. For example, the RCA 7835 tube had been used successfully with the 50-MeV injector linac at the Argonne ZGS laboratory to provide 5-MW pulses to the linac tank. Others had used triodes of lower pulse power ratings, in parallel.

The area of design that was in a state of flux in 1962, with no clear indication of the direction of future development, was the higher frequency (800 MHz) structure required for protons of energy above 100 MeV. Both the type of structure for these higher frequencies and the power sources to excite the system were uncertain and required further development before decisions could be made. The starting point was the Yale design which proposed a set of iris-loaded waveguide cavities operating at either 800 or 1200 MHz. The first Yale design report called for 142 cavities, each 2.5 m long and operating at 805 MHz to produce 600 MeV. Although this system was the initial LASL reference design, it was fully expected that major changes would come with further development. It was also believed that rf power amplifier tubes suitable for cavities at this frequency would become available in the near future from commercial developments.

The decision to use a frequency of about 800 MHz for the major portion of the linac came from analyses similar to those at Yale. Wheeler and others in the Yale group had calculated the longitudinal dynamics of protons accelerated in a 200-MHz drift-tube linac to an energy of 100 MeV or higher. They found that during acceleration the phase spread damps to about 1/4 of the phase acceptance at injection. This reduced phase spread can fit into the phase acceptance bucket of another linac having a frequency of 4 times 200 MHz. The LASL designers recalculated the dynamics of phase motion and arrived at the same conclusion. So the frequency of the high-energy portion of the linac (805 MHz) was chosen to be the fourth harmonic of the drift-tube linac frequency of 201.25 MHz.

The first opportunity for the LASL staff to demonstrate their new-found expertise was at the Linac Conference[51] held at Yale in October 1963. Sixteen LASL representatives attended. The LASL staff had no real experience with a linac as yet, but Nagle had become a capable systems analyst, Knapp was an expert on rf structures, and others had become accomplished in other fields. The iris-loaded waveguide described in Yale Report Y-6 was studied in some detail and was found to be limited by severe phase shifts and amplitude distortions during turn-on and in the beam-loaded state. Computer analyses, calculations, and model studies made at LASL verified this limitation. These self-made experts submitted several papers for the Conference; papers were presented by

- D. E. Nagle and E. A. Knapp – Behavior of Coupled Circuits,
- E. A. Knapp – Accelerating Structure Research at LASL,
- M. Jakobson – Standing vs Traveling Waveguides,
- D. C. Hagerman – RF Power Sources,
- A. D. McGuire – Experimental Target Area Design, and
- H. G. Worstell – Hydrogen Purging Technique.

Back at LASL, a model program for testing accelerating structures was under way. In turn, the known types were theoretically analyzed and dimensions calculated. Each type was first tested with lightweight models at low power to measure the basic parameters and then with working prototypes at high rf power. They investigated the standard Alvarez-type drift tubes for 200-MHz operation. But most of the effort was in studying 800-MHz structures such as the "iris-loaded" waveguide, the "crossbar," and the "cloverleaf" π-mode cavities.

The most important progress during 1963 was the start of a development program on resonant coupled structures, first described by Dunn, Sable, and Thompson[29] at Harwell, which eventually led to the LAMPF side-coupled cavity system. Coupled resonator analyses were made by Nagle and Knapp. Models were built and tested in which the coupling structures were various resonant devices attached to the outside of the array of accelerating cavities, with each coupling device viewing two successive cavities. Properties improved with continued development of shapes of cavities and coupling structures. Eventually, it became evident that the side-coupled cavity was a new and different linac structure with greater stability and higher rf efficiency than any of the structures considered previously.

The next Linear Accelerator Conference[52] was held at the MURA laboratory in Madison on July 20-24, 1964. By this time the LAMPF design group was much more experienced and in certain respects they were leading the field. At this conference, the germs of all basic ideas to be used in the LAMPF linac were available for presentation and most of the theoretical calculations had been made. Some of the new ideas had yet to be tested and proven in the laboratory, but the essential principles were understood and the important decisions had been made. Sixteen members attended the conference and eight papers were presented.

- D. E. Nagle – Coupled Resonator Model of Linac Tanks.
- E. A. Knapp – 805 MeV RF Structure.
- M. Rich and W. M. Visscher - Green's Function Calculation of Drift Tube Cavities.
- H. C. Hoyt – Drift Tube Calculations.
- M. Jakobson and W. M. Visscher - Particle Dynamics at High Energy.
- M. Rich – Beam Dynamics Calculations for Alvarez Linac.
- R. A. Jameson – RF Phase and Amplitude Control.

Another important event for LAMPF was the Summer Study Session held during July and August 1964. A number of prominent scientists attended and discussed the future experimental program with the LASL staff. Among the visitors were H. Fechter, A. Goldhaber, A. Kerman, H. Frauenfelder, M. Ebel, and E. Henley. This summer study initiated the planning activity that culminated in the formation of a LAMPF Users Group in June 1968.

In the Theoretical Division, Harry Hoyt developed a computer code for analyzing the rf efficiency and the field patterns of three-dimensional cavities; this "LALA" code has been widely used by other linac design groups.

The experimental program that paralleled the planning effort was carried on in the "mock-up building" adjacent to the Physics Division laboratory. One of the early important jobs was to build and test an electron analogue[53] of the cloverleaf type of resonant-cavity accelerator system. This was the first structure seriously studied to be used for proton acceleration. Knapp designed the cloverleaf structures, which were built in the LASL Shops Department, SD-5. Hagerman developed and built the rf power system needed for the model. The staff member primarily responsible for the tests was R. Emigh, assisted by D. Mueller and J. Brolley. For the tests, a 20-cell section of the cloverleaf-type cavity resonating at

805 MHz was installed within a cylindrical vacuum chamber. Electrons were accelerated to 189 keV by a dc power supply and then given an additional few keV energy by rf power applied to the cavities. The efficiency of the resonant rf system was determined using stopping potentials of 1 to 2 kV applied to a grid at the beam exit. Because the velocity of 189-keV electrons is the same as that for 347-MeV protons, the properties of the accelerating structure for high-energy protons could be tested with this much simpler electron source.

The design phase culminated in a set of system parameters that defined the goals to be achieved. These are described in the first Quarterly Report of the newly established MP Division, as of July 1, 1965. They provided basic specifications for further detailed development and were not significantly modified as studies proceeded.

The unique characteristics of the proposed LAMPF linac were its long duty cycle and its very high average intensity. Beam loss in the accelerator structures, beam handling, and targeting took on a much greater significance than in any previous accelerator. The cumulative harmful effects of small errors and misalignments, or of noise in electrical systems, required more careful analysis and precision of construction than had previously been needed for proton linacs. As a consequence, the engineering involved in the detailed design and construction required a high level of quality and perfection of detail. Continuing development of cooling procedures to maintain physical dimensions was needed to meet the special demands coming from those high power requirements. By early 1965, the design specifications were complete, model tests had been made, and most of the special features needed to meet the high-intensity goals were basically understood.

B. Ion Sources and Preaccelerators

A favorable feature of the linac as an accelerator is that several kinds of particle beams can be accelerated simultaneously (or sequentially) in each pulse and can be analyzed into separate beams at the target station to supply independent research experiments. It is desirable to have separate ion sources and preaccelerators for each of the different particle beams. At LAMPF this flexibility was recognized and plans were made at an early date to locate three preaccelerators at the input end of the linac. In the earliest plans, one was the primary high-intensity proton beam injector, a second was a spare in the event of injector failure, and the third was for a future polarized beam injector. At a later date a negative hydrogen ion beam injector was substituted for the spare proton injector to give still greater flexibility.

The injector system consists of three separate ion source and preaccelerator units, capable of operating either independently or at the same time. The three beams go into a beam transport area which directs each one into the entry end of the drift-tube linac without interference with the others. The pulsed beams are timed to enter at preselected instants during the rf accelerating cycle. Each preaccelerator unit is housed in a large room-sized enclosure formed of aluminum sheet, insulated, and grounded at one point. The purpose of this Faraday cage type of enclosure is to minimize the effects of sparks from the high-voltage terminal of the preaccelerator on external electrical apparatus. The enclosures are made 20% larger than would be required at sea level to avoid sparking in the reduced atmospheric pressure at the Los Alamos elevation. Dimensions and specifications were provided to the architect-engineers at the time the building design was revised in 1966 by Robert Emigh, who was responsible for most of the preaccelerator and ion source development and was Associate Group Leader of MP-4 (Injector Systems) from the time it was organized in 1965 until it was reorganized in 1971.

Two 750-kV high-voltage generators of the Cockcroft-Walton voltage multiplier type, designed by the Injector Systems Group, were contracted to Haefely, Inc., of Basel, Switzerland. The Haefely Company has also supplied high-voltage sets of this type to other linac laboratories in this country in recent years. The voltage multiplier circuit is basically simple; it uses solid-state rectifiers supplied by 5-kHz transformers to charge capacitors in parallel and discharge in series. The high-voltage terminals are enclosed in smoothly finished aluminum housings supported on insulating columns. The units ordered for LAMPF are rated for 1.0 MV at sea level but operate at 0.75 MV at Los Alamos.

From the start of design planning, a primary concern has been the development of proton sources capable of providing very high-intensity beams with large duty factors. Earlier proton linacs did not have such rigorous specifications. Mueller initiated the LAMPF ion source program in the spring of 1966 when he visited Brookhaven to study their developments. For a high-intensity proton source he picked the Brookhaven design, a Von Ardenne duoplasmatron source with expansion cup. After further development at LASL, including design assistance by Emigh, this source has produced peak currents of over 100 mA during pulses of over 500-μsec duration and with a time duty factor of up to 12%.

One of the most persistent problems has been the development of a modulator circuit for the duoplasmatron arc that will give constant current and voltage during a very long pulse. The modulator output of about 200 V is applied to the cathode of the ion source. After three to four years of development, a circuit has been evolved that provides reasonably stable long pulses of 50- to 100-mA output; nevertheless, further improvements are still considered desirable. Another technical problem has been the development of a satisfactory plasma aperture. The solution achieved at LAMPF is a 30-mil aperture in a septum formed as a sandwich of iron (for magnetic focusing) and copper (to conduct heat) sheets welded together. Mueller and Emigh have been jointly responsible for most of these source developments.

An important advantage of the LAMPF accelerator over other types of proton accelerators is that beam losses can be very small, reducing the otherwise serious radiation problems. To take advantage of this inherent capability, the quality of the injected beam must be extremely good (low emittance). Theoretical work on the design of an accelerating column to extract protons from the duoplasmatron source and maintain a low emittance in the column was begun in 1966.[54] A 200-keV partial prototype was built and successfully tested in 1967. A full 750-keV accelerating column was built by Earl Meyer, who joined MP-4 in 1967, and was operational in 1970.

The possibility of accelerating negative hydrogen ions (H^-) during the reverse phase of rf potential in a proton linac has been recognized by several designers. H^- ions have the significant advantage of being magnetically separable from the proton beam following acceleration to high energy. They can then be transformed into H^0 or H^+ particles on traversing "charge-stripping" foils. The need for a separately controlled ion source for the High Resolution Spectrometer was discussed in a Users Summer Study in 1968, and led to the suggestion that a H^- beam be used for the purpose. The advantages of a negative-ion beam at LAMPF were first presented by Allison and Emigh[55] in 1968. It was an easy decision for the LAMPF planners to adapt the available spare proton injector system to this purpose.

A H^- ion source of the charge-transfer type has been developed by Allison who joined the Injector Group in 1966. The source which Allison built and bench tested at LAMPF directs a 100-mA beam of H^+ ions at 15 kV from a standard duoplasmatron proton source through a channel filled with H_2 gas at low pressure, and yields a H^- ion beam of 1 to 2 mA. The development started in 1969 and the second Cockcroft-Walton preaccelerator was ordered from Haefely, Inc., at that time. A larger ion source enclosure was specified to house the H^- source. The system was installed in the Injector Building in 1971 and was ready for use after preliminary 800-MeV operations.

A third bay in the Injector Building is reserved for another Cockcroft-Walton preaccelerator having a polarized hydrogen ion source. Plans are made, and support funds have been requested, to procure this third preaccelerator in FY 1973. A polarized H^- ion source has been developed[56] by McKibben and associates in Group P-9 of LASL's Physics Division, and is used for research experiments with the Van de Graaff generator. Ralph Stevens joined Group MP-4 in 1966 and is in the process (1971) of adapting the polarized source to fit within the dome of a Cockcroft-Walton set. Progress toward achieving such a polarized source is consistent with plans for procuring the third preaccelerator unit described above. Meanwhile, the original polarized H^- ion source is being used by McKibben and his associates in P Division.

C. Drift-Tube Accelerator

As mentioned earlier, the type of accelerator used for the first 100 MeV was accepted from the start to be the Alvarez drift-tube linac developed in many laboratories over a period of 10 to 15 years. The most advanced design in progress during 1962-1964 was at the MURA laboratories in Madison, by a team consisting of F. Mills, D. Swenson, J. Von Bladel and D. Young. The geometry of the MURA drift-tube and tank structure was based on the MESSYMESH computer program developed by R. Christian, formerly of Los Alamos, which solved the electromagnetic field equations within the linac tank. If the input to this program is the geometry of the drift tubes and the external tank, the computer output will give the resonant frequency, impedances, fields, and power losses. It was the first linac program to include the effect of the axial holes in the drift tubes. The LASL planners talked with MURA staff members at an early date and decided to base their 100-MeV section on the MURA design. It was sufficiently well understood that its specifications were accepted and used in the first LASL proposal without modification. Therefore, only a minor effort was applied to the drift-tube linac at LASL for the first two years, while more difficult problems were being worked out.

Swenson, who had done much of the particle dynamics calculations at MURA, joined the Los Alamos project in December 1964 and was assigned responsibility for the detailed design of the drift-tube linac. He utilized the same MESSYMESH computer program, developed geometrical shapes and dimensions, and made particle dynamics analyses. Earlier, Visscher and Rich of T Division had done some basic dynamics calculations – sufficient to prove feasibility of the two-element linac system for the original proposal. From the time of his arrival, Swenson took over the drift-tube linac at LAMPF. His assignment was as Associate Group Leader of MP-3, Accelerator Structures. Swenson's conclusive dimensional analysis is contained in an internal LASL Report.[57]

In 1966, Swenson and K. Crandall made space charge calculations for the drift-tube linac and did the beam-loading analysis, with the important guidance of R. L. Gluckstern as Consultant. Gluckstern had done most of the original analytical calculations at Yale; Crandall handled the detailed numerical calculations for the LAMPF machine. Incidentally, Crandall also made the basic particle dynamics calculations for the side-coupled cavity linac, working closely with Swenson.

The early beam loading studies at Yale made it seem probable that a drift-tube linac could accelerate very high proton beam currents, of 100 mA peak intensity or higher. Such an extremely high peak current was found not to be necessary at LAMPF. Rather, design planning at LAMPF was directed toward a very large duty factor, initially 6% and ultimately 12% of total time, to provide a long operating cycle for experiments using electronic detection equipment. So the significant paramenter at LAMPF became the average current, which was chosen to be 1.0 mA. With a 6% duty factor, the peak current requirement is only 17 mA, well below the maximum achievable. However, the large duty factor and the large average current of 1.0 mA result in a beam power of 100 kW. This average power is ten times greater than was achieved in previous linacs of comparable energy with duty factors of less than 1%. As a result, all hardware in the linac has been designed for a considerably higher average power level than for any previously designed linac. This feature has required some significant changes in the structural design of the drift tubes and the enclosing cavities. For example, water cooling passages are provided in the noses of drift tubes, and the enclosure tanks are surrounded with water jackets.

The LAMPF drift-tube linac development has been aided by paralleling developments in two other laboratories: the Mark II 200-MeV injector linac for the AGS at Brookhaven, and a 200-MeV injector linac for the 200-GeV machine at the National Accelerator Laboratory in Batavia, Illinois. These three new linacs were in process of design and construction during the same period between 1966 and 1970. Consultations between the three groups were so frequent and complete that each group benefited significantly from design improvements of the others. The three laboratories chose essentially the same basic design features, including the use of copper-clad steel tanks, quadrupole magnets mounted within drift tubes for focusing, and the same frequency of about 200 MHz.

One significant difference at LAMPF is that the design energy is only 100 MeV, utilizing the economic advantage of the side-coupled cavity structure for energies above 100 MeV. The design energy of the drift-tube linac has changed several times as the plans and designs for higher frequency cavities proceeded: from 200 MeV in 1962, to 160 MeV in 1964, and back to 200 MeV in 1967 in Swenson's first dimensional analysis. The decision to reduce energy to 100 MeV was made in 1968 with the experimental success of a side-coupled cavity model and revised cost analyses which showed the economic breakpoint to be lower than previously expected.

A 4-ft-long tank that could be equipped with full-size drift tubes was built in early 1967 for model studies. It was used for full power tests at 200-MHz frequency and to study the cooling requirements with long pulse lengths (6%). It was also used in developing a ceramic window for inserting an rf coupling loop.

The most significant improvement originating at LASL was the discovery by Knapp and Swenson in June 1967 of the "post coupler" for tuning and stabilizing the drift-tube structure; it has improved the stability by a factor of 100 or better. Knapp had noted that the excellent stability of the side-coupled cavity system at 800-MHz frequency was due to the $\pi/2$ resonant side cavities used for coupling, and hoped to stabilize the 200-MHz drift-tube structure by a similar technique. He suggested the first structural arrangement. Swenson suggested a second technique using T-bars along the inside of the tank enclosure. They combined their ideas to conceive and develop a system using a set of resonant stems along the tank wall opposite each drift tube, with eccentric nosepieces on the stems to adjust the tuning of the tank. They recognized that such a stem coupler was excited $\pi/2$ out of phase and did not dissipate power, in a manner similar to the $\pi/2$ resonant side cavity used for coupling in the 800-MHz system.

When LAMPF reported their post-coupler concept, the Brookhaven design was too far along for BNL to utilize the idea; they had earlier developed a multistem system that provided many of the same properties. However, the NAL designers recognized this feature as an important improvement and did incorporate it in the design of the NAL 200-MeV linac.

The final design of the drift-tube linac at LAMPF consists of four tanks: one short tank accepting protons from the source at 0.75 MeV and accelerating to 5 MeV, and three longer tanks producing terminal energies of 41, 73, and 100 MeV. The total length including intertank spacings is 202-1/2 ft. Final parameters of the drift-tube linac are given in Table V.

The first step in constructing the drift-tube linac was to build and test the short 5-MeV tank. Because this included the shortest drift tubes with internal quadrupole magnets and had the most congested spacings, it represented the most critical part of the linac. To braze drift tubes and quadrupoles at elevated temperatures, the quadrupole windings were constructed with ceramic insulation. This feature has proved to be a valuable asset during high-power operation and as protection against radiation

TABLE V

DRIFT-TUBE LINAC PARAMETERS

Cell No.	Tank 1 1 to 31	Tank 2 32 to 59	 60 to 97	Tank 3 98 to 135	Tank 4 136 to 165
Energy in (MeV)	0.75	5.39		41.33	72.72
Energy out (MeV)	5.39	41.33		72.72	100.00
Δ energy (MeV)	4.64	35.94		31.39	27.28
Tank length (cm)	326.0	1968.8		1875.0	1792.0
Tank diameter (cm)	94.0	90.0		88.0	88.0
D. T. diameter (cm)	18.0	16.0		16.0	16.0
D. T. corner radius (cm)	2.0	4.0		4.0	4.0
Bore radius (cm)	0.75	1.0	1.5	1.5	1.5
Bore corner radius (cm)	0.5	1.0		1.0	1.0
G/L	0.21-0.27	0.16-0.32		0.30-0.37	0.37-0.41
Number of cells	31	66		38	30
Number of quads	32	29	38	20	16
Quad gradient (kG/cm)	8.34-2.36	2.44-1.89	1.01-0.87	0.90-0.84	0.84-0.83
Quad length (cm)	2.62-7.88	7.88	16.29	16.29	16.29
E_0 (MV/m)	1.60-2.30	2.40		2.40	2.40
φ_s (deg)	-26°	-26°		-26°	-26°
Power (MW)	0.305	2.697		2.745	2.674
Intertank space (cm)	15.90	85.62		110.95	—

Total length including intertank spaces = 6174.281 cm (202 ft 6.819 in.)

damage. The 5-MeV unit was installed in the drift-tube section of the linac tunnel in early 1970 and was operated for the first time on July 1, 1970.

Assembly of the remaining three tanks of the drift-tube linac was completed in early 1971, and first operation at 100-MeV energy and 1-mA current intensity occurred on June 21, 1971. Tune-up and operational performance tests continued intermittently for the following year, resulting in routine operations before July 1, 1972.

D. Waveguide Structures

A linac is a linear array of coupled resonant cavities or circuits in which the rf voltage across successive gaps is in phase to accelerate the moving particles. In proton linacs the standing wave set up must have identical phases across the accelerating gaps even though the spacing between gaps increases with particle velocity. Power is fed in to compensate for resistive losses and beam loading effects, preferably at only a few points along the waveguide. The problem is to control both amplitude and phase and to keep the accelerating electric fields constant along the successive gaps as beam loading is increased. This was a recognized difficulty in the early drift-tube type linacs and led to severe beam current limitations. It was also a known limitation in the designs proposed at Harwell and Yale for higher frequencies.

In electron linacs such as SLAC the particles travel at essentially the velocity of light. The waveguide is iris-loaded with a uniform iris spacing that produces a group velocity equal to that of light, and it propagates a traveling wave in the π-mode. Electrons ride the front of the traveling wave much as a surf board rides a water wave. The accelerating electric fields can decrease along the waveguide without affecting the phase as beam loading increases. The simultaneous control of both amplitude and phase is not needed for such relativistic particles, and the points where power is fed into the waveguide are not critical.

Early experimental studies of structures for high-energy proton linacs were based on the developments at Harwell and Yale. The cloverleaf-type cavity initially showed the best promise and was the first to be modeled and studied in detail at LASL. It had good rf characteristics but was difficult and costly to build. Nevertheless, a full-scale 40-cell unit was built and tested at high power. Measurements on cloverleaf models continued for several years, until the side-coupled system had been thoroughly developed and proven.

Dunn, Sable, and Thompson of Harwell first proposed[29] the use of resonant coupling structures between successive accelerating cavities in a high-energy proton linac; however, they did not find an efficient coupling device. From the start, it was recognized that a standing wave system was more suitable than traveling waves for a proton linac, and that both amplitude and phase must be controlled and corrected for beam loading along the full length of the linac. This required a sequence of resonant cavities producing accelerating rf fields. To keep such resonant systems in phase the cavities must be tightly coupled. The Harwell scientists suggested that these coupling systems should also be resonant, and experimented both with loop couplers and with resonant slots.

The development at LAMPF that led to the side-coupled cavity system started from the early Harwell concepts and was improved in a series of steps starting in 1963. The persons chiefly concerned with the analysis were Knapp and Nagle. The technical development was accomplished by a team led by E. Knapp consisting of B. Knapp, W. Shlaer, and J. Potter. It was recognized that the resonant coupling system should operate in the standing wave $\pi/2$-mode which has no power loss except for resistive losses due to transmitted power. To transmit power for the beam and to make up losses, a traveling wave component must also be present; this requires phase shifts that involve higher-mode terms. The first resonant-coupling model used at Los Alamos had external $\lambda/4$-wave coaxial lines with coupling slots opening into two adjacent accelerating cavities. Experiments with this model showed excellent response to tuning the coaxial lines and good control of phase along a multicell model. In fact, this early model later led to the concept of tuned $\lambda/4$-wave resonant posts applied to the Alvarez-type drift-tube accelerator.

Next, an external resonant cavity operating in the $\pi/2$-mode, coupled by slots viewing each of two successive accelerating cavities, was found to be an even more efficient system to provide the necessary phase shifts. Continued studies with experimental models led to major improvements (increases) in the shunt impedance of the system. The shape of the resonant accelerating cavity was modified by rounding the inner wall surfaces, which lowered resistive losses and reduced the volume of magnetic field. Nose cones were added that raised the shunt impedance due to the transit-time effect. The result of the several shape modifications was to raise the shunt impedance by about a factor of three above that of the equivalent iris-loaded waveguide; the power needed to produce a given electric field for acceleration was reduced by the same factor.

The resonant side-coupling cavity was also modified in shape to reduce resistive losses, to minimize construction costs and errors, and to provide a mechanism for precision fine-tuning after installation. Still another experimental study was to determine the most efficient size and shape of the coupling slots between the coupling units and the accelerating cavities.

The resulting coupled system operates at the center of the pass-band where the slope is steepest and so gives maximum mode separation and is least sensitive to coupling errors or tuning errors. Field amplitudes in the accelerating cavities are independent of frequency errors to the first order. It was observed that the side-coupled cavity system had greater stability and higher rf efficiency than any previously considered structure for proton linacs.

A movie was made to demonstrate the coupled-circuit theory, which explains and interprets the performance. To illustrate, a computer program developed the amplitude and phase response with time of each cavity in the system, and the response is shown in the film. The movie has been shown to interested audiences at several recent linac conferences.

The first report of the side-coupled cavity and its tuning system was made to the 1964 Linac Conference[52] in Madison. Step-by-step developments were reported in a sequence of other conferences during the next few years. As a result, the principle was never patented and became available to all. One consequence was that commercial firms manufacturing electron linacs for x-ray applications have adopted the side-coupled cavity for their electron linacs that produce multi-MeV x rays for hospitals, medical centers, and industrial plants. With this structure, unusually high field gradients are possible, of over 4 MeV/ft. The short physical length of linac allows gimbel-mounting of x-ray units, a distinct advantage for therapy applications. By 1971, Varian had markered 4-, 8-, and 12-MeV units, SHM 4-MeV, Arco 12-MeV, Nippon Electric 4-MeV, and Mitsibishi Electric 6-MeV units.

In October 1968, a 4-ft model of an early side-coupled cavity design was installed as the resonant load on the test stand, and considerable time was spent making measurements of gradients and fields at high rf power levels. Shapes for the final prototype and the production units were determined from these studies. A decision was made about this time to perform the final machining and assembly steps of the linac construction at LAMPF in the Equipment Test Laboratory, and suitable machine tools and furnaces were installed.

An important part of the waveguide story concerns the development of the technical expertise to build and assemble the complicated structures. This program was aided by the transfer to MP Division of experienced engineers and technical staff having previous experience with vacuum systems, pumps, precision-made chambers, alignment supports, etc., from the Physics Division, GMX Division (the PHERMEX program), and other LASL Divisions.

The engineering design of the waveguide structures was initiated by E. Knapp and D. Nagle. Mechanical engineering and supervision of construction was provided by Hairston (Spike) Worstell and his technical staff. Worstell came to Group P-11 in September 1963 as their first mechanical engineer to work on the model program. He had previous experience in the PHERMEX program, which involved linac-type cavities and vacuum systems. When the MP Division was formed in July 1965, Worstell became Associate Group Leader of MP-3 (design, development, models), and chief mechanical engineer for accelerator structures. During the design phase, the MP-3 engineering staff reporting to Worstell included most of the mechanical engineers, draftsmen, machinists, and technicians employed in the model program. A variety of waveguide models were designed, installed, and operated by this group; this included several cloverleaf cavity systems, one of which was installed in a vacuum chamber and operated with electrons, by Emigh and his associates, to gain experience with rf systems. The culmination of the model program in 1968 was the Electron Prototype Accelerator (EPA), which was the first practical test of the side-coupled cavity system. Construction of the waveguides for the EPA was carried out at CMB-6, the LASL metallurgical group.

An early technical decision was to subcontract as much as possible of the casting, forging, crude machining, shaping, etc., to outside firms, but to do all the critical work of finishing, final assembly, and precision tuning of the waveguides in the Equipment Test Laboratory (ETL) at LAMPF. Many factors were involved in making this decision, including problems of transportation, engineering supervision, and the special brazing treatments required. For example, there were 352 separate accelerating tank sections built for the 805-MHz waveguides, each with different dimensions. Few commercial firms were equipped with brazing furnaces capable of assembling full-length tank sections. One of Worstell's first assignments was to design and procure electric-heated, hydrogen-purged furnaces to perform the great variety of brazing operations; these were installed in a special high bay in the ETL Building. Lathes were procured for the precision turning jobs required for cavity tuning; test stands designed by the rf group were installed to life-test the klystrons provided by commercial firms; and cleanrooms with filtered air were installed to handle assembly procedures requiring a dust-free environment. Another reason for local assembly was to minimize the initial stock of spares and to be able to replace units rapidly if necessary.

During the accelerator design phase, the mechanical engineers and draftsmen on the LAMPF staff produced about 2000 drawings, most of which were used to specify production contracts. More than 80 vendors and contractors used these designs to fabricate accelerator components. Procurement of the materials for the waveguides and other machine components was greatly aided by the Supply and Property Department of LASL, particularly by R. J. VanGemert and D. Bryson.

Other LASL divisions and shops have contributed to the total local effort: CMB-6 makes the ceramics for insulators; SD-5 does many specialty machining jobs and provides experienced machinists for the LAMPF shops; the inspection department of SD-4 provides engineering inspection services; the SP (Supply and Property) Department does the buying, keeps records, makes payments, and controls shipping; the Personnel Department supplies new staff needs. In summary, it is clear that the experienced staff and the technological expertise existing at LASL provided much of the know-how needed to build the LAMPF accelerator.

E. Radiofrequency Power Systems

The type of rf power amplifer most suitable for excitation of the high-frequency 800-MHz structures needed for the major portion of the linac was a source of argument between experts for several years. George Wheeler and his collaborators at Yale did exploratory design studies for a linac meson factory and believed strongly that a triode power tube would be best, using the "coaxitron" design then under development at RCA which had been successful at lower frequencies and lower peak power. Blewett at Brookhaven also favored triodes; his 50-MeV injector linac for the AGS used 200-MHz triodes built by the CSF Company in France.

In 1962, most linac experts strongly disliked klystrons, probably due to unfavorable experiences with klystrons during the development program at Brookhaven. Furthermore, no klystrons had yet been built for 1-MW peak power desired for the linac application at 800 MHz. Still another possibility was the "amplitron" being developed at Raytheon, a crossed-field amplifier using a secondary emission cathode theoretically capable of long tube life and high rf efficiency. This was the existing situation when LASL entered the field in 1962, and it continued without much change until late 1964 when the definitive LAMPF proposal was submitted to the AEC.

The original team considering the technical problems of linac design at LASL consisted of D. Nagle, E.

Knapp, D. Hagerman, and A. McGuire. As the design study intensified, Hagerman became individually responsible for the planning and supervision of the rf power problems and the other members specialized on other aspects. The LASL staff at that time had no applicable experience in rf power systems to help them make a choice between the three potential types of power tubes. It seemed that their only recourse was to sponsor the development of suitable tubes by manufacturers, and to build a test facility at LASL to observe the comparative performance.

RCA made a proposal to LASL in August 1963 to develop a 1-1/4-MW peak power tube of the "coaxitron" design for 800-MHz frequency, with 50% rf efficiency and a duty factor of up to 5%. This fitted the needs, so LASL placed a development contract with RCA for five tubes on the basis of their proposal. Meanwhile, a negotiation for a joint LASL-Yale-Brookhaven development order with RCA was started, but progress was slow due to limited funds. In September 1963, Raytheon sent a proposal for a 1-MW amplitron operating at 200 MHz; however, this proposal was for the wrong frequency and was not acceptable.

The first technical step at LASL was the construction of a power tube test stand which was mostly built of surplus equipment from a discontinued Nike-Zeus radar installation at White Sands. The first tube to be tested was a 100-kW tetrode to be used as an intermediate power amplifier (IPA). The first RCA coaxitron for 1-1/4-MW peak power at 800 MHz was received and put under test in December 1964. The last tube of this first order from RCA came in June 1965. During this testing period many unpleasant surprises occurred; the tube characteristics failed to meet the anticipated specifications in many ways. A major limitation was the short lifetime and short duty cycle; a typical result was 50-h life at 1% duty factor. The state of progress was reported[58] to the National Accelerator Conference in early 1965.

Thomas Turner, who had previous experience with rf power systems at SLAC (Stanford) joined Group P-11 in 1964. His first assignment was to develop a 100-kW driver stage for the RCA coaxitron. This development ultimately succeeded, using a klystron built for the television industry by Eimac (4KM70LH), and was used as the driver in the test station during the 1965 testing of RCA triodes on resonant loads. This was LASL's first success with a klystron; later the unit was permanently installed in the LAMPF system. Turner played a leading role in the rf development until his untimely death in 1970.

This first success with a klystron stimulated further studies. R. Jameson, who had joined LASL in 1963 and did a PhD thesis at LASL for the University of Colorado in RF Controls Engineering, continued his studies on controls and transfer functions of triodes and klystrons.[59] He found the klystron tractable for controls and acceptable as a resonant circuit driver. This was a major step forward. From this time (mid-1965) on, the klystron replaced the tetrode for drive applications.

A second contract was placed with RCA in late 1965 for further development of a 6% duty factor triode. Studies of these RCA 1-1/4-MW triodes continued on the test stand during 1966.

During 1966, the desire to have a still higher duty factor (12%) and higher average power grew to become a firm demand. It was increasingly obvious that the RCA triodes could not meet this additional specification. But klystrons showed promise. They had been successful in producing both high peak and high average power at SLAC at 3000 MHz, and experience was accumulating at several tube plants in the 800-MHz frequency range. In October 1966, development orders for five tubes each for 1-1/4-MW klystrons capable ultimately of a 12% duty factor were placed with Litton and with Varian (which had absorbed Eimac). At this same time, an order was placed with Raytheon for two 1-1/4-MW amplitrons at 800 MHz, also for a 12% duty factor.

This duplication of development contracts was considered necessary to obtain a successful power tube in time to meet the LAMPF schedule. Meanwhile, the original RCA contract for triodes was terminated by negotiations started in April 1967, and the 100-kW tetrode (IPA) was abandoned as the driver stage. During 1966-1968, the type of power tube that would prove capable of exciting the 800-MHz portion of the linac was uncertain. This uncertainty caused much concern to members of the staff and became a major bottleneck to meeting the desired schedule for completion.

The first 1-1/4-MW amplitron was received from Raytheon in April 1967 (utilizing two units in series). Under test, the amplitron had serious feed-back problems and was almost impossible to control. Nevertheless, testing of Raytheon amplitrons continued to November 1968 when the contract was terminated. The first 1-1/4-MW klystron was received from Litton in June 1967, but was found to have many unsatisfactory features; it was noisy and had low rf efficiency. Nevertheless, the experience with this tube ultimately led to the decision to use klystrons as the power source.

The first good tube to be tested was a Varian klystron (VA-862) received in November 1968; it performed well[60] at over 50% efficiency. This tube was still in service in the LAMPF system in 1971 after operating for over 2000 h. The Varian five-tube contract was completed by July 1969. However, Litton productivity was less satisfactory, with no deliveries of acceptable tubes until October 1969. By this time, LAMPF took the specifications and parameters of the successful Varian tube and applied them to the Litton contract.

The loads used on the test stand were both resistive and resonant. The resistive load was a water cell that could dissipate the full 1-1/4 MW. A multicell section of the water-cooled cloverleaf-type waveguide was the first resonant system to utilize full power from the klystrons under test; later an early model of the side-coupled cavity was used, also water cooled. By early 1970, a 40-cell unit of the production design side-coupled cavity was tested in LASL's Equipment Test Laboratory. Three power test stands were installed in this building for testing production klystrons.

A production order for 45 klystrons (44 total required) was placed with Varian in March 1970, for completion July 1972. For those delivered up to the date of writing this report, the record has been good – only one failure and this only after over 6000 h of service. An order for 25 tubes with essentially identical specifications was placed with Litton in May 1971; these will become available as spares. The question is still open as to whether LAMPF will develop its own klystron repair and rebuilding shop for long-term maintenance needs.

One of the major technical advances in the rf system for the LAMPF accelerator is the control system of phase and amplitude. This system has several novel features that have not been used on other linacs. A simplified description of the amplitude control process might be: a pick-up loop samples the rf field in the accelerator tank; this is compared with a reference voltage (coming from a battery) that generates an error signal, which is fed back to the driving amplifier. A similar pick-up, reference phase voltage, error signal, and feedback is used for phase control. Developing the control system required a wide band width and absolute standards for amplitude and phase. The person primarily responsible for this development was R. Jameson, who was the originator and continuing supervisor to the step-by-step process.

In the absence of absolute standards of field strength, a method was devised to obtain the precise tuning conditions from the behavior of the accelerator beam. This development involved R. Jameson, K. Crandall, and D. Swenson. The resulting system is sufficiently unique to be known by the special name of the "Δt turn-on;" in this process the power units are turned on one by one from the entry end of the linac, and each one is carefully tuned for precise amplitude and phase before going on to the next unit. A disadvantage of the size of the powering units for this purpose is that each unit is about one phase oscillation in length (about 16 MeV at 100 to 200 MeV).

The Electron Prototype Accelerator (EPA) was designed and built in 1967 to test the operation and performance of the side-coupled cavity. It also served an essential function in providing a working system on which to study the rf control problems at the designed frequency of the main linac (805 MHz). The EPA was completed and operated for the first time in December 1967. During 1968-1969, Jameson studied the rf control problems. Initially he was unable to make the power balance between the four rf power units (tanks) as the duty factor and average power were increased. This was due to lack of adequate cooling; but more importantly, it was clear that there was inadequate understanding of the coupling and tuning errors. During this study, Jameson further developed the basic concepts of the "phase-amplitude control" system described above. By late 1969 these problems were satisfactorily solved. For example, the EPA was operated many times for 10 to 20 h with a measured variation in beam energy of about 0.1%. This development led to significant changes in cooling design and in tuning techniques and produced a much better understanding of the precision and quality control problems of the rf structure. The result was a successful completion of the phase and amplitude control system that has proven essential to the efficient performance of the linac.

It should be noted that in August 1971, Jameson was placed in charge of testing, etc., of the side-coupled structure by the Construction Steering Committee.

We now go back to 1966 to describe the parallel development of the rf power system for the 100-MeV drift-tube linac operating at 200-MHz frequency. As mentioned above, the RCA 7835 triode was known to be satisfactory as a power tube capable of delivering short pulses at up to 5-MW peak power. The problem was to develop an intermediate power amplifier (IPA) and modulator for the much larger (12%) duty factor and higher average power needed at LAMPF. Again, Hagerman was the group leader and Boyd was a prime mover.

In January 1966, the tube and associated equipment for a standard IPA unit at 200 MHz was put on order. Meanwhile, a modulator was needed to handle the large duty factor and, as a first try, two RCA 8618's were used in parallel. Difficulties occurred in the modulator development at this high average power level, and also in the IPA when it was received in October, largely due to rf leakage in the containment hardware supplied by Continental Electronics Corporation. Tests continued, with frequent modifications, until early 1967, and by this time many of the problems were resolved. The first operation of a complete driver system with a 7835 power tube at 6% duty factor occurred on April 30. As the goal was pushed toward 12% duty factor, still other limitations showed up in the 7835 cavity provided by Continental and in the blocking capacitors, which continued for another year of development. Continued engineering improvements led to firm specifications by mid-1969. Funds became available at this date to place orders for the operational units.

Module 1, which powers the first 5-MeV tank, was installed in its permanent location and became operational in March 1970. It was used to obtain the first 5-MeV beam on July 1, on schedule. Module 2 became operational in April and by November installation of all four modules was complete and system improvement tests were under way. Successful operation at 100 MeV was achieved in June 1971. All evidence suggests that the major problems are solved and that the complete power system for the 200-MHz linac will operate as designed.

F. Controls and Instrumentation

The concept of a control system organized about an on-line digital computer appeared very early in the history of LAMPF. The idea was first proposed at a P-11 group meeting in September 1963. The importance of computer control was also noted in a letter from Kolstad of the AEC dated September 26. A preliminary study[61] of the feasibility of a central computer control system was prepared by R. A. Jameson and H. S. Butler in October. It argued that a computerized system offered greater flexibility, higher reliability, and more uniform operation than a conventional hard-wired system and was well worth the possible higher capital costs.

The matter lay dormant until February 1964 when T. M. Putnam transferred to P-11, from the Sherwood Project, where he was group leader of the Engineering Group. Putnam became a member of the P-11 "Steering Committee" and accepted responsibility for the control system. His first act was to develop the design goals against which any approach to a control system could be evaluated. During the summer of 1964, Putnam directed EG&G in an intensive study of the controls problem, aided by T. M. Schultheis and Jameson. The conclusion of this study is contained in the following sentence.

> "...EG&G recommends the use of a control digital computer installation for accelerator status monitoring, beam program establishment, and direct digital control at LAMPF..."

With this recommendation as a starting point, serious consideration was given to the design of a computer-based control system for LAMPF. A conceptual design for the system and the tasks to be performed by the computer were presented in a paper[62] by Putnam, Schultheis, and Jameson at the first Particle Accelerator Conference. The design reflected the modular arrangement of equipment along the length of the accelerator. A typical module included an rf power amplifier, one to four accelerating cavities, radiation monitors, water and vacuum systems, beam-monitoring equipment, several magnets, and beam-steering controls. In all, about 100 data and control signals were associated with each of the 60 modules, giving a total of 6000 channels on the accelerator.

The controls for each module were consolidated at a central location. This module control point served two essential functions. First, it provided the controls for operating the equipment locally during installation, checkout, and maintenance. Second, it served as a remote terminal for all data and control signals going to and from the control room. Each module control point was linked to the Central Control Room (CCR) by transmission lines. These lines terminated in a special multiplexer connected to the computer. A functional design for the complete interface system between the computer and the accelerator was published in November 1965 by Butler and Smith.[63]

In spite of the compelling arguments for computer control, it was necessary to justify so distinct a departure from accelerator technology. This justification took the form of a prototype computer control system for the 24-MeV Electron Prototype Accelerator (EPA). The computer for the prototype system, an SEL-810A costing $2000,000, was delivered in March 1967. The linac was first operated from a manual control system during December 1967. Development of these manual controls was supervised by Putnam and R. A. Gore. The responsibility for the computer interface hardware lay with D. T. Van Buren and, later, with D. R. Machen. Computer control of the EPA, from turn-on through beam steering, was demonstrated in the spring of 1968. The programming effort was supervised by Butler and R. F. Thomas. About 12 man-years were invested in the programming system.

In parallel with the development of the prototype control system, an effort was made to evolve a control philosophy for LAMPF. A summary of the overall control system design philosophy was made by Putnam in November 1967.[64] The principles set forth in that report became the guidelines for developing the LAMPF control system. Subsequently, a committee of nine senior staff members met weekly between January and May of 1968 to discuss various facets of the subject. Minutes of these meetings were distributed, but never summarized in a single document. A few of the major points are listed below.

a. The accelerator, switchyard, and permanent portions of the beam lines will be operated from CCR through a centralized control system.

b. Sufficient manual controls will be provided at each module for equipment installation, checkout, and maintenance.

c. These manual controls will be designed so that parameters can be set locally and then switched to remote control without any interruption in operation.

d. Data and control signals will be transmitted bi· serially between CCR and each module over a digital multiplexer system involving very few cables.

e. In general, the only control loops to be closed through CCR will be those requiring considerable analysis, such as for beam optimization.

f. "Operation by exception" will be the rule in the design, with a human operator standing by to handle the exceptions.

g. Equipment will be self-protecting; all circuits related to personnel and machine protection will be hard-wired and interlocked locally.

h. The system design will be modular to speed maintenance and reduce the spare parts inventory. The module designs will minimize the number of circuits and components consistent with system requirements.

i. Personnel safety will be of prime importance in all phases of the design.

Work on the prototype control system continued through the fall of 1968. At that time the PERT chart for LAMPF indicated that a choice had to be made between conventional and computer control. On the basis of the success achieved with the EPA system, it was proposed by Butler[65] that an SEL-840MP computer be purchased as the core of the LAMPF control system. This course of action was approved first by the Steering Committee and later by the entire Technical Committee of LAMPF.

With that fundamental decision made, the tempo of work on the control system increased markedly. Prototyping activities were brought to a conclusion. The designs for all systems were reviewed to ensure their compatibility with computer control. Procurement actions reached a peak in 1969. Essentially all of the equipment was built commercially from designs developed by the controls and instrumentation group.

The installation and checkout of the control system was started in 1970 and picked up momentum all through 1971. The control computer was delivered in March 1970. Five months later it was installed permanently in CCR. The interface system between the accelerator and the computer was connected in the fall of 1970. The programming system evolved all during that year. In December 1970, an operator seated at the console in CCR used the computer controls to bring up a beam in the Injector and steer it through the low-energy transport region to the drift-tube linac. During the 211-MeV beam test in August 1971, the CCR was the center of operations.

Although this history has emphasized the computer-related aspects of the control system, a comparable effort went into developing the operational systems. The distributed operational systems extend over the length of the facility and are essential to the operation of the accelerator. Included in this category are the timing, fast-protect, run-permissive, personnel safety, and radiation-safety systems. The TV, communications, and video (pulse-viewing) systems comprise the auxiliary operational systems. The local control systems were all developed from a set of nine standard control modules packaged in NIM bins. This approach greatly reduced the spare parts inventory and the time to effect repairs.

Throughout the entire development, Putnam was Group Leader of MP-1 and coordinated the controls system development. In parallel with this, he also served as the LAMPF Safety Officer, and by 1971 he assumed continuing responsibility for the safety program, which will become an increasingly important activity as operations and the experimental program start. As this load increases Gore will take over as MP-1 Group Leader to guide completion of the accelerator instrumentation and control work, and to develop the capabilities within the group to provide electronic support for the experimental program. In addition, MP-1 has been given the responsibility for developing the LAMPF data-acquisition system for the Experimental Area. In both these activities, Gore will be assisted by Butler, Machen, and Thomas.

G. Beam and Target Handling

The radiation effects of the unusually large beam power of the LAMPF accelerator were also anticipated from the start of planning. It was known that the large fluxes of mesons and neutrons from targets would require massive shielding, and that the induced radioactivity near targets following beam turn-off might reach intensity levels of tens of kilocuries. Remote handling from behind shields was known to be essential for all targets and equipment exposed to the primary beam. One of the strong arguments in favor of Los Alamos as a location for a meson factory was their experience in handling high levels of radioactivity.

To plan research experiments (as well as to design shielding) it was necessary to determine the radiation flux with some precision at an early date. Several members of the Physics and Theoretical Divisions contributed to the calculations of the nuclear cascade in targets and in shielding materials, and to predictions of the fluxes of secondary radiations. These included R. Bivens, J. Wooten,

D. Cochran, D. Mueller, and S. Whetstone. An early goal was to determine basic shielding requirements to provide data to prepare cost estimates for the proposal to the AEC known as the "Blue Book;" this involved coordination with McGuire and others preparing building specifications. The set of Monte Carlo calculations of the intranuclear cascade that were made were based on a revised version of the Monte Carlo code of Metropolis et al. from J Division. Using the sophisticated transport codes of Kaye Lathrop and Forrest Brinkley of T Division and the Monte Carlo results as input data, Harvey Israel, of H Division, and Cochran calculated the required proton beam line shielding. One major report[66] on the status of the cascade calculations during P-11 days was written by S. Whetstone in December 1964.

So it became possible to calculate meson and neutron fluxes with good precision at an early stage, and so to define the shielding requirements around targets and other portions of the beam run. This allowed the design of the beam runs, target systems and experimental arrangements to proceed. This "first-cut" design was intended to provide sufficient detail to allow responsible engineering cost estimates of the experimental building. McGuire did much of this initial planning and supervised the engineering cost estimating.

To obtain minimum volume iron was chosen for the shielding around target stations. Light material was also needed to reduce fast neutrons emerging from iron to acceptable low intensity, which implied an outer sheathing of concrete. Calculations showed that 13 ft of iron and 3 ft of concrete might be needed around each target. Shielding was designed to provide maximum personnel access around targets, even though it increased shielding cost. A sequence of four to six target stations along the beam run was visualized, each shielded for maximum beam loss. Shielding was specified as mobile, stacked, and close-fitting – a fairly expensive construction option. An experimental building to house these target stations, with overhead crane to handle shielding, roughly resembles the present "Area A." In the initial plans, the crane operator was to be placed in a fixed control room with remote viewing and manipulators. Another important activity in 1963-1964 was the design of magnets and other devices for the beam-handling channels for pion and muon beams, done primarily by Butler; engineering cost estimates of these equipment items were also prepared. The result of these early studies was a cost estimate of the experimental building and its equipment which, fortunately, has remained valid through many subsequent revisions. McGuire left LASL (temporarily) in January 1965 and F. Tesche assumed responsibility for subsequent revisions.

This was the state of planning when Mahlon Wilson transferred to LAMPF in May 1967. Wilson had previous experience with radioactive hot cells and remote handling problems in CMB Division and had recently completed his Doctorate in Mechanical Engineering with a thesis on a problem in cryogenics. He was assigned to the MP-6 Group (Experimental Areas) under Cochran, where he became Associate Group Leader. One of his first acts was to propose[67] a new approach to the concept of shielding and remote handling that led to the system known as "Merrimac."

The concept of Merrimac is that of an iron-clad movable vehicle (hence the name) that can service all target stations along the main beam, and transport radioactively hot items within a shielded box to a hot laboratory for handling or replacement. The Merrimac vehicle rides on top of the pile of iron and concrete shielding along the main beam. It can service Experimental Area A (three targets), the radioactive isotope production area, the biomedical area, and the beam stop. Merrimac also includes a unified system of connect-disconnects for vacuum chambers, electrical power, and cooling water systems for the magnets and other beam-handling equipment along the beam run. A major virtue is its flexibility to solve unanticipated problems of remote handling and manipulation. It can remotely remove targets and transport them to the hot lab within a box having 16-in. steel walls (adequate protection for 4000 Ci in the handling time required). It can carry 30 tons of weight (an iron-copper magnet of 4 by 4 by 4 ft) within its shielded box (10 by 10 by 6 ft internal dimensions). The loaded carrier weighs 200 tons. It runs on four aircraft landing gear units obtained as surplus from early-model B-52 bombers.

The operating technique used with Merrimac is summarized.

a. Roll Merrimac over target area on aircraft landing gear wheels.

b. Open top shielding doors over target area horizontally on rollers to form a top opening.

c. Lower shielded box (open bottom) into hole using four screw jacks.

d. Use remote-control manipulators within shielded box to make a target change or disconnect faulty equipment.

e. Lift target or faulty component up into shielded box by winch.

f. Raise shielded box up into Merrimac chassis by screw jacks.

g. Close top doors on shielding stack over the target.

h. Transport component to hot cells.

The entire operation is directed and controlled by an operator riding in a cab on the side of the Merrimac chassis, who is protected from radiation by a 16-in. steel shield.

Development of the engineering concepts for moving and handling the heavy shielding and large loads involved several members of Group MP-6. Wilson conceived the basic system for a rolling vehicle carrying heavy loads. After studying the limitations on loading of railroad-type rails and wheels, Paul Franke suggested the use of very large pneumatic rubber tires. Linas Thorn studied Janes' "All the World's Aircraft" and found that four B-52 landing gear units would carry the load. An availability study located some obsolete early-model B-52 landing gear assemblies that could be obtained from salvage. Six assemblies were obtained from which the four units were assembled for Merrimac.

The steel needed for the Merrimac shielded box was also procured quite cheaply, utilizing rejected slabs from U.S. Steel (20 ft by 6 ft by 6 in.) and surplus counterweights (20 ft by 3 ft by 6 in.) from Atlas missile silos. The engineering design of the Merrimac system and mechanisms was supervised by Wilson and drawn by Group MP-6. The total cost of Merrimac, including the loading gantry crane, the landing gear units, shielded box, and all gearing and electric drive systems was about $300,000. This was less than the cost of a single target station as originally estimated and made a much more extensive system of target stations possible within the budget. In fact, it is possible to conclude that the most important feature of Merrimac was the bargain basement cost that allowed this extension of target arrangements within the strictly limited budget for experimental areas.

The target changing system may utilize the shielding and fast access provided by Merrimac, if desired. A target changing mechanism built into a "bottom entry" cask can be carried in the shielded box. The target is disconnected by remote handling devices and is raised up into the portable cask which is then transported to the hot laboratory for chemical processing. A fresh target is inserted with the same handling devices. Other target systems (for uncooled targets) utilize pneumatic-tube delivery to the hot laboratory.

Targets for beam intensities up to 0.5-mA average can be made of graphite or water-cooled copper. For highest intensity and smallest spot size (0.1 x 1 cm^2) a molybdenum wheel target that continuously spins to expose a fresh cooled surface is planned. The maximum radioactive intensity anticipated on a thick copper target is 40 kCi. For the final beam stop beyond all targets, the beam will be spread over a 6-in. diam and will be absorbed in a thick water-cooled iron slug. Cooling water will be recirculated through a heat exchanger within the shielding and the gaseous H^3 radioactivity induced in the water will be locally trapped and concentrated for removal.

Group MP-6 has a wide range of responsibilities related to the primary beam. They design and develop all components used in the target areas and beam switchyards up to and past the "first bend." This includes bending magnets, quadrupoles, beam diagnostic equipment, vacuum chambers, targets, etc. Of special interest is the mineral-insulated magnet coils that provide major radiation hardening developed by Alex Harvey. MP-6 works closely with Group MP-7, which has responsibility for developing, constructing, and checking out all the secondary beam lines. MP-6 and MP-7 assist scientists to plan experiments and cooperate in designing the equipment. They develop instrumentation for measuring pion and neutron fluxes as radiation backgrounds.

H. Site Planning and Cost Estimation

The site selected for LAMPF is on "Mesita de Los Alamos" paralleling the main Los Alamos mesa on the south, but separated by a deep canyon. In the fall of 1962, the LASL Engineering Department made a study of possible sites within Laboratory boundaries that were sufficiently flat and straight enough for a half-mile-long linac. The study included an aerial survey of the more promising sites. The chosen site has a subsoil of soft tuff rock favorable for machine excavation yet providing firm foundations. Access to LAMPF is from the East Jemez road (the Los Alamos truck route) which not only makes it convenient to other LASL facilities, but saved road construction costs. The site was tentatively chosen in time to be included in the Preliminary Proposal[3] dated December 28, 1962, and was later approved and authorized by the Director and by AEC representatives.

The earliest reasonably complete plans for the buildings and site arrangement were made by Austin McGuire, in consultation with other planners and with assistance from the LASL Engineering Department, in time to be included in the definitive Proposal[11] known as the "Blue Book," dated September 1964. These plans proposed an underground tunnel for the linac housing, with 20 to 30 ft of earth to provide the basic overhead shielding from radiation during operations. Buildings for the injector system and for an extended target complex were at extreme ends of the tunnel; housing for rf power, cooling systems, and controls extended along the half-mile tunnel above ground; and structures for laboratory and office use and for equipment assembly were arranged nearby. These building requirements were used by Giffels and Rossetti to obtain the initial cost estimates for constructing the physical plant. McGuire left the linac design group for other interests soon after the Proposal was completed.

As designs matured, many changes were made in the site arrangements and in the detailed plans for auxiliary buildings, but were kept within the original total construction cost estimate. Perhaps the most extensive changes were made in the experimental areas; the final arrangements are indicated in Fig. 1 in Chap. 6.B. Another major change was to use the funds originally assigned for equipment assembly in the Target Building complex to construct a separate Equipment Test Laboratory (ETL) removed from the main buildings. Ground was broken for the ETL in February 1968.

Various other problems were identified and resolved during this redesign phase. A natural hollow across the mesa would have required major earth moving to provide shielding; so the longitudinal location of the accelerator tunnel was shifted to locate the injector building, which did not require thick shielding, into this hollow. The risk of earthquake damage was raised by the AEC staff and resulted in an assignment to Giffels and Rossetti to analyze the natural resonances of the linac machine and building structures on the tuff foundation. The result showed negligible earthquake risk. A detailed study led to a choice of 26.5 ft for the earthfill shielding over the high-energy end of the linac tunnel; in practice, it was found that this same thickness could be extended over the full length of tunnel without increased cost.

The person chiefly responsible for coordinating these modifications was Paul Edwards, who joined the P-11 design group in May 1965 and transferred to Group MP-5 when LAMPF was formed in July 1965. The Group Leader at that time was F. Tesche, who joined LAMPF in July 1965 and continued in this capacity until he left the project in June 1968. During this period, the final forms of the revised building arrangements took shape. Edwards became Group Leader when Tesche left. One of Edwards' major accomplishments has been to pry realistic buildings criteria out of the several Groups in time to incorporate them in construction contracts.

The philosophy used in developing the building specifications was to concentrate on the detailed designs sequentially following the predictions of a Program Evaluation Review Technique (PERT) cost and time analysis. As a result, the various parts of the project were designed and constructed serially. For example, the concepts of the beam switchyard in the target area and of the Merrimac handling system came at a late date in 1969, and were quite different from the original concepts. The major items or packages put under contract during site construction in the date sequence when the items were started are listed here.

4/64 -	Preliminary design contract with Giffels and Rossetti.	
1/66 -	Basic architect-engineer contract with Giffels and Rossetti	
2/67 -	Site and Utilities, I (incl cut for linac tunnel)	~ $0.6 million
2/68 -	Construction of ETL Building	~ $0.8 million
5/68 -	Injector Building and 100 MeV Facility	~ $2.2 million
5/68 -	Site and Utilities, II	~ $0.3 million
7/68 -	115-kV Substation	~ $0.7 million
12/68 -	Laboratory-Office Building	~ $1.4 million
1/69 -	805-MHz Facility	~ $5.56 million
4/69 -	Design Contract with Giffels and Rossetti for Experimental Area	
6/69 -	Operations Building (controls)	~ $0.6 million
9/69 -	Experimental Area, I (main target building)	~ $2.9 million
10/70 -	Experimental Area, II (experimental areas)	~ $4.2 million
6/71 -	Experimental Area, III (extension to beam stop)	~ $1.5 million
6/71 -	Site and Utilities, III	~ $0.1 million

The first cost estimate included in the Preliminary Proposal was taken from two sources: (1) an estimate of equipment and labor costs for construction of a 750-MeV proton linac with 1-mA average beam prepared by William M. Brobeck and Associates, based on specifications for such a linac given in Yale Report[32] Y-6 of October 1962, and (2) initial estimates for building construction and site-related costs prepared by the LASL Engineering Department. The total estimated project cost given in the Preliminary Proposal was $42,137,000. This same estimate was detailed and repeated in the Schedule 44, Construction Project Data Sheet, presented to the AEC in August 1963.

In an Appendix to the Preliminary Proposal, R. Emigh presented an alternate estimate obtained by scaling up the costs of the PHERMEX project recently completed at Los Alamos to the higher power and larger magnet, vacuum and cooling requirements of LAMPF. The estimate obtained by this scaling process was $55,500,000. It is interesting to note how close this was to the final estimate.

Engineering and cost studies were continued during the following years with the assistance of other commercial firms. The rf power systems were studied and cost estimates were made by Radio Corporation of America and by Continental Electronics; Edgerton, Germeshausen and Grier made a study of the control system; Brobeck and Associates continued studies of the linac components; and Giffels and Rossetti analyzed the revised buildings and site requirements. Giffels and Rossetti made an independent estimate of the total project cost as $60 million, which somehow became known to the news media and was reported in a New York Times article by John Finney on September 14, 1964, entitled "AEC Considering Meson Factory at Los Alamos." The LASL Administration was concerned that this high cost estimate might detract from the chances of success. On September 22, Rosen sent a memo to Bradbury indicating that the estimate could be reduced by a minor rescoping of the project. On September 30, Bradbury informed McDaniel of the AEC of his confidence that LASL could build the proposed facility for $55,000,000 (including escalation and contingency).

This round number of $55 million became the official LASL cost estimate. The reports from the consulting engineering firms were slightly rescoped and re-estimated to bring the total of the cost estimates to this desired figure. The details were reported to the AEC in a Schedule 44 dated October 30, 1964. This figure remained firm throughout the early construction period, up to late 1969, when the FY 1970 budget was reduced by $10.3 million below that scheduled and requested by LASL. As a consequence of this postponement of construction funds, costs were increased by $1,000,000 and the total cost-to-completion was revised to $56,000,000. At this time (1972), construction is approaching completion and the current estimate of total cost is $56,985,000.

LAMPF management decided to act as its own general planner and to employ separate architect/engineering firms to develop designs and cost estimates for competitive bidding. William M. Brobeck and Associates were commissioned to prepare the initial cost estimates for construction of the accelerator and its associated equipment. The detailed design and cost estimating for buildings, site, and facilities was contracted (cost plus fixed fee) to Giffels and Rossetti, who also prepared specifications for bidding and supervised construction performance. MP Division staff provided supervisory control over the A/E firms, by permission of the AEC contracting officer, and also supervised some of the vendors of really critical components. However, most of the supervisory duties for building construction were performed by the LASL Engineering Department staff and other service groups assigned and attached temporarily to LAMPF. This procedure has been successful in maintaining high-quality performance on contracts and has minimized costs that would otherwise accrue to a general architect/engineer.

CHAPTER 5

ORGANIZATION AND ADMINISTRATION

A. Design Phase

The administrative organization for LAMPF grew from the experience and practice at LASL. Technically, LAMPF leaned heavily on the support and service structure of the Laboratory. During the early planning and design phase, all activities were part of the Physics Division, as described in Chap. 1. Beginning in 1962, L. Rosen acted as coordinator of planning for the meson facility. He was named Alternate Division Leader of P Division on September 1, 1962. Rosen was the chief spokesman for the local planning group, both within LASL and in Washington, as the project moved into the proposal phase. He organized and wrote much of the material in the proposals on the scientific justification for a meson facility, and continuously emphasized its scientific importance.[68] One of Rosen's most valuable functions was to find and cultivate channels of political influence within the Atomic Energy Commission and the Joint Committee on Atomic Energy, and to use them to promote the meson project. An important early activity of the design group was a model-study program to test rf structures and power systems, led jointly by Nagle, Knapp, and Hagerman. Austin McGuire was responsible for supervising the activities of subcontractors such as the William B. Brobeck Associates in their engineering and cost analyses. During this initial phase, the planning staff came chiefly from P Division, which was then headed by J. M. B. Kellogg, and support came primarily from the P Division budget. The Preliminary Proposal[2] for a Meson Facility, dated December 28, 1962, was prepared by 19 members of the LASL staff and three consultants.

Technical studies and consolidation of plans continued for several years under the administrative umbrella of P Division and was supported by DMA funds. Planning and design activities for the meson facility were handled through a new group, P-11, organized in February 1963, with Darragh Nagle as Group Leader. The prime purpose was to firm up technical decisions and prepare an authoritative proposal. The first formal action was the submission to the AEC of a Schedule 44, Construction Project Data Sheet, complete with manpower and cost estimates, in August 1963. These technical and engineering studies continued into the next year. The P-11 Progress Reports[4] give details of the design progress.

In April 1964, the AEC Division of Research made available a fund of $500,000 to prepare a definitive design proposal, which allowed LASL to increase the design effort and to employ more professional assistance. This phase culminated in the preparation of the definitive Proposal[11] for LAMPF and its submission to the AEC in September 1964. The full-time staff applied to the design effort during 1964 averaged 15, but the total number of LASL staff involved was much greater. For example, the Proposal lists 68 LASL staff and 14 consultants as contributors.

The LASL Bulletin for October 3, 1964, announced that Rosen had been appointed Acting Project Director for LAMPF. With the availability of special funds to support the design, and an official responsibility, Rosen increased and expanded the design effort. From that time on he reduced his research activities in P Division and devoted increasing time to the administration, planning, and promotion of LAMPF. A new 6000-sq-ft building (the so-called "Mock-up" building) was added to P Division to house experimental waveguide tanks, rf power systems, and control system prototypes. Later, a wing was added to provide a site for the Electron Prototype Accelerator (EPA) built to test the efficiency of the new side-coupled cavity waveguide system. This additional space was completed and occupied in early 1966.

Recognition of the maturing status of LAMPF within the Laboratory came with the formation of the new division for Medium Energy Physics (MP Division) in July

1965. Rosen was named Division Leader, and Group P-11 was discontinued. (Note that the symbols MP describe the general field of medium-energy physics, not meson physics as is frequently assumed.) Within the MP Division the organization of the LAMPF staff was similar to the practice in the Physics Division; areas of responsibility were assigned to several Group Leaders, each with Associate or Alternate Group Leaders. A listing of the major assignments and activities during 1965-1966 include

MP-DO	
Louis Rosen	MP Division Leader (also Acting Project Director of LAMPF)
Darragh E. Nagle	Associate Division Leader - Systems Planning, Linac Characteristics, Accelerator Physics
Frederick R. Tesche	Associate Division Leader - Administrative Services
MP-1	
Thomas M. Putnam	Group Leader, Controls and Instrumentation
Harold S. Butler	Alternate Group Leader - Beam Transport
MP-2	
Donald C. Hagerman	Group Leader - RF Systems
Thomas Boyd	Alternate Group Leader - RF Systems
Robert A. Jameson	Alternate Group Leader - RF Phase and Amplitude Control
MP-3	
Edward A. Knapp	Group Leader - Accelerator Structures
Hairston G. Worstell	Associate Group Leader - Mechanical Engineering
Donald A. Swenson	Associate Group Leader - 200 MHz Accelerator
MP-4	
Darragh E. Nagle	Group Leader - Injector System (also Associate Division Leader)
C. Robert Emigh	Assistant Group Leader
MP-5	
Frederick R. Tesche	Group Leader - Building, Budgets, PERT, Scheduling (also Associate Division Leader)
Paul D. Edwards	Site and Building Requirements
Also:	
George A. Cowan	Radiochemistry
John E. Brolley, Jr.	Electron Analog Experiment

In the summer of 1966, George Kolstad of the Washington Office of the AEC Research Division spent several weeks in Los Alamos and produced a document[69] describing a possible organizational structure for the operating phase of LAMPF with suitable functions and responsibilities. Although this was not an official document, it did call attention to many potential problems and policy questions before they became critical, and so served a most useful purpose. It recommended a structure of advisory and working committees and indicated their functions. It discussed the factors to be considered in the approval of proposals for experiments and in scheduling experimental operations.

B. Construction Phase

The organization described above, a Division Office and five Groups, continued with little change following authorization of the first funds for construction in early 1966. Group Leaders and their professional staff enlarged their activities by specifying construction items as required and spending construction funds. Nagle was named Alternate Division Leader and given authority to make technical decisions and sign major orders. Nagle and the other Group Leaders became an informal executive committee to advise Rosen on decisions involving priorities and budget allocations. Two new groups were added as new needs developed: MP-6, Experimental Areas, was formed in 1968, first with Rosen and then with Cochran as Group Leader; and MP-7, Secondary Beam Lines and Spectrometers, was formed in 1970 with Lewis Agnew as Group Leader.

The availability of construction funds added a new kind of money to LAMPF. Each year funds were allocated from the Research and Development (R&D) budget of the AEC. These funds were used to pay staff salaries and to support the design and development activities. When construction funds became available they were used for all outside contracts and materials and for all inside activities resulting in equipment or products used in the meson facility, including the salaries and wages of those employees engaged in specifying and spending such funds. The construction budget was referred to locally as the A/E (architect/engineer) budget.

This existence of two kinds of money required that employees be paid from R&D or A/E Funds depending on the kind of work they were assigned. New administrative procedures at LASL were needed to solve the problem. The A/E staff were, in principle, expected to be employed only for the duration of construction. However, certain exceptions to the temporary nature of employees paid from the A/E account might be noted: MP-3 included a number of permanent LASL employees transferred to LAMPF from other Divisions to utilize their technical and mechanical skills, and a group of 20 or more LASL staff from the Engineering Department were attached to MP-5, who were used as engineers, designers, and inspectors. Furthermore, employment levels and skills in the A/E staff were planned to enable MP Division to move from construction to installation to operation and maintenance with a minimum change in numbers and maximum continuity of employment. It is expected that most A/E staff will be shifted to Operations or become technical assistants to research groups following completion of construction.

A listing of the staff members and other employees involved in the construction of LAMPF is given in Appendix A to retain a record for future reference. The list gives the staff as of June 1971, but also includes a few who terminated before that date. The names are listed under headings of the Division Office and the seven technical groups; employees paid from the construction budget are included in separate listings. The job title (or job description) is given for each person, the professional training or background is indicated, and the date he entered either Group P-11 or MP Division. The administrative and supervisory staff, with their titles, are listed at the head of each group.

Two committees have steered the course of design and construction, and have coordinated the efforts of the several groups involved. The MP Technical Committee was started in July 1967 for the "discussion of outstanding technical problems and to stimulate ideas for their solution." Membership initially included Group Leaders and Alternate or Associate Group Leaders, totaling 15 persons. During the following year, meetings were called at approximately two-week intervals. The agenda broadened to include not only the more important technical matters, but also budgetary planning, schedules, personnel requirements, and many minor administrative problems. As the staff grew, membership increased to 24 or more and the meetings became more and more just information meetings to keep the Division staff informed. By the end of 1969 the Technical Committee was no longer a useful working entity.

A true working committee with only three members was formed in May 1968 and was called the Design Review Committee. It had the authority "to delve into all aspects of accelerator construction and to make decisions on the scope, direction, and implementation of all MP Division activities related thereto." The members of this Committee were Don Hagerman, Paul Edwards, and Edward Knapp (rotating chairmanship). In August 1970 the group was expanded to include Robert Warner and renamed the Construction Steering Committee, with essentially the same terms of reference and authority.

This system of using a committee for making construction policy decisions has worked well. In spite of strikes, deferred construction funds, and difficulties in developing criteria, the "bricks and mortar" part of the project has gone well. Installation has rarely been delayed by building construction, and the amount of rebuilding after construction was completed has been very small.

C. Operations Phase

Plans for an orderly move from Construction to Operations and Research Support were prepared well in advance of completing the Accelerator. A reorganization of the Group structure with some reassignments of responsibilities will be implemented as soon after January 1, 1972, as is feasible without causing unacceptable disruption to construction activities. The revised organization is summarized here.

MP-DO

L. Rosen, Division Leader	Medium Energy Physics Division
D. Nagle, Alternate Division Leader	
D. Hagerman, Associate Division Leader	Operations and Chief of Operations
E. Knapp, Associate Division Leader	Practical Applications
T. Putnam, Assistant Division Leader	Safety
P. D. Edwards, Assistant Division Leader	Facility Planning and Budget Control

E. Dunn, Administrative Assistant

MP-1

R. Gore, Group Leader — Instrumentation and Computer Systems

H. Butler, Alternate Group Leader

D. Machen, Assistant Group Leader

R. Thomas, Assistant Group Leader

Electronic Instrumentation and computer-based data acquisition syst‹ms. Support all groups, including LAMPF Users.

MP-2

D. Hagerman, Acting Group Leader — Accelerator Operations

R. Warner, Alternate Group Leader

Accelerator operations and light maintenance.

MP-3

E. Knapp, Group Leader — Practical Applications

Practical Applications of LAMPF and LAMPF technologies.

MP-4

D. Nagle, Group Leader — Nuclear and Particle Physics

Basic research responsibility for all such research in MP Division and for coordinating the MP program with all other users.

MP-5

To be disbanded. Scheduling, construction planning, and budget control activities to move into MP-DO.

MP-6

D. Cochran, Group Leader — Experimental Areas

R. Macek, Alternate Group Leader

M. Wilson, Associate Group Leader

P. Franke, Assistant Group Leader

Maintain and manage experimental area, including remote handling, targets, beam dumps, effluent control, isotope production, and cryogenic operations.

MP-7

L. Agnew, Group Leader — Secondary Beam Lines

H. A. Thiessen, Alternate Group Leader

Maintain and improve secondary beam lines.

MP-8

T. Boyd, Group Leader — Engineering Support

H. Worstell, Alternate Group Leader

Electrical and mechanical engineering, including drafting, metronics laboratory, klystron repair, and improvements to accelerator.

MP-9

R. Jameson, Group Leader — Systems Development

D. Swenson, Associate Group Leader

C. R. Emigh, Associate Group Leader

Development of advanced concepts for improvement of accelerator reliability and capability.

D. LAMPF Policy Board

In early 1968, Bradbury established a Policy Board composed of senior members of the national scientific community to advise him on the overall policy, progress, and effectiveness of the LAMPF program. In his letter of invitation he indicated the national character of the facility and the magnitude of the administrative responsibility. Initially, the function of the Board was to review the technical design and the construction schedule and to consider matters of policy having to do with personnel, administration, fiscal arrangements, and plans for experimental facilities.

The following nine individuals accepted membership: Herbert L. Anderson, George A. Cowan, Herman Feshbach, Clark Goodman, Robert Hofstadter, Vernon Hughes, M. Stanley Livingston, E. Gerald Meyer, and R. Ronald Rau. Vernon Hughes was named Chairman at the first meeting; two years later he was succeeded by Herbert Anderson. Meetings were held at approximately six-month intervals until the construction phase was complete; dates were: October 12, 1968; January 17-18, 1969; June 12-13, 1969; January 23-24, 1970; June 5-6, 1970; January 22-23, 1971; and June 24-25, 1971.

At the first and most subsequent meetings, detailed presentations were made by Rosen and his staff on the status of accelerator construction and plans for research facilities. Tours of the site were arranged to demonstrate progress. At almost every meeting, the threat of a cutback in construction funds was a major concern. At several of the more critical times the Board wrote strongly worded letters to the Director (at his request), describing the damaging consequences of such reductions, to assist him in his effort to have the cut-backs restored.

The Board noted the LASL interest in conducting some classified research with the LAMPF beams, which might conceivably interfere with other research activities. They urged that the beam arrangements be revised to achieve physical separation of the beams to be used for weapon's research. This was accomplished successfully by the staff by redesigning the beams areas and diverting a beam into a security area called the "Weapons Neutron Facility." With this arrangement, short beam pulses can be diverted out of the experimental building through an underground channel to a special guarded laboratory where weapons research can be conducted with a negligible effect on the beams in other channels used for research and without introducing any significant personnel security problems.

There was extensive discussion of the staffing plans for MP Division on the assumption that LASL staff would not only maintain and operate LAMPF but would use about half of the machine beam time for research. The importance of developing a LASL staff having high quality and creativity was recognized, including the need for a group of first-rate theorists. Procedures for achieving this happy goal were discussed at length with Bradbury and Rosen. In several instances, Board members used their personal influences to locate and persuade high-quality candidates.

The Board was informed of the plans for producing a beam of negative pions to be used in a biomedical program aimed at developing techniques of pion radiation therapy for the clinical treatment of human cancerous tumors. Members were impressed and pleased with these plans and strongly supported Rosen and the other sponsors of the Biomedical program.

The Policy Board continuously emphasized the National Facility aspect of LAMPF and took a strong interest in the LAMPF Users Group and its needs. The Board studied the technical plans for the experimental areas and major experimental facilities and certain members joined personally with design task forces to plan experimental facilities. They recognized that the major problem was obtaining funds to support the needs of the Users, including staff, technical developments, and computer services, and urged the Users to develop more reliable estimates of these needs.

The Board early recognized that housing non-LASL users of LAMPF might constitute a severe problem, and urged Bradbury and later Agnew to take necessary steps to avoid a serious and embarrassing situation. The housing problem has in fact been the main task the Board asked the Director of LASL to resolve.

The Board took a strong stand for having a totally open laboratory at LAMPF, with no security restrictions; the Director of LASL was urged to strive for simplified security procedures and for prompt authorization of visitors. Of particular interest was the process of approval for visits to Los Alamos of non-U.S. citizen scientists; it seemed important to minimize the paperwork of applications and the time required for approval. With this urging, the Director took steps to investigate possibilities for reducing some of the more objectionable features of existing personnel security procedures. These steps have met with reasonable success.

At the meeting on January 22-23, 1971, the Board met with the new Director of LASL, Harold Agnew, who welcomed four new members: Bruce Cork, Richard Garwin, Gerry Phillips, and Robert Stone, and took leave of four retiring members: Goodman, Hughes, Livingston, and Rau. Dr. Agnew gave the Board updated information on several of the policy problems considered earlier and requested the Board's assistance on other LASL problems. The major problem for future years of operation still appeared to be that of funding the research programs both at LASL and for the outside users.

CHAPTER 6

SCIENTIFIC USE AND RESEARCH FACILITIES

A. LAMPF Users Group

The anticipated use of LAMPF as an open research laboratory in medium-energy physics required that new policies and procedures be developed to supply the needs of visiting scientists from the universities. LAMPF was expected to become both a national and regional facility to provide beams of particles and technical support for teams of user scientists and students from throughout the U.S. and abroad, and especially from institutions in the Rocky Mountain and Southwestern regions. The LASL scientific staff was expected to compete directly or in collaboration with the outside users. It was estimated that LASL scientists would use about 50% of the beam time.

Since 1950, LASL has provided opportunities to students and faculty from universities for thesis or post-doctoral research in various fields of science. Much of this research was unclassified but for convenience the outside personnel were usually processed for security clearance. LASL staff members frequently provided thesis advice and supervision. Arrangements were normally made directly with the individuals, with University agreement to accept a thesis with LASL supervision. In 1956, the University of New Mexico (at Albuquerque) established a graduate center at Los Alamos, with courses taught by UNM and LASL staff offered to both graduate and under-graduate students resident and working at LASL. All these arrangements have proved to be highly valuable, both to Los Alamos and to the University staff and students.

However, the unique character of the meson facility and the magnitude of the government's investment required that broader and more formal arrangements be made for the unclassified research programs to be carried on by user scientists from the universities. This has been accomplished through the establishment of a "LAMPF Users Group" with an organization and an Executive Committee independent of LASL.

The initial move toward such an arrangement was a letter from Bradbury to the Presidents of 20 Southwestern and Rocky Mountain universities inviting them to send representatives (the Graduate Dean and Head of Physics Department were suggested) to a meeting at Los Alamos on December 17, 1963. The purpose was to describe the proposed meson facility and to discuss its potential usefulness to the university scientific teaching and research programs. At the meeting, Rosen discussed the scientific motivation for LAMPF and Nagle described the accelerator design plans.[7] Following this first meeting, Bradbury wrote letters to the participants summarizing the plans for LAMPF, the opportunities for the universities, and reporting the formation of an *ad hoc* committee of university representatives to work with LASL staff on plans for a more permanent organization.

An organization calling itself the Associated Rocky Mountain Universities (ARMU) was started in 1959. Its original purpose was to stimulate projects of a regional nature that required interuniversity cooperation for their achievement. Areas of interest ranged from humanistic and social to scientific and engineering. Later, in 1967, the ARMU charter was amended, the membership expanded, and the name changed to Associated Western Universities (AWU), with a more specific emphasis on cooperation with the AEC and industrial laboratories throughout the western United States in the physical sciences. The plans for LAMPF at Los Alamos were a prime stimulant to this refocusing of emphasis. This followed the pattern of university cooperation initiated following World War II by a group of east coast universities who formed Associated University, Inc. (AUI), to operate the Brookhaven National Laboratory.

A second conference on regional university cooperation for LAMPF was called jointly by LASL and

ARMU for February 4-5, 1965. The status and progress of the LAMPF program was reported. Administrative representatives discussed procedures for implementing University-LASL cooperation. A small group of university scientists met with LASL staff members at this time to consider the equipment required and the problems involved in making effective research use of the facility.

Interest by the academic community increased sharply during 1966-1967. Many scientists visiting Los Alamos took an interest in the potential scientific uses of the meson facility and joined in planning discussions with the LASL staff. A partial listing of these interested visitors would include Professors Gell-Mann of Cal Tech, Hughes of Yale, Phillips of Rice, Jakobson of Montana, and Telegdi and Anderson of Chicago. Medical scientists showed increasing interest in the use of negative pion beams for cancer therapy, including Dr. Chaim Richman from Berkeley and Dr. Robert Stone of the University of New Mexico.

The concept of a LAMPF Users Group crystallized out of the two conferences of regional university representatives described above, and the activities of Rosen and his staff in publicizing the scientific potential of LAMPF in visits to universities and in talks at scientific meetings. The group of potential users widened to include scientists from large universities of the east and west coasts and from other national laboratories, including many prominent scientists with experience in users groups at other large facilities. An *ad hoc* committee chaired by Harry Palevsky of Brookhaven met at Los Alamos on January 17, 1968, and called for a meeting of potential users of LAMPF to be held on June 20, 1968, following the American Physical Society Meeting at Los Alamos. At this first meeting, the general purposes and functions of the Users Group were discussed and committees were named to prepare a charter, nominate officers, and make plans for a second and more official meeting. A list of universities and laboratories whose representatives participated in this first LAMPF Users Group meeting is given in Appendix B.

At the second LAMPF Users Group Meeting on January 16, 1969, a Charter was adopted (Appendix C). It sets forth the regulations and bylaws for the Group and gives the procedures for electing officers and an Executive Committee. The initial slate of officers and Executive Committee elected were

Chairman:	Harry Palevsky, Brookhaven National Laboratory
Chairman-elect:	David Lind, University of Colorado
Executive Committee:	Roy Haddock, University of California, Los Angeles
	Arthur Poskanzer, Lawrence Radiation Laboratory
	Harvey Willard, Case Western Reserve University
Liaison Officer:	Lewis Agnew, LASL (appointed by Director, LAMPF)

The first task of the Executive Committee was to appoint a Technical Advisory Panel (TAP) to work closely with LASL scientists on plans for various features of the experimental program. The TAP was continued in succeeding years and became the major implement to transmit user's needs to the attention of the LAMPF staff. An important activity of the Liaison Officer was to initiate a series of Newsletters reporting to the membership. The first Newsletter was published on March 21, 1969; others followed, reporting actions of Users Group Meetings, meetings of Working Groups, and other business. For example, during 1969-1970, working sessions of small groups of users were held on specific programs such as

a. pion beams (August 5-6),
b. stopped muon channel (August 4),
c. nucleon physics (August 4-8 and October 29),
d. high-resolution spectrometer (August 6-7 and December 9),
e. medium-energy physics
f. biomedical applications (July 16, September 10, and October 28),
g. energetic pion channel and spectrometer (EPICS) (August 8 and January 19),
h. nuclear chemistry (January 14-15), and
i. isotope separator facility (January 14-15).

These activities continued and intensified during the next two years.

Annual Users Group Meetings were held on October 29, 1969, in Boulder, and on October 30-31, 1970, and November 8-9, 1971, at Los Alamos. New officers were elected each year and new members of the Technical Advisory Panel were appointed. The Users Working Groups continued their activities in consulting on plans for the major experimental facilities. As funds became available, the LASL staff started construction of the most critical of these facilities. A preliminary version of a

LAMPF Users Handbook[70] was mailed to the Users in January 1971. The first call for research proposals was issued by Rosen on October 30, 1970, at the Annual Users Meeting, and the first meeting of the Director's Program Advisory Committee was called for April 3-4, 1971. Users were informed that the scheduling of beam time for approved experiments would be announced at least six months before the anticipated date of initial operations.

The number of scientists in the Users Group totaled 830 in February 1972. A summary of the statistics of the Users Group as of that date is given in Table VI. In retrospect, the Users Group has provided an essential breadth and depth to the planning for experimental facilities and the research program in the years prior to operation. Experimental requirements developed in the working sessions supplied technical specifications for beam channels and for the initial array of beam-handling equipment. Much of the information developed by the working groups was used by the LASL staff responsible for equipment design and construction. The Users organization has had, from the very beginning, a very strong influence on formulating policy governing experimental capabilities, as well as in the detailed design of equipment. A most important aspect affecting the morale of the users, as well as providing the best possible research facilities, has been the complete independence of the Users Group from the established LASL administration. This independence has brought general approval and support from the university scientists for the program at LAMPF and has enhanced the reputation of LASL.

B. Research Facilities

Planning for secondary beam lines and the associated research facilities started early and modifications have continued during accelerator construction. Most of the interests of the Users Group prior to operation lay in planning for research facilities. The first significant working meeting of the Users Group was held in January 1969, when a charter was adopted and officers and an Executive Committee were elected. But a more important accomplishment was the decision to divide up the facilities field between a number of small Working Groups, each involved in a specific program, and to initiate detailed studies. A list of nine programs on which Working Groups concentrated during 1969-1970 is given in the preceding section. Two others, Computing Facilities and Neutrino Research, have since been formed. This method of organizing users activities has been highly successful, making it possible for potential users from individual universities to work closely with other experts in their field. Many new ideas and important improvements have come from these working sessions. LAMPF has benefited through the detailed study of specifications and criteria used in the design of the research facilities.

The LAMPF staff member most broadly involved in the Research Facilities field is Lewis Agnew. He came to LASL in November 1968 from graduate training at Berkeley and an assignment as Head of the Physics Section of the International Atomic Energy Agency in Vienna, and joined Group MP-6, Experimental Areas. Rosen was acting as temporary Group Leader at that time. Cochran was Alternate Group Leader and later became Group Leader of MP-6.

One of Agnew's first assignments was to organize the first Users Group Meeting described above. He helped to implement the working group sessions that proved to be such a useful result of the Meeting. Rosen soon appointed Agnew to be LAMPF Liaison Officer to the Users Group. In this capacity, he has published a series of Newsletters reporting activities and progress to the users, and has carried out most of the routine business for the Users Group.

TABLE VI

STATISTICS OF USERS GROUP, FEBRUARY 1972

Regional Breakdown	
East	189
Midwest	94
South	29
Southwest-Mountain	177
Far West	117
Foreign	60
LASL	164
User Membership	830

Number of Institutions	
Government	30
Universities	113
Hospitals and Medical Centers	33
Industry	19
Foreign	33
Total number of Institutions	228

Agnew was also assigned the specific job of developing criteria for Beam Area B, the area tentatively assigned to be the nucleon physics laboratory. He was assisted by J. Simmons of P Division, who has had a continuing interest in the nucleon-nucleon problem, especially that dealing with neutron beams. Out of this study came a report[71] that led to the final form of the Area B experimental arrangement.

Another long-range research interest at LASL is the development of a beam to produce a pulsed source of neutrons for studies involving weapon's applications. Although LAMPF is open for unclassified research, this beam for possible military applications would be diverted through a narrow underground channel into a guarded laboratory. Those involved in the early planning were L. Agnew, J. R. Beyster, A. Hemmindinger, and R. Fullwood. Present design studies are continuing. The first concept for a weapon's research beam was a fast-chopped short pulse of protons at the start or end of the normal long linac pulse. It was modified to utilize the H^- beam when this alternate beam became possible. Nagle suggested that further plans include a small storage ring in which the H^- beam can be stored and ejected in a single turn to give an extremely short, high-intensity pulse of neutrons. A channel stub-out for diverting the beam out of the main switchyard has been built, but construction of a storage ring or a weapon's research laboratory must await future allocations of funds.

A new Group, MP-7, Secondary Beam Lines and Spectrometers, was organized in June, 1970, with L. Agnew as Group Leader. Agnew continued as Liaison Officer to the Users Group and as the major contact for scientists from outside LASL. The new group is responsible for the design and construction of the beam handling equipment for secondary beam lines. When MP-7 was established, the planning and design work for the beam channels was organized by appointing one scientist and one coordinating engineer from LASL to be responsible for each beam. An important part of their assignment is to work directly with each of the Users Working Groups. Several inter-Group task forces have also been formed within MP Division to coordinate the design and development of major devices or services such as magnets, power supplies, vacuum systems, support and alignment devices, and water cooling systems.

In the Fall of 1970, a decision was made to proceed with the design and construction of three beam systems in Areas A, B, and C, and for a number of specialized beam channels. A list of the channels and facilities is given in the Users Handbook[70] published in January 1971. A brief summary follows.

1. Meson Physics (Area A). The main beam is sent successively through several targets to generate secondary pion (and muon) beams. The objective is to provide for both high-precision experiments and a wide variety of meson research studies. Four channels are

a. Low-Energy Pion Channel: Positive and negative pions from 20 to 300 MeV with π^+ flux at 100 MeV of 1.9×10^7 at a resolution $\Delta p/p$ of ±0.05% or 1.5×10^9 at $\Delta p/p$ of ±2%.

b. Energetic Pion Channel and Spectrometers (EPICS): Includes magnetic channel, spectrometers, scattering chamber, and detection system; characterized by good energy resolution (< 50 keV) and good angular resolution (< 10 mrad). The channel will deliver $\pi^\pm$ up to 300 MeV with a π^+ flux of 3×10^8/sec at 200 MeV; the spectrometer has maximum momentum of 680 MeV/c.

c. Pion and Particle Physics Channel (P^3): Provides a versatile $\pi^\pm$ beam of high energy (100 to 600 MeV) and high intensity (>10^{10}/sec), intended for elementary particle and nuclear reaction experiments.

d. Stopped Muon Channel: Provides $\pm\ \mu$ beams from 0 to 250 MeV/c with intensities $\simeq 10^7$/sec-MeV/c for a variety of muon experiments including polarization studies.

2. Nucleon Physics Laboratory (Area B). The objective is to provide beams of protons, and neutrons from a liquid D_2 target, of low intensity and good energy resolution (±5 MeV) from 300- to 800-MeV energy, for nucleon-nucleon research. Plans also include a polarized proton beam.

3. High-Resolution Proton Spectrometer (HRS) (Area C). A high-momentum resolution (±0.01%) spectrometer at ±0.8-mrad resolution in scattering angle. Intended for studies of low-lying excitation states of nuclei. This important facility is so costly that the Users Working Group made a separate request[69] for support from the AEC Research Division. A fund of $2.5 million was granted to be applied to construction of the HRS starting in FY-1970.

The Users Handbook gives detailed characteristics of each of the beam lines outlined above and the names of the appropriate LASL staff members to be contacted. It also gives instructions on how to prepare and submit proposals for research experiments. A simplified sketch of the Experimental Areas is shown in Fig. 1.

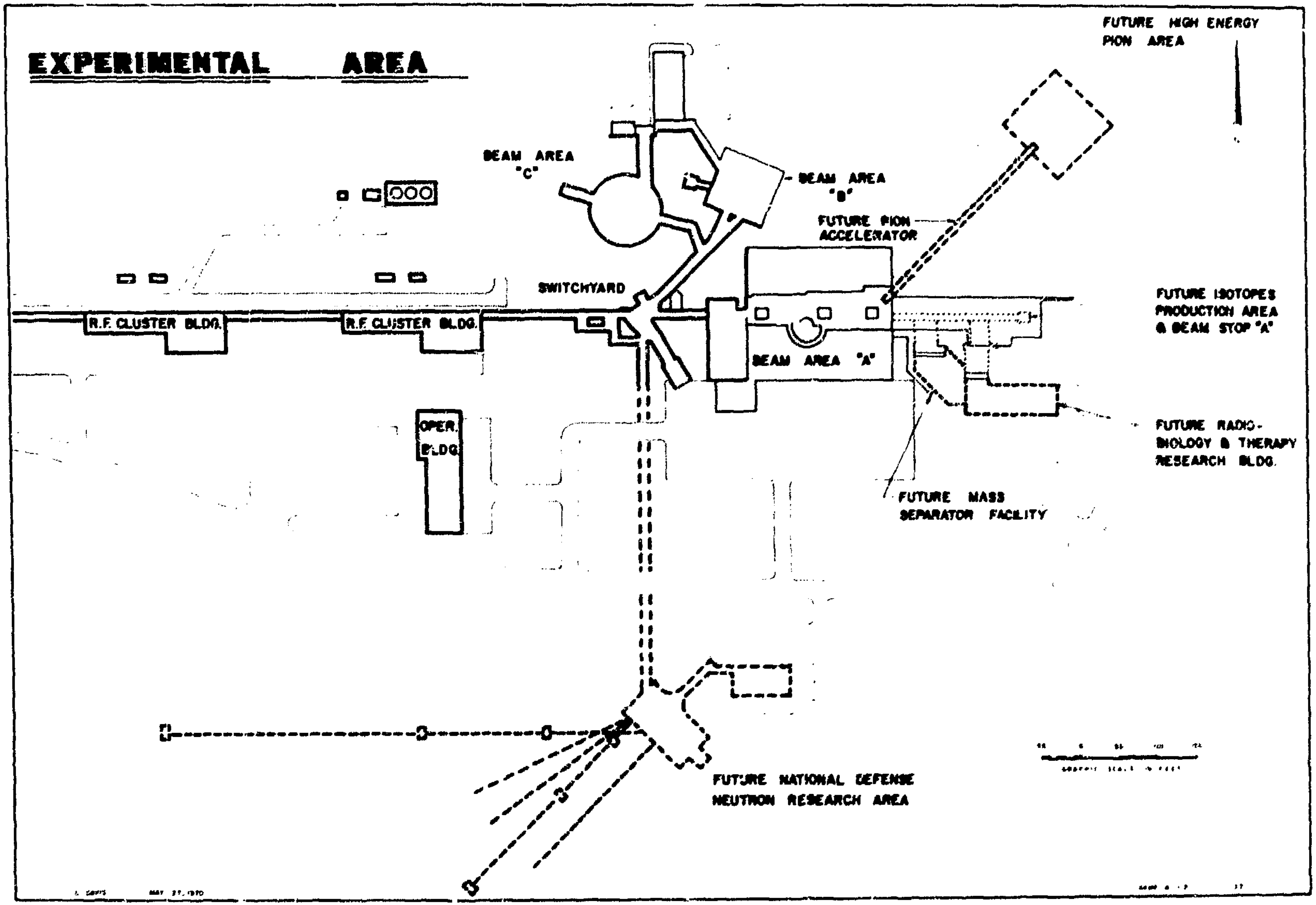

Fig. 1.
LAMPF experimental area.

C. Research Program

The original motivation and primary justification for constructing the LAMPF accelerator was the eventual development of a broad-ranging program of research in nuclear physics using the secondary particle beams. The Bethe Panel, so instrumental in persuading the AEC to support LAMPF, expressed a strong conviction of the importance of the study of nuclear structure using subnuclear particles such as mesons as projectiles. In 1964, the Bethe Panel listed the specific problems of interest to be

1. Nuclear force
   - a. Pion-nucleon elastic scattering
   - b. Pion-pion scattering
   - c. Nucleon-nucleon forces
   - d. Meson production
2. Nuclear structure, using strongly interacting particles in flight
   - e. Elastic scattering by the nucleus
   - f. Various form factors
   - g. Quasi-free scattering
   - h. Ejection of clusters from nucleus
   - i. Pickup reactors
   - j. Pion charge exchange
   - k. Muon scattering
3. Research with stopped pions
   - l. Pion capture
   - m. Pi-mesic atoms
   - n. Mu-mesic atoms
   - o. Muon capture
4. Weak interactions
   - p. Stopped pions
   - q. Stopped muons
   - r. Neutrinos
5. Neutron source
6. Possible extension to strange particles.

The Bethe Panel also identified the most important experiments in the fields listed above and stated that intensities with factors of 100 to 10,000 over those available from synchrocyclotrons would be needed. The very high intensity projected for a proton linac was one of the most important parameters that favored the linac over other meson producing accelerators.

With the authorization of funds to build LAMPF and with the growth of a Users Group as described in an earlier section, the plans for a research program became more extensive. Each successive Users Group Meeting and MP Division Progress Report expanded the scope and increased the detail of the anticipated research program. In the definitive Proposal of September 1964 to the AEC, Chap. IV on the "Scientific Motivation" filled 264 pages – more than half of the volume. Many hours of discussion by would-be experimenters have explored the possibilities, and reams of paper have been covered with calculations for projected experiments. Out of these studies have come many changes in the original plans for experimental areas and research facilities. The number and variety of beam lines and of facilities for beam handling and analysis have multiplied. Cost estimates soon totaled more than any conceivable budget. It became necessary to coordinate the facilities planning program. How this was accomplished is described in preceding chapters. The initial research program can best be appreciated by a study of the initial layout of beam channels and research facilities as described in the preceding section on research facilities.

D. Program Advisory Committee

Early in 1971, Rosen appointed a panel of working scientists to serve as a Program Advisory Committee (PAC). This group studies the research proposals submitted to LAMPF and advises the Director of LAMPF on the priorities to be assigned based on

1. Scientific merit,
2. Technical feasibility, and
3. LAMPF resources and running time required.

The initial membership of the PAC consisted of the following.

M. Boon, M.D.	A. M. Poskanzer
K. M. Crowe	R. Rau
G. Friedlander	J. E. Rothberg
N. Hintz	J. Schiffer
V. Hughes	R. Taschek
A. Kerman	T. A. Tombrello
D. Lind	D. E. Nagle

The first meeting of the Program Advisory Committee was held on April 3-4, 1971, and a second meeting on July 5-6, 1971. The initial deadline for submission of proposals was April 1, but others were sent later. By July 5, nearly 80 proposals had been received and considered by the PAC. At the second meeting it became clear that the "case load" for the full Committee could be reduced by preliminary study of certain special fields in subcommittees. Accordingly, two subcommittees were established: (1) Nuclear Chemistry - Gerhardt Friedlander, Chairman, and (2) Biomedical Applications - Max Boone, Chairman.

The PAC is aided in its studies by preliminary analysis and evaluation of proposals pertaining to the separate beam channels or facilities by the several Users Working Groups responsible for organizing the programs for such channels or facilities. These single-facility Working Groups also serve a useful function in arranging for collaboration between research groups whose proposals overlap. However, the relative balance and priority between all of the beam channel users is the responsibility of the PAC. PAC's recommendations of the program priorities to the Director of LAMPF have great weight and go far toward establishing the working schedules.

A third meeting of the PAC was held on October 21-23, by which time the number of proposals received had increased to over 100. Following their report to the Director, letters indicating acceptance of proposals were sent out to about 60 scientific groups, indicating their place in the schedule for the particular beam channel following start of full-scale operations.

E. Radioisotope Production

A potentially valuable application of LAMPF is the utilization of the residual beam for the production of radioisotopes. This opportunity was explored in a series of papers by LASL staff presented to the AEC Division of Isotope Development on December 15, 1970, and published later as a LASL Report.[72] The intent of these studies was to estimate the capabilities of the beam, calculate the yields of radionuclides, and justify support for constructing an isotope production facility at LAMPF. The funds requested were needed to provide the target housing and target handling facilities at LAMPF. Chemical processing facilities for the radioisotopes that will be produced already exist and are available at LASL.

The medical and scientific needs and uses of radioisotopes are well known. In the past they have justified a large AEC investment in equipment for the production of radioisotopes from reactors and in chemical processing plants. For example, during 1966, AEC facilities produced more than five million administrations of radioisotopes for medical purposes, involving more than three million patients. It is safe to assume that this need will not only continue but will increase significantly. The proton-rich isotopes from LAMPF should be especially valuable for medical diagnosis and localization.

When LAMPF reaches full design capability it will produce more beam power than any other high-energy accelerator in the world, with an energy of 800 MeV and a time average beam current of 1 mA. The primary purpose is the production of momentum-analyzed beams of protons and secondary radiations such as pions for nuclear structure research. Following the beam splitters and targets that supply these beams for research, the residual proton beam will still have an energy of 700 ± 20 MeV and an intensity of 400 ± 100 μA, or a beam power approaching 300 kW. If used for the production of radioisotopes, this beam can yield greater intensities than all other accelerators put together. It will result in radioisotopes lying farther from the stability line than from lower-energy accelerators and of the proton-rich type that cannot be produced in reactors.

The principle mechanism for the production of isotopes off the stability line is high-energy proton-induced spallation in which many nucleons are knocked out of the nucleus. The products will have a broad distribution in mass below the target mass, which simplifies the problem of targeting, and will give useful intensities in the fission and low mass regions. One paper in the study at LASL[72] predicts the yields and describes the medical applications of a long list of radionuclides. Another paper describes the targeting system to be used at LAMPF including target cooling, a remotely controlled target removal system, and the mechanisms for handling and transporting the targets to the LASL radiochemistry laboratory. Calculations of the thick target penetration for 700-MeV protons suggest the radioisotope yields to be expected and also predict the heat-dissipation requirements in the targets.

In 1971, LAMPF used $50,000 of construction funds to build a stub-out for a beam to be diverted out of the main beam at the location of the isotope facility. And in FY 1972, the AEC authorized LASL to divert $100,000 of General Plant Projects funds to the construction of basic target facilities for the isotope facility at LAMPF to enable a minimal program of isotope production to be started.

F. Biomedical Facility

From the earliest LAMPF planning days, the use of negative pion beams for the treatment of malignancies in humans was known to be a possibility. However, this would require the development of a biomedical facility at LAMPF, which was not included in the original scope, and the cooperation of competent biological and medical staff to make the facility useful.

Nuclear physicists have known for years of the special property of negative pions, on slowing down in matter, being attracted to and absorbed by atomic nuclei with the release of the surplus mass energy of the pion as a "star" of nuclear fragments. The ionizing particles in such stars (primarily protons and alpha particles) produce a concentration of ionization at the end of the range of pion beam that is considerably greater than the Bragg peak of ionization at the end of range of protons or light charged particles. Such a concentration of ionization was known to some physicists, as well as to some medical therapists, to be potentially useful in the treatment of deep-seated tumors.[73] However, the use of pions for this purpose will become possible only when pion beams of sufficient intensity become available.

In early 1962, Rosen calculated the yield of pions expected from a meson factory of the energy and intensity planned for LAMPF and convinced himself that radiation doses of 50 to 100 rad/min over approximately 1000 cm^3 would be achievable. This intensity is therapeutically valuable, and it gave him confidence to proceed with plans to exploit this property of the pion beams. However, the biomedical utilization of LAMPF was never claimed to be a major reason for building the facility.

Rosen took on himself the task, which extended over several years, of convincing the medical community that pions might provide a worthwhile method of cancer treatment. One of the first important steps was a publication of a paper[74] by Rosen in December 1968 presenting his calculations of radiation dosage and discussing the favorable oxygen enhancement ratio for anoxic tumors. Some of his early supporters in the medical profession were Dr. Max Boone of the University of Wisconsin, Dr. Chaim Richman of the University of Texas, Dr. Robert Stone of the University of New Mexico, and Dr. Henry S. Kaplan of Stanford.

The AEC was informed at an early stage of the developing plans for a biomedical facility, and Rosen described the opportunities for such practical utilization of LAMPF to the Joint Committee on Atomic Energy at Hearings in Washington in February 1967 and again in April 1969 and March 1970. Discussions were held with Commissioners Seaborg, Thompson, and Johnson and also with Dr. John R. Totter, Director of the Division of Biology and Medicine. Early planning for the desired facility was supported under a Schedule 189 activity entitled "Applied Science – Development of Practical Applications of LAMPF" which was funded by the Division of Research. This study resulted in a preliminary proposal for the construction and operation of a biomedical facility. The proposal and an accompanying Schedule 44 were forwarded to the AEC in April 1969.

In early 1970, Dr. Totter wrote to Rosen and suggested that a group be set up in LASL's MP Division to continue planning activities for the biomedical facility. He strongly implied that eventual support for construction of the facility might be expected from the Division of Biology and Medicine. In response to Dr. Totter's letter, another Schedule 189 was prepared at LASL entitled "Biomedical Uses of Pions and Muons," dated August 3, 1970, requesting supporting funds sufficient to pursue the planning and design of a suitable facility and to develop a biomedical program within MP Division.

In the Spring of 1970, Rosen testified before the JCAE on the status of LAMPF and dwelled on the biomedical capabilities. As a result of this testimony, the JCAE authorized the AEC to proceed with a "stub-out" for the biomedical facility within the base funding. Early construction of this stub-out and the basic target system in the main beam was desirable to avoid a shut-down of operations at a later date. This start made it possible to construct the rest of the facility as funds became available without interference with the on-going operation of the accelerator.

A formal proposal[75] was prepared by Wright H. Langham, Associate H Division Leader, for the Biomedical Research Group describing the broad cooperative interest in a facility at LAMPF capable of providing a pion beam and accommodations for its clinical utilization. A program of biological research and clinical trials was described. A cost estimate of the complete facility (in addition to the $300,000 applied to the beam channel) came to $2,300,000. Copies of the document were transmitted to the Division of Biology and Medicine of the AEC.

The policy developed during early discussions with AEC representatives was that LAMPF would provide the site and the pion beam, but that the responsibility for clinical meson therapy would be assigned to an organization experienced in medical techniques and tradition and capable of handling large numbers of patients. Because the University of New Mexico Medical School was nearby, was interested and had a fine staff, it was the first choice to become this responsible organization. The LASL H Division formed a group under Dr. Chaim Richman, in 1971, to utilize the LAMPF biomedical facility. Dr. Morton Kligerman of the University of New Mexico Medical School was appointed Assistant Director of LASL for Radiation Therapy in October 1971; he is also Director of the Cancer Research Center at the Medical School.

The overall responsibility for support of the facility would appear to be within the province of the National Cancer Institute. The NCI has initiated support by a grant to the UNM Medical School to develop plans for pre-clinical trials and an eventual patient management program. Also, the State of New Mexico has voted substantial funds to support some initial activities of the UNM Medical School in planning for their utilization of LAMPF.

As a result of the interest generated within the medical profession, a Biomedical Users Group evolved in 1969-1970 and was organized within the broader framework of the LAMPF Users Group. A "Biomedical

Charter" was adopted at the Fourth LAMPF Users Group Meeting on October 30-31, 1970. A Users Steering Committee for biomedical applications and six standing subcommittees were established to carry on the planning. The initial Biomedical Applications Steering Committee (1970) consisted of

Chairman: Chaim Richman (then University of Texas)

Alternate Chairman: W. H. Langham (H-4, LASL)

Assistant to Chairman: David E. Groce (JRB Associates, La Jolla)

Subcommittees:

Cellular Radiation Biology:

Chairman: Paul Todd (Pennsylvania State University)

Alternate Chairman: Donald F. Peterson (LASL)

Therapy:

Chairman: Max Boone (University of Wisconsin)

Facility and Beam Line:

Co-Chairman: Paul Franke (MP-6, LASL)

Co-Chairman: Richard Hutson (MP-7, LASL)

Whole Animal Radiation Biology and Pathology:

Chairman: Charles Key (University of New Mexico Medical School)

Alternate Chairman: J. F. Spalding (H-4, LASL)

Physical and Biological Dosimetry:

Chairman: M. R. Raju (LRL, Berkeley)

Alternate Chairman: Phillip N. Dean, (H-4, LASL)

Isotopes and Diagnostic Applications:

Chairman: Jon Shoop (University of New Mexico Medical School)

Alternate Chairman: Harold O'Brien, (MP-7, LASL)

A full meeting of the Biomedical Applications Steering Committee was held November 11-12, 1970, at the University of Texas, Dallas, and a following meeting was held at the University of New Mexico on January 22-23, 1971. Subcommittee meetings were scheduled and planning activities started for each of the working groups. At the time of writing (1971), the major problem appears to be that of obtaining funds to start construction of the housing for the basic Biomedical Facility at the LAMPF site.

Just before his departure from the Atomic Energy Commission, when it became clear that the AEC was not going to be able to include funds for the desired biomedical facility in the FY 1972 budget request, Chairman Seaborg arranged for a meeting involving Rosen, AEC staff, and National Cancer Institute staff on the question of AEC/NCI joint support for the biomedical facility. From this meeting emerged a tentative agreement whereby NCI will provide $1,000,000 for construction of the pion channel portion of the LAMPF Biomedical Facility and associated controls. AEC is seeking funds for the remainder of the facility in its FY 1973 budget request.

APPENDIX A

LAMFF CONSTRUCTION STAFF, JULY 1971

	Name	Job Description	Degree	Start Date
MP Division Office				
Staff Members:	Rosen, Louis	Division Leader	Ph.D. Phys	9/62
	Nagle, Darragh E.	Alt Div Ldr	Ph.D. Phys	2/63
	Warner, Robert F.	Magnet Task Force Ldr	B.S. ME	7/70
	Tesche, Frederick	Assoc Div Ldr	Ph.D. Phys	6/65-6/68
Admin, Sec, & Clerical:				
	Dunn, Eleanor D.	Admin Asst & Div Sec		7/65
	Harper, Kay L.	Ed Asst	B.A.	2/66
	Marlett, Mary L.	Alt Div Ldr Sec		1/66
	Miller, Billie F.	Sec	B.A.	1/66
	Roybal, Eliza U.	Receptionist		6/70
	Schreffler, Laura J.	Sec	B.S.	1/70
MP-1 - Controls and Instrumentation - R&D Staff				
	Putnam, Thomas M.	Group Leader & Div Safety Ofc	Ph.D. Phys	2/64
	Butler, Harold S.	Alt Grp Ldr	Ph.D. Phys	9/63
	Gore, Raymond A.	Assoc Grp Ldr	Ph.D. EE	5/67
	Machen, Donald R.	Asst Grp Ldr	M.S. EE	10/67
	Thomas, Richard F.	Asst Grp Ldr	M.S. Phys	10/70
Staff Members:	Bergstein, Joe	Elec Engr	M.S. EE	7/70
	Biswell, Lavon B.	Elec Engr	B.S. EE	6/69
	Criscuolo, Alph. L.	Elec Engr	M.S. EE	1/69
	Elkins, Edgar P.	Elec Engr	B.S. EE	2/70
	Hill, Robert E.	Elec Engr	B.S. EE	4/70
	Little, James D.	Physicist	B.S. Phys	6/67
	Lundy, Arvid S.	Elec Engr	B.S. EE	7/67
	Parker, Joseph R.	Safety Syst	M.S. Engr	9/63
	Schultheis, Tom	Elec Engr	B.S. EE	7/65-3/67
	Simmonds, Dennis D.	Physicist	B.A. Phys	1/71
	Rogers, W. Vern	Elec Engr	B.S. EE	7/69

Admin, Sec, & Clerical:				
	Gutierrez, Cleo	Steno		10/70
	Harris, Robert E.	Draftsman		2/66
	Holterman, Daniel	Storesman		5/70
	Ungnade, Pauline	Grp Sec		3/66
	Wallis, Phyllis A.	Data Analyst	B.S.	10/67
Skilled Craft Personnel:				
	Conley, Andrew P.	Sr Tech		3/66
	Easley, James D.	Elec Tech		3/70
	Ekeroth, Gustaf A.	Elec Tech	Jr. College	3/67
	Garcia, David L.	Elec Tech		3/67
	Lederer, Harold M.	Elec Tech		5/68
	Potter, Jerry M.	Elec Tech	Tech Inst	2/66
	Smith, Wayne L.	Elec Tech	Tech Inst	12/67

MP-1 - Construction Staff

Staff Members:	Hartway, Bobby L.	Elec Engr	B.S. EE	7/69
	Plopper, Clifford M.	Programmer	B.S. Math	2/67
	Sharp, John B.	Elec Engr	M.S. EE	6/68
	Shlaer, Sally D.	Elec Engr	B.S. Math	2/66
Admin, Sec, & Clerical:				
	Chavez, R. M.	Draftsman		1/70
	France, Stephen W.	Draftsman		10/68
	Labadour, Benedict	Draftsman		9/69
	Martinez, Elvira	Clerk III		9/69
	Vigil, Herman J.	Draftsman		5/67
Skilled Crafts Personnel:				
	Andreatta, Henry	Elec Tech	Tech Inst	1/70
	Bagley, Richard C.	Elec Tech		1/70
	Bowie, Albert E.	Elec Tech	Tech Inst	12/69
	Garcia, Leroy M.	Elec Tech		6/69
	Gomez, Bennie G.	Elec Tech		12/69
	Hastings, Ray D.	Elec Tech		6/68
	Kercher, Delbert D.	Elec Tech		2/69
	Lopez, Michael J.	Elec Tech	Tech Inst	12/69
	Lopez, Thomas A.	Elec Tech	Tech Inst	10/69
	Ortiz, Emilio E.	Elec Tech		2/70
	Roybal, Leonard A.	Elec Tech		2/69
	Salazar, Gilbert J.	Safety Tech		6/69
	Vigil, Modesto D.	Elec Tech		3/69
	Walker, Donald	Safety Tech		2/66
	Williams, Harry E.	Elec Tech		10/65

MP-2 - Radiofrequency Systems - R&D Staff

	Hagerman, Donald	Group Leader & Asst Div Ldr	Ph.D. Phys	2/63
	Boyd, Thomas J.	Alt Grp Ldr	B.S. Phys	2/63
	Jameson, Robert A.	Assoc Grp Ldr	Ph.D. EE	6/63

Staff Members:	Cady, Robert L.	RF Engr	M.A. Phys	1/66
	DeHaven, Russel A.	RF Engr	B.S. EE	11/67
	Doss, James D.	RF Engr	M.S. EE	2/64
	Faulkner, J. Ross	RF Engr	M.S. EE	5/69- 7/71
	Hoffert, William J.	RF Engr	M.S. EE	4/66
	Kandarian, Robert	Mech Engr	M.A. Mech.	12/65
	Liska, Donald J.	Mech Engr	M.S. ME	11/65
	Newell, Robert H.	RF Engr	B.S. EE	8/64
	Tallerico, Paul J.	RF Engr	Ph.D. EE	2/68
	Turner, Thomas	RF Engr	B.S. EE	8/64- 9/70
	Wallace, Jerry D.	RF Engr	M.S. EE	7/67
Admin, Sec, & Clerical:				
	Eutsler, Margaret	Steno		7/69
	French, Garrison H.	Draftsman		2/66
	Rayburn, Lois	Grp Sec		5/70
	Thorn, Wayne K.	Draftsman		10/66
Skilled Crafts Personnel:				
	Cushing, Steven B.	Elec Tech	B.S.	7/65
	Davis, Jerry L.	Elec Tech	Tech Inst	3/67
	Dugan, Michael P.	Elec Tech		7/69
	Eichor, James R.	Elec Tech	Tech Inst	4/65
	Lyons, Kenneth M.	Elec Tech	Tech Inst	3/66
	McCabe, Charles W.	Elec Tech	Tech Inst	10/66
	Martinez, Robert	Elec Tech		7/70
	Patton, Robert D.	Elec Tech		4/67
	Quintana, Celestino	Elec Tech	Tech Inst	9/67
	Thomas, Arlo J.	Elec Tech		4/64
	Woodard, Charles	Elec Tech		7/67

MP-2 - Construction Staff

Staff Members:	Ferguson, Harold D.	Mech Engr	B.S. ME	7/67
	Hardwick, Jack N.	RF Engr	M.S. Math	7/67
	Kelly, Maxie M.	Mech Engr	B.S. ME	6/68
	Morris, Duard I.	RF Engr	B.S. ME	9/67
	Tubb, George E.	RF Engr	B.S. Phys	8/66
	Riedel, Jack	RF Engr	Phys	1/71
Admin, Sec, & Clerical:				
	Baran, Edward J.	Draftsman		3/67
	Gallegos, Jose	Draftsman		6/69
	Helland, William R.	Elec Tech		3/64
	Mills, Rene	Data Analyst	B.S.	10/69
	Roller, Theodore	Draftsman		2/67
	Hawkins, Walter L.	Elec Tech		9/67
	Katcher, Joe G.	Elec Tech		12/67
	Ridlon, Rae N.	Elec Tech		5/67
	Zastrow, John A.	Elec Tech		7/69

MP-3 - Accelerator Structures - R&D Staff

	Knapp, Edward A.	Group Leader & Asst Div Ldr	Ph.D. Phys	2/63
	Swenson, Donald	Assoc Grp Ldr	Ph.D. Phys	12/64
	Worstell, Hairston	Assoc Grp Ldr	B.S. ME	9/63
Staff Members:	Bush, Edgar D.	Design	M.S. ME	6/65
	Busick, John F.	Accel Oper	B.S.	8/68
	Gillis, Robert C.	Design	B.S. ME	6/65
	Goplen, Bruce C.	Beam Dynamics	M.S. Phys	7/70
	Hart, Valgene E.	Install & Alignment	M.S. ME	3/64
	Kelly, L. Michael	Design	B.S. ME	6/66
	Koczan, Steven P.	Fabrication	B.S. ME	1/66
	Martin, E. Ray	R&D	Ph.D. Phys	10/67
	Paciotti, Michael	Beam Dynamics	Ph.D. Phys	1/70
	Rislove, Seth E.	Cooling Systems	M.S. NE	4/66
	Ruhe, James R.	Vacuum	M.S. NE	7/65
	Schneider, Edward	Elec Design	B.S. EE	11/66
	Shlaer, William	R&D	Ph.D. Phys	8/65
	Swain, George R.	R&D	Sc.D. EE	10/65
	Tregellas, Richard	R&D	B.S. EE	8/67
	Trump, Michael	R&D	B.S. EE	6/68
Admin, Sec, & Clerical:				
	Garcia, Steve F.	Draftsman		12/69
	Harrison, Ronald	Draftsman		1/69
	Miller, Kaye	Grp Sec		7/71
	O'Neal, Melvin K.	Draftsman		8/65
	Smith, Chester R.	Draftsman		5/64
	Stroik, Paul J.	Draftsman		8/65
Skilled Crafts Personnel:				
	Adams, Edwin L.	Accel Oper		2/70
	Armijo, Valerio	Mech Tech		12/66
	Manger, Charles E.	Elec Tech		3/66
	Mynaugh, Charles	Phys Tech		11/65
	Ortega, Jose P.	Elec Tech		1/70
	Sherwood, Jerald	Mech Tech		6/64
	Studebaker, Jan K.	Elec Tech	Tech Inst	9/65
	Suazo, Gilbert	Mech Tech		10/66

MP-3 - Construction Staff

Staff Members:	Colston, Elbert W.	Install & Alignment	B.S. ME	1/69
	Rhorer, Richarard	Design	M.S. ME	6/67
	Schamaun, Roger R.	Design	M.S. ME	5/67
	Stovall, James E.	R&D	B.S. Phys	6/67
	Van Dyke, W. Joseph	Design	B.S. ME	6/67

Skilled Crafts Personnel·

Arquero, Eligio	Mech Tech	5/70
Briceño, Eugene W.	Elec Tech	12/70
Canfield, Craig T.	Mech Tech	5/70
Chellis, Kenneth	Accel Supv	2/69
Clayton, Richard	Mech Tech	1/67
Clayton, Ronald D.	Mech Tech	5/70
Cordova, Justo F.	Mech Tech	1/70
Espinoza, Alfred	Mech Tech	1/69
Gonzales, Gilbert	Mech Tech	5/70
Harrison, Robert F.	Mech Tech	7/69
Herman, Lloyd J.	Mech Tech	2/69
Johnson, Jerald L.	Mech Tech	12/67
Jones, David F.	Mech Tech	11/67
Jones, David M.	Elec Tech	7/70
Lopez, Eugene J.	Mech Tech	11/70
Martinez, Richard	Mech Tech	5/70
Martinez, Vidal	Mech Tech	11/68
McClellan, Patrick	Mech Tech	2/70
Mills, Ennis	Mech Tech	9/69
Ortiz, Benjamin F.	Mech Tech	7/69
Poe, Bobby F.	Mech Tech	5/67
Rector, Bobby	Mech Tech	2/69
Rivera, Oliver M.	Mech Tech	5/69
Romero, Jerry	Mech Tech	5/70
Roybal, Gustavo	Mech Tech	5/70
Sandoval, Daniel A.	Mech Tech	1/70
Trujillo, Faustin	Mech Tech	4/69
Weiler, Edward R.	Mech Tech	7/69
Welch, Carl L.	Mech Tech	10/67
West, Dennis K.	Mech Tech	5/69

MP-4 - Injector - R&D Staff

	Nagle, Darragh E.	Group Leader Alt Div Ldr	Ph.D. Phys	2/63
	Emigh, C. Robert	Assoc Grp Ldr	Ph.D. Phys	3/65
Staff Members:	Allison, Paul W.	Ion Source	Ph.D. Phys	5/66
	Crandall, Kenneth	Beam Dynamics	B.S. Phys	10/65
	Meyer, Earl A.	Accelerating Column	M.S. Phys	10/67
	Mueller, Donald W.	Ion Source	A.B. Phys	7/63
	Oostens, Jean M.	Spectrometer	M.S. Phys	7/70
	Potter, James E.	R&D	M.S. Phys	7/70
	Stevens, Ralph R.	Beam Transport	Ph.D. Phys	9/66
Admin, Sec, & Clerical				
	Trussell, Patsy	Grp Sec		4/71
Skilled Crafts Personnel:				
	Dauelsberg, Lawrence	Mech Tech	Tech Inst	3/69
	Kohl, Donald	Instr Dev		4/66
	Newlin, Theodore	Accel Oper		12/70

	Rajala, Robert E.	Elec Tech		8/65
	Scott, Leonard	Elec Tech		10/69

MP-4 - Construction Staff

Admin, Sec, & Clerical				
	Leavitt, John N.	Sr Designer		1/70
	Vasquez, Joe E.	Draftsman		3/70
Skilled Crafts Personnel:				
	Dalton, Charlie	Mech Tech	B.S.	3/69
	Lemons, Wayne W.	Mech Tech		1/69
	Milder, Martin	Elec Tech	Tech Inst	9/67
	Rodriguez, Joe E.	Mech Tech		2/70

MP-5 - Building and Site Construction - R&D Staff

	Edwards, Paul D.	Group Leader	M.S. Phys	5/65
	Claiborne, Eddie	Alt Grp Ldr	B.S. Engr	12/69
	Tesche, Frederick	(Group Leader)	Ph.D. Phys	6/65-6/68
Admin, Sec, & Clerical:				
	Burdette, Robert S.	Liaison Engr	B.S. Engr	3/66
	Cutler, Louis	Prop Supv		2/66
	Riggs, Mary V.	Grp Sec		7/68
	Vigil, Epitacio	Prop Rep		7/69
Skilled Crafts Personnel:				
	Gonzales, Pablo A.	Driver		3/70

MP-5 - Construction Staff

Staff Members:	Wilhelm, Richard	Programmer		3/70
	York, Don A.	Engr	B.S. ME	7/65-7/71
Admin, Sec, & Clerical:				
	Garreffa, Larry	Comp Analyst		5/67
	Ryan, Bernard L.	Procurement		7/67
	Whittemore, Pat	Clerk		5/68

MP-6 - Experimental Areas - R&D Staff

	Cochran, Donald R.F.	Group Leader	Ph.D. Chem	2/64
	Wilson, Mahlon T.	Assoc Grp Ldr	Ph.D. ME	5/67
	Franke, Paul R.	Asst Grp Ldr	B.S. Phys	5/67
Staff Members:	Gram, Peter A.M.	Beam Diagnostics	Ph.D. Phys	1/68
	Harvey, Alexander	Magnet Design	B.S. EE	2/70
	Hassenzahl, William	Magnet Measure	Ph.D. Phys	9/67
	Roeder, Dennis	Computation	A.B. Phys	6/69
	Shively, Frank T.	Beam Transport	Ph.D. Phys	9/69

Admin, Sec, & Clerical:				
	Grote, Freda A.	Grp Sec		9/69
	Thorn, Linas L.	Sr Designer		11/67
Skilled Crafts Personnel:				
	Uher, Joseph L.	Mech Tech		10/69

MP-6 - Construction Staff

Staff Members:	Bridge, James A.	Switchyard Dev	B.S. ME	7/70
	King, Charles R.	Exper Area Oper	M.S. EE	5/71
	Meier, Karl	Target Dev	M.S. ME	7/70
	Turner, Robert D.	Magnet Design	B.S. ME	7/70
Admin, Sec, & Clerical:				
	Christiansen, R.	Designer		11/68
	Davis, Lawrence	Draftsman		1/70
	Havens, James H.	Draftsman		7/70
	Martinez, Ricardo	Draftsman		12/68
	McInteer, Carlotta	Data Analyst	B.S. Math (Eq)	6/71
	Michaud, Francis	Designer		3/68
	Montoya, William	Draftsman		1/70
	Roybal, Phillip	Draftsman		5/70
	Sharp, Nancy	Data Analyst	B.S. Math	10/70-6/71
Skilled Crafts Personnel:				
	Caine, James C.	Elec Tech	Tech Inst	9/69
	Leydig, Robert	Elec Tech		4/70
	Martinez, Lonjino	Mech Tech		7/70
	Montoya, Teodosio	Mech Tech		1/68
	Mueller, Charles	Mech Tech		7/70
	Roberts, Maynard	Mech Tech		7/70
	Voss, Hans J.	Elec Tech		7/70

MP-7 - Secondary Beam Lines and Spectrometers - R&D Staff

	Agnew, Lewis E.	Group Leader	Ph.D. Phys	11/68
	Thiessen, H. A.	Assoc Grp Ldr	Ph.D. Phys	10/66
Staff Members:	Amato, James J.	Low Energy Pion Channel	Ph.D. Phys	9/69
	Burman, Robert L.	Low Energy Pion Channel	Ph.D. Phys	9/68
	Cowan, Helen D.	Pion Channels	B.S. Chem	10/69
	Dunwoody, Wade E.	EPICS	B.S. ME	6/70
	Hutson, Richard L.	Bio Med	Ph.D. Phys	10/69
	Hwang, Chester F.	Nucleon Phys	Ph.D. Phys	2/71
	Macek, Robert J.	P^3 Pion Channel	Ph.D. Phys	2/69
	Novak, Jan K.	Nucleon Phys	M.S. ME	4/70
	Schillaci, Mario	Raa Isotope Prod	Ph.D. Phys	1/70
	Tanaka, Nobuyuki	HRS	Ph.D. Phys	8/69

	Thompson, Patrick	Muon Channel	Ph.D. Phys	4/71
	Vogel, Herbert F.	Muon Channel	Dipl Engr	5/66
Admin, Sec, & Clerical:				
	Thorn, Patricia	Grp Sec	B.A.	6/70
	Weinbrecht, Nancy	Data Analyst		4/69
MP-7 - Construction Staff				
	Yourd, Roland B.	Magnet Design	M.S. ME	12/70

APPENDIX B

UNIVERSITIES AND LABORATORIES PARTICIPATING IN FIRST LAMPF USERS MEETING, JUNE 20, 1968

Virginia Associated Research Center
Chalk River (AECL)
Columbia University
Texas A & M
Carleton University
University of California, Berkeley
University of Wisconsin
Ames Laboratory
Catholic University
University of Toledo
Michigan State University
University of Wyoming
Brigham Young University
New Mexico State University
University of South Carolina
University of Utah
University of Oregon
University of Southern California
Brookhaven National Laboratory
University of Houston
Virginia Polytech
College of William & Mary
Rice University
Northeastern University
University of Victoria
Lawrence Radiation Laboratory
University of Denver
Oak Ridge National Laboratory
Florida State University
Montana State University
California Institute of Technology
University of Texas
Carnegie-Mellon University
University of Iowa
Associated Western Universities
Colorado College
University of Maryland
Massachusetts Institute of Technology
University of Alberta
Duke University
Yale University
USAEC-Washington & Idaho Falls
Arizona State University
University of Montana
Northwestern University
University of Idaho
University of California, Los Angeles
University of Rochester
Los Alamos Scientific Laboratory
University of Arizona
Argonne National Laboratory
Colorado State University
University of New Mexico
University of Colorado
University of Illinois
University of Washington
Stanford Linear Accelerator Center
University of Georgia
University of North Carolina
University of Minnesota
Texas Institute of Technology
University of Chicago
Texas Nuclear Corporation
University of Manitoba
University of Virginia
Purdue University
University of British Columbia
Case Western University
University of Indiana
University of Maryland

APPENDIX C

USERS GROUP

Los Alamos Meson Physics Facility

CHARTER

The Los Alamos Meson Physics Facility (LAMPF) Users Group is an organization of active scientists and engineers with a special interest in LAMPF and, in particular, its research program. The purpose of this group is two-fold:

a) To provide a formal channel for the exchange of information between the LAMPF administration and scientists of other laboratories who will utilize this facility for their research.

b) To provide a means for involving scientists and engineers from user groups in specific projects at LAMPF and for offering advice and counsel to the LAMPF management on LAMPF operating policy and facilities.

Through a wide representation of scientists the group will make known to the LAMPF administration the needs and desires of those scientists actively engaged in research projects. As an example of the relationship between the users community and the LAMPF administration, it is understood that some members of the Program and Scheduling Committee will be selected from candidates proposed by the Users Group.

1. Membership. The membership of the Users Group is open to practicing scientists and engineers. The LASL-appointed Director of LAMPF and University and National Laboratory Scientific Administrators shall be invited to be nonvoting members of the Organization. Following the drawing up of an original membership list, new members will be added by action of the Executive Committee of the Users Group upon receipt of a written request. In addition, each member will indicate in writing at the time of each general election his desire to remain on the membership list for the coming year.

2. Officers and Executive Committee. The officers of the Users Group shall consist of a Chairman, Chairman-elect, Liaison Officer, and three other elected members. The Chairman, Chairman-elect, and three elected members will constitute the Executive Committee of the LAMPF Users Group. The Liaison Officer will be an ex officio member of the Executive Committee. The Chairman-elect and the three committee members will be elected annually by mail ballot. The first slate of officers shall be elected by a plurality of the users attending the initial organization meeting held at Los Alamos on January 16, 1969, and thereafter elections shall be held as described in 2a, b, c, and d.

a. A Chairman-elect shall be elected annually by members of the Users Group by written ballot, distributed prior to October 1 to the membership as of September 1, and shall take office on January 1 of the following year. A plurality of votes cast is sufficient for election.

b. The Chairman-elect will succeed to the office of Chairman at the end of one year.

c. The term of the Chairman of the Users Group for LAMPF is for a period of one year.

d. The three other members of the Executive Committee will be elected annually.

e. A Liaison Officer of the Users Group is to be appointed by the LAMPF Director in consultation with the Chairman and Chairman-elect of the Users Group. It will be the duty of the Liaison Officer to act as secretary of the meetings and keep the minutes. He will request nominations, send and tally mail ballots, and generally serve as secretary to the Users Group. It is further the duty of the Liaison Officer to keep the Users Group informed by means of frequent news letters of new developments at the LAMPF and other matters of interest to the users. The Liaison Officer shall serve for a period of two years and can be reappointed for an additional two. He should not serve three consecutive terms.

f. A person who has served as Chairman cannot be nominated as Chairman-elect for a period of three years.

3. Meetings. The LAMPF Users Group shall meet at least once each calendar year at a time and place designated by the Chairman, upon advice of the Executive Committee. Notice of the meeting should be sent to the members of the Users Group at least a month in advance and shall include the agenda for the meeting. The Secretary-Liaison Officer will prepare summaries of all meetings, which will be mailed to all members, arrange details of meetings and other necessary work of the Committee.

4. Procedures.

a. The Executive Committee may, on its own initiative, and shall, upon instruction of a majority of the members attending a general meeting, submit questions for consideration to the full membership. Results of the deliberations of the Users Group shall be communicated to the Director of LAMPF.

b. The Executive Committee shall recommend to the LAMPF administration names of user scientists for consideration as members of LAMPF's Program and Scheduling Committee.

c. The Executive Committee will appoint a Technical Advisory Panel (TAP) from the membership of the Users Group. The Chairman of the Executive Committee will act also as Chairman of TAP. This Committee shall consist of twelve (12) members appointed for two years in such a way that six (6) new members are added each year to take office on January 1. The duties of the TAP will be to collaborate with the staff of the LAMPF in devising new experimental facilities and evaluating future developments. The TAP will meet at least twice a year, and the Chairman-elect and the Liaison Officer are to be members ex officio.

d. The Executive Committee shall appoint a Nominating Committee consisting of five members of the Users Group, but not including any officers, who are charged with the duty of nominating a slate of candidates for the Chairman-elect and the three other elective positions of the Executive Committee. The Nominating Committee may meet in person if it wishes or may transact its business by mail or by telephone. The Chairman of the Nominating Committee will be designated by the Chairman of the Users Group. Direct nominations, for each of the positions, from the membership can be made by a petition from at least ten (10) members, sent to the Chairman of the Executive Committee prior to September 15.

5. This Charter shall be adopted, if approved, by two-thirds of the prospective members attending the initial meetings.

6. This Charter may be amended by a written vote of the members. A proposed amendment shall be introduced at a general meeting. A two-thirds majority of the members voting is required for passage of the amendment. The vote must be taken within a month of the time the amendment was introduced.

Adopted at
Second LAMPF Users Meeting
Los Alamos, New Mexico
January 16, 1969

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