284
11-1-77

Sh. 1546

LA-6878-MS
Informal Report

Master

UC-28 and UC-34

Issued: September 1977

LAMPF

A Nuclear Research Facility

M. Stanley Livingston*

*Consultant. 1005 Calle Largo, Santa Fe, NM 87501.

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87545

UNITED STATES
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
CONTRACT W-7405-ENG. 36

LAMPF

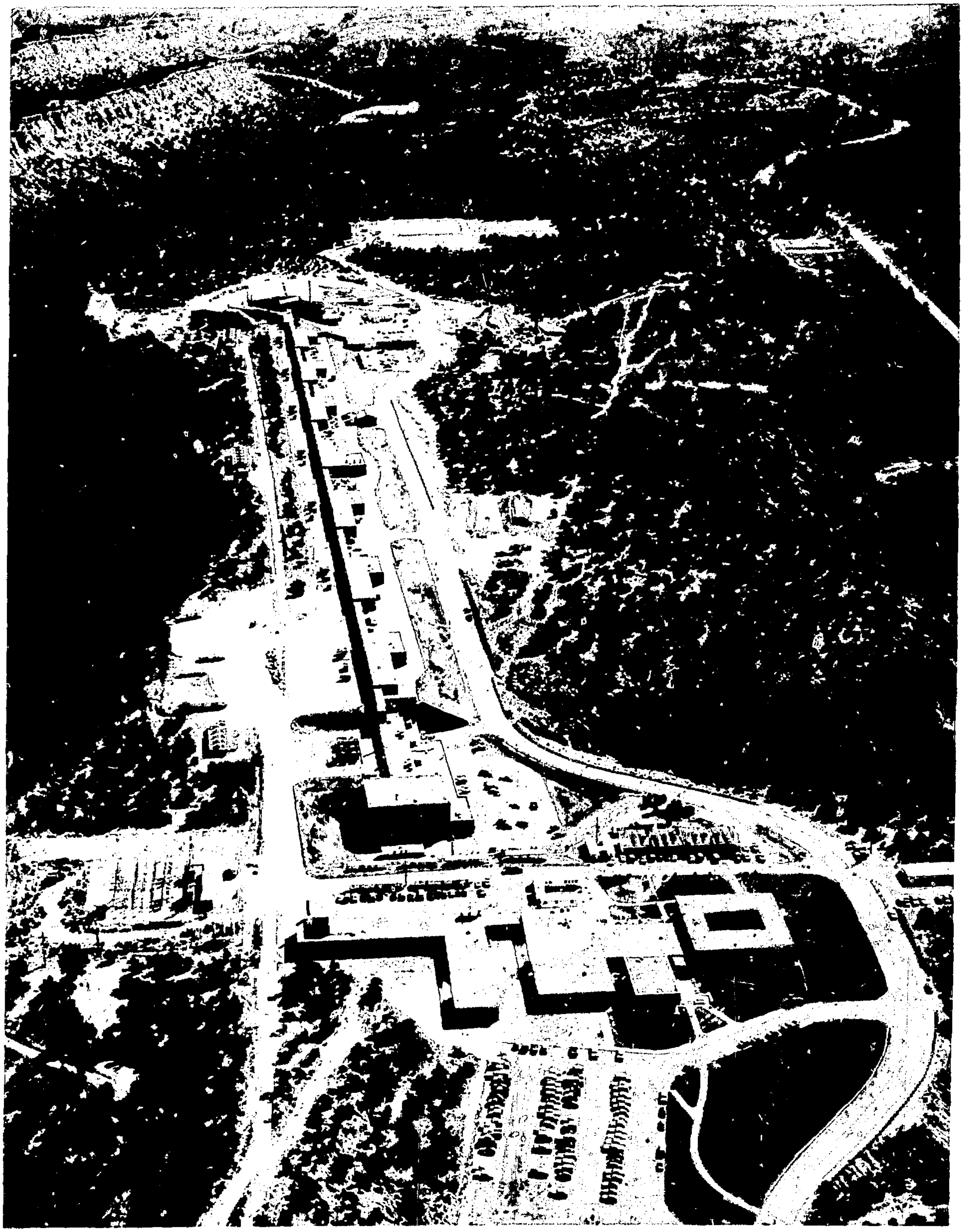
A NUCLEAR RESEARCH FACILITY

of

Los Alamos Scientific Laboratory
Los Alamos, New Mexico

by

M. Stanley Livingston



Frontispiece.

PREFACE

An enterprise of the magnitude of the Meson Physics Facility at Los Alamos Scientific Laboratory truly involves the efforts of countless persons. Among these, a great many are essential to the project; without them it could not be completed. In the following pages some of the most important contributors are named.

Exercising the author's prerogative, I should here like to emphasize particularly the contributions of four persons without whom LAMPF could not have come into being:

The two Directors of LASL, under whom LAMPF was conceived and built:

Norris E. Bradbury

Harold M. Agnew

The present Director of LAMPF and MP-Division Leader at LASL:

Louis Rosen

And, finally, a man whose extraordinary vision and talents made him an essential contributor to this project, to LASL, and to his adopted state of New Mexico; the man for whom this project was named, to whom I dedicate this work with admiration and appreciation, the late

Senator Clinton P. Anderson.

M. Stanley Livingston

Santa Fe, New Mexico

June 1977

CONTENTS

LAMPF — A NUCLEAR RESEARCH FACILITY

by

M. Stanley Livingston, Consultant

ABSTRACT

This report presents a description of the recently completed Los Alamos Meson Physics Facility (LAMPF) which is now taking its place as one of the major installations in this country for the support of research in nuclear science and its applications. Descriptions are given of the organization of the Laboratory, the Users Group, experimental facilities for research and for applications, and procedures for carrying on research studies. Results of the research program are published elsewhere.

I. INTRODUCTION

The name LAMPF describes a nuclear research facility at the Los Alamos Scientific Laboratory. It utilizes a high-intensity 800-MeV linear accelerator which provides beams of protons and a variety of secondary particles and radiations, of which the most useful are positive and negative pions. The facility includes targets, beam-handling devices, and the instrumentation for research experiments. A sketch of the installation is shown in Fig. 1. LAMPF is primarily a research laboratory for nuclear physics; it is also of major interest to radiochemists, biologists, and solid-state physicists. It provides facilities for important applications in medicine, in isotope production, in the structure of materials, and in defense science.[1,2] LAMPF is a national research facility, available to all professionally qualified members of the scientific community.

On completion, the facility was named the Clinton P. Anderson Meson Physics Facility. Following initial operation of the linac at 800-MeV energy in June 1972, and the start of a preliminary research program in August, it was dedicated, and Senator Anderson was honored, at a ceremony on September 29.

A beam intensity of 100-μA average was achieved by August 1976. During the latter half of 1976 the number of scientists participating in experiments totalled 310, of which 86 were from LASL. Others were from universities, other national laboratories, and from hospitals and medical centers. Even at this early stage of operations, it is possible to claim a significant success for this facility, which shows promise of becoming a major research installation. The success is due primarily to the continuing efforts of the LAMPF staff, ably led by the Director, Louis Rosen.

This report is a description of the operating facility, intended for general informational purposes. Features covered in the report include the basic properties of the facility and of the several beam channels, the organization of the laboratory and of the Users Group, and a description of the procedures for initiating a research program. It is hoped that this report will provide a useful overview of this new and important research facility as it matures and joins with other laboratories in this country in providing support for research in nuclear science and its applications.

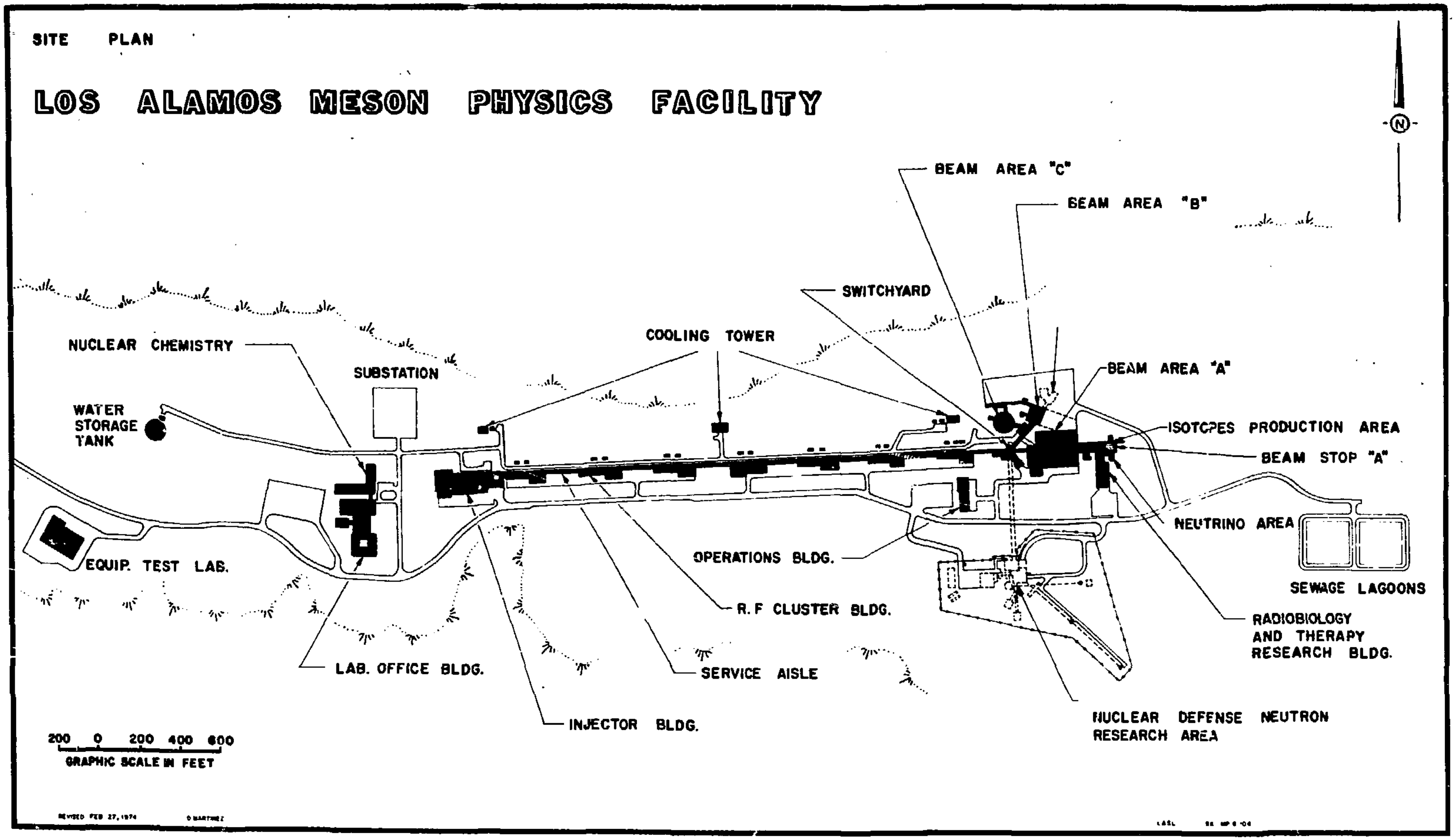


Fig. 1
Diagram of LAMPF Installation.

CHAPTER 1

ORIGINS AND PRESENT STATUS OF LAMPF

A. Location

The LAMPF linac and research facility is located on Mesita de Los Alamos, a long, narrow mesa south of the main plateau on which the town of Los Alamos is situated. The top of the mesa is essentially level, providing an excellent site for the half-mile-long linear accelerator, with wide and deep arroyos on both sides and at the eastern end. The mesa is formed of tuff, a soft, low-density volcanic-ash rock. The main linac is in a tunnel formed by cutting a deep trench in the rock, with backfill above for shielding.

LAMPF is operated within a division of the Los Alamos Scientific Laboratory and has benefited from the skills and technical expertise accumulated at LASL over its 30 years as a research and weapons laboratory. A significant distinction is that LAMPF is planned as an open laboratory available to qualified scientists from across the nation or from foreign countries, while LASL continues a large effort in weapons research under strict (Class A) security control. LAMPF is located outside the LASL security gates; the only controls required are those for identification of authorized personnel and the protection of government property (Class B security).

A valuable bonus for the visiting research worker is the town of Los Alamos, an ususually well-planned and attractive site for family living, with excellent schools, churches, shopping centers, and other facilities.

B. Authorization and Construction

The Los Alamos Meson Physics Facility was conceived in 1962 by a small group of LASL scientists, mostly from the Physics Division, under the leadership of Louis Rosen. A study group headed by D. E. Nagle, whose other members were Austin McGuire, D. C. Hagerman, and E. A. Knapp, became active in design planning in 1962 and prepared the first tentative proposal. The concept was shepherded through the design and authorization phases from 1962-66 by this same group and was constructed with funds allocated by the U.S. Atomic Energy Commission during 1966-72. The story of the development of this facility is given in a LASL report "Origins and History of the Los Alamos Meson Physics Facility," LA-5000, June 1972.[3]

A preliminary proposal by the LASL staff was submitted to the Division of Physical Research of the Atomic Energy Commission in December 1962, which announced the Los Alamos plans to enter the field of meson-producing accelerators. In August 1963, the LASL group prepared a "Construction Project Data Sheet"[4] entitled "Los Alamos Meson Physics Facility," which was submitted to the AEC by the LASL administration and which proposed schedules for construction and cost estimates. The acronym "LAMPF," coming from the title of the document, soon became the popular name of the facility. This early design work was supported by the LASL administration using funds primarily coming from the AEC Division of Military Applications.

Competition was severe for supporting funds for meson-producing accelerators during 1962 to 1964.[5] The only available source was the U.S. Atomic Energy Commission (although later the National Science Foundation did support the rebuilding of an existing installation at Columbia University which operates at considerably lower intensities). A proposal for a similar proton linac was submitted by Yale University.[6] based on the same evidence available to LASL. A proposal for a high-intensity isochronous cyclotron came from the Oak Ridge National Laboratory,[7] and a plan for a negative-ion (H^-) sector-focused cyclotron was proposed by a group in the Physics Department of the University of California at Los Angeles.[8]

The LASL proposal came closest to meeting the recommendations of the "Bethe Panel" Report.[9] The Bethe Panel, chaired by Professor Hans Bethe of Cornell University, was appointed in 1963 by the then Office of Science and Technology to advise the Government on the needs for high-intensity, medium-energy (<1.0 GeV) accelerators which could produce mesons. As a result of their Report, a new budget entity was formed by the AEC to support the medium-energy field, and the recommendations of the Bethe Panel were adopted as AEC policy. So the LASL proposal was approved for support by the AEC in early 1964.

Construction funds were not obtainable on short notice, but in April 1964 the Physics Research Division of the AEC made a fund of $500 000 available to LASL for a study to define the scope, design basic engineering features, and develop reliable cost estimates. These funds allowed the LASL group to expand staff, intensify the model program, employ commercial firms to start architect/engineering studies of buildings and site requirements, design and estimate costs of radio-frequency power systems, and study the problem of computer control. This engineering and cost study was completed by September 1964, and from these data a revised "Construction Project Data Sheet"[10] was presented to the AEC on October 30, 1964. The cost estimate was $55 000 000, and the time for construction estimated as six years. This became the basic cost and time estimate for construction.

Detailed design and construction of the LAMPF facility started with authorization of the first construction funds by the Congress in the FY-1966 budget. Further amounts were authorized in successive years, but during several years were reduced below the requested amounts. These postponements of funds delayed completion of some parts of the installation and increased the cost. Major construction funds became available in October 1968. Construction of the Equipment Test Laboratory began in early 1968. A first unit of the linac housing, the Injector Building, was started in early 1969. By this time the design of the accelerator itself was essentially complete and construction contracts had been placed covering most of the linac components. Construction of the tunnel and of the radio-frequency power cubicles spaced along the tunnel was completed to meet the scheduled dates for equipment installation in all cases. The last unit of the building complex to be specified and built was the housing for the target areas and experimental areas at the end of the linac.

The linac was brought into initial operation at 800 MeV with a low-intensity beam on June 9, 1972, within the time schedule and the revised cost estimate of $57 000 000.

C. Linac Performance

Progress during the subsequent developmental state of the linac can be illustrated by the following list of the more important events:

June 9, 1972
First beam of 800-MeV protons obtained with a few μA intensity at the end of the linac.

August 1972
First experiments started at low-beam intensity mostly of the satellite type.

March 28, 1973
First ion (H^-) beam accelerated to 800 MeV.

July 15, 1973
Proton beam of 250 MeV and 0.5-μA-average intensity obtained in Area B.

August 26, 1973
Proton beam of 447 MeV and 0.6-μA-average intensity used in Area A. Beams of p^+, e^+, π^+, and μ^+ separated for the first time.

April 1974
Pion beam channel in the Biomedical Facility operable.

January-December 1974
Increasing use of beams for research: 70 experiments given beam time; 1600 shifts of research operation; 40 000-μA h delivered to experiments.

September 24, 1974
Announcement of "Great Shutdown," starting in late December 1974, to improve linac intensity, radiation harden the main beam line components, add shielding, and install more experimental installations.

A summary of the progress in research made during 1974 is listed:

1. A total of 66 experiments were mounted. Operation of these experiments and analysis of the results proceeded throughout the year.

2. Simultaneous delivery of beam was made to eight experiments.

3. The Line A beam stop location was used for initial data on three neutrino experiments (Experiments 24, 31, 38).

4. Muonic x-ray studies were made on several targets to determine quadrupole and hexadecapole moments, and to give accurate charge radii (Experiments 7, 166, 163).

5. Pion-produced charge-exchange reactions were produced and radioactive products were measured (Experiment 102).

6. Inelastic pion scattering on Zr and C was studied (Experiments 191, 180).

7. Liquid tritium (^{3}T) was produced and used as a target for pion-capture reactions (Experiment 50).

8. Measurements were made of pion total cross sections at low energy (Experiment 2).

9. Measurements were made of scattering of pions by H at low energy (Experiment 96).

The "Great Shutdown" extended through August 1975. Developments of the linac and facilities accomplished during this time can be summarized:

1. improvements of quantity, cooling, and configuration of shielding in switchyard and main beam run,
2. radiation hardening of target cells with addition of shielding,
3. improved facilities for handling radioactive samples and equipment,
4. repair and replacement of some faulty drift-tube bellows in 100-MeV linac,
5. improved alignment of drift-tube linac to increase beam acceptance,
6. resurvey of main linac alignment with levels, transit, and taut wires,
7. correction of phase errors in main linac due to misalignments,
8. installation of many new experiments in the experimental areas.

A major result of the shutdown was an increase of beam intensity. Routine operation at 100-μA average beams of H^+ ions was achieved by August 1976. The H^- ion beam diverted to Area B was also increased in intensity, to 6-μA average. Spinning target wheels were developed for target locations A-1 and A-2, capable of handling intensities of 100 μA, and water-cooled windows have been installed at Beam Stop A-6. By May 1977, the facility was in production at 150-μA average, and one run was made at 300 μA with a duration of over one hour. These developments are a good indication that LAMPF will eventually reach its design intensity of 1-mA average H^+ beam at 800-MeV energy, at $\sim$6% duty cycle. Even at present intensities the available beam power (energy × intensity) exceeds that available at any other accelerator. Proton beam intensity exceeds the sum of intensities from all proton accelerators of energy above the pion threshold. The potential usefulness of these high intensities has hardly been explored and promises results of major importance.

Another important accomplishment of the shutdown was the installation of many new experiments, with beam control equipment and adequate shielding for higher intensities. The use of multiple branching beams allows more experiments to be run simultaneously. Typically, 10 or more experiments receive beam simultaneously utilizing the available facilities. Nearly 100 experiments in various stages of installation or operation have been set up in the many possible locations.

By June 1977 the Facility had been developed to full capacity for research use, if not to ultimate full intensity. A total of over 1000 scientists were members of the Users Group and had submitted over 300 proposals for experiments. The operations phase now starting (Summer 1977) should be a most productive period.

CHAPTER 2

ORGANIZATION

A. Medium Energy Physics Division

The LAMPF facility is operated by the MP-Division (Medium Energy Physics) of the Los Alamos Scientific Laboratory. Louis Rosen is Division Leader, and also Director of LAMPF, appointed by the Director of LASL. The MP-Division is a broader organizational entity than LAMPF and can be assigned wider responsibilities than the meson physics facility, although in practice the two organizational entities overlap almost completely. To illustrate the distinction: Rosen is responsible for all research activities of the staff of the MP-Division, whether they are performed at LAMPF or elsewhere. The linear accelerator beam is also put to other uses than for the LAMPF research facilities. For example, the Weapons Neutron Research area uses a fractional beam diverted from the linac through a tunnel into a separate building where research is carried on by other LASL Divisions.

The staff of the facility hold assigned positions of responsibility within either the MP-Division Office (MP-DO) or in one of the twelve groups: MP-1, MP-2, MP-3, MP-4, MP-7, MP-8, MP-9, MP-10, MP-11, MP-12, MP-13, and MP-14. They can also be said to hold parallel positions on the LAMPF staff. But their official positions are as members of the MP-Division. (Note that other groups, the missing numbers, were active during design and construction but were phased out when LAMPF became an operating facility.)

The name LAMPF has become a simplification useful in describing the facility and the arrangements of the laboratory. It covers the scientific research functions and those aspects of its operations dealing with the scientific users. In 1968-69 when scientists from outside LASL were meeting to plan the Users Group, a clear distinction was made between LAMPF, which was to be an open laboratory providing facilities for outside scientists, and LASL, the existing laboratory, part of which was classified and part of whose mission was weapons development. The potential users believed that a substantial autonomy of LAMPF within LASL must be achieved if it were to attract qualified scientists and develop a significant research program. With this in mind the users wrote into their charter the arrangements by which the users would deal with the "Director" of LAMPF, and the extent to which the "Director" would accept their guidance on scientific matters and the research program. This title is not normally given to division leaders at LASL. The Director of LASL has accepted these arrangements as proper to ensure the scientific success of the new research facility. In so doing, he has accepted the existence of a "LAMPF" entity distinct from the MP-Division and has authorized the use of the title of "Director" for the leader of LAMPF.

In his capacity as the scientific leader of the meson facility, it is the responsibility of the LAMPF Director to approve and authorize the research programs to be carried out at LAMPF. At suitable intervals he calls for proposals for research experiments from the scientific users. These proposals are submitted to him and, with the assistance of his operations and support staff and with the advice and recommendations of the Program Advisory Committee (PAC) which he appoints, the Director authorizes and schedules the research experiments.

One method of describing the organization is an outline form based on the several groups, with staff titles and assignments, as given in Table I. Another description is an organization chart of MP-Division which, though somewhat simplified, shows some of the interrelations between groups; such a chart is shown in Fig. 2.

TABLE I

ORGANIZATION OF MP DIVISION

June 1977

MP-DO — Medium Energy Physics Division Office

1. MP-Division Leader, L. Rosen (also LAMPF Director)
2. Alternate MP-Division Leader, D. E. Nagle
3. Associate Division Leader for Operations, D. C. Hagerman
    a. Operations Staff
    b. Accelerator Committee
    c. Scheduling Committee
        D. C. Hagerman, Chairman
        L. E. Agnew
        D. R. F. Cochran
        T. M. Putnam
        D. E. Nagle
        A. A. Browman
        S. P. Koczan
4. Associate Division Leader for Experimental Areas, Lewis Agnew
5. Associate Division Leader, E. A. Knapp
6. Users Group Office
    a. Administrative Services, E. Dunn
    b. Users Liaison, D. R. F. Cochran
7. Assistant Division Leader for Planning Budgets, R. F. Warner
8. Assistant Division Leader for Experiment Evaluation, Special Problems, Secretary to PAC, D.R.F. Cochran
9. Assistant Division Leader for Safety, T. M. Putnam

MP-1, Electronic Instrumentation and Computer Systems, H. S. Butler, Group Leader

MP-2, Operations, J. Bergstein, Group Leader

MP-3, Practical Applications, J. N. Bradbury, Group Leader

MP-4, Nuclear and Particle Physics, D. E. Nagle, Group Leader

MP-7, Experimental Areas, L. E. Agnew, Group Leader

MP-8, Engineering Support, E. D. Bush, Group Leader

MP-9, Accelerator Development, R. A. Jameson, Group Leader

MP-10, EPICS and HRS, H. A. Thiessen, Group Leader

MP-11, Accelerator Support, J. D. Wallace, Group Leader

MP-12, Injector Systems, R. R. Stevens, Jr., Group Leader

MP-13, Beam Line Physics, R. Macek, Group Leader

MP-14, Pion Generator for Medical Irradiations, D. A. Swenson, Group Leader

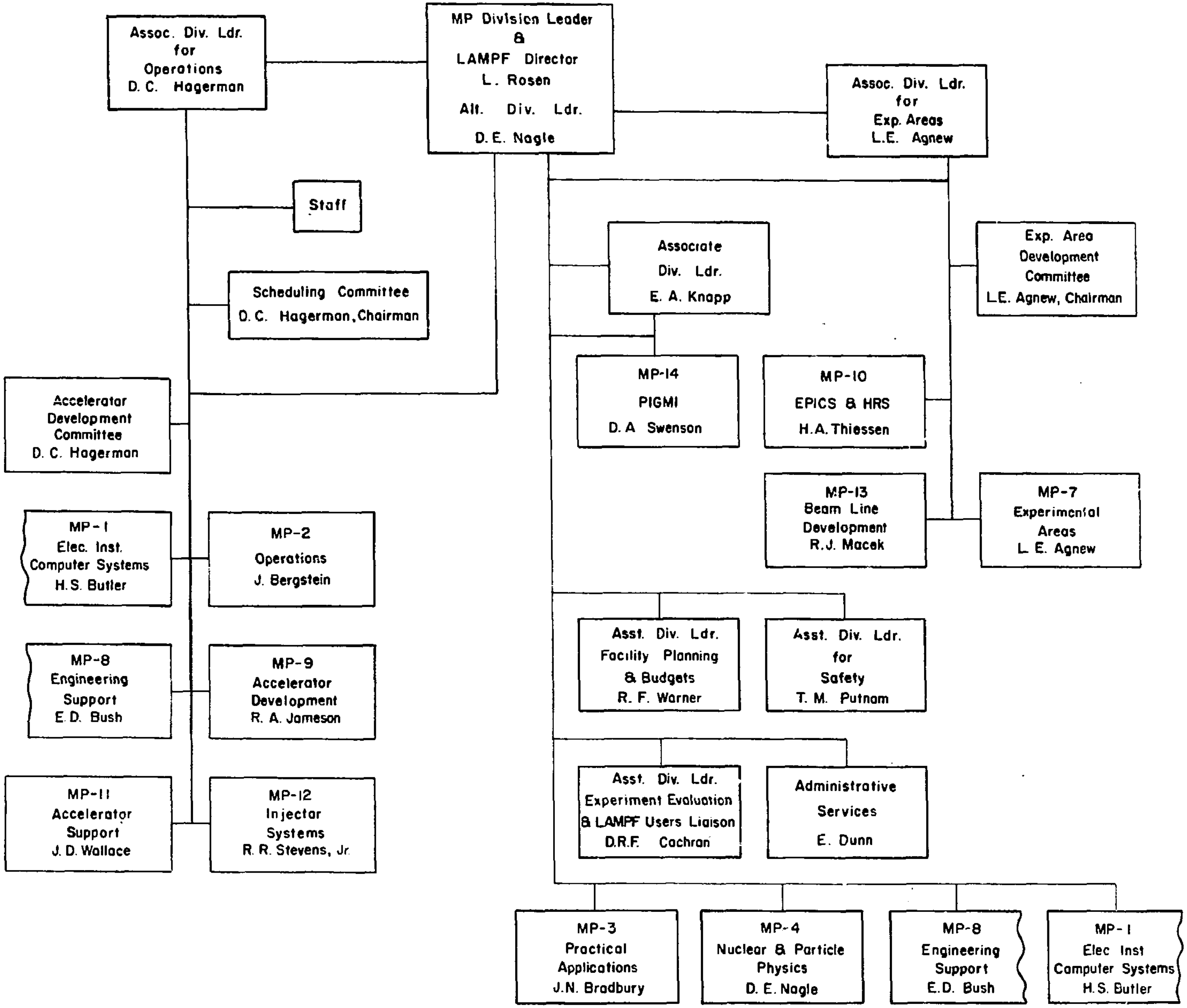


Fig. 2
LAMPF Organization Chart.

B. Users Group

Another aspect of the organization is the Users Group, which is independent of the official structure of the LASL laboratory but operates as a service to the scientific users from other institutions. The Users Group has its own organization and Board of Directors and is incorporated under the laws of the State of New Mexico pertaining to nonprofit corporations. It appoints a Technical Advisory Panel (TAP) to work closely with the LAMPF support staff on plans for the experimental program, to study new capabilities and support systems, and to make recommendations to the Director of LAMPF.

The LAMPF organization provides offices, administrative liaison, secretarial services, and all necessary facilities to the Users Group, to assist them in accomplishing their purposes. The director of LAMPF accepts advice and suggestions from the Technical Advisory Panel whenever practicable, and accepts the Board of Directors of the Users Group as the official spokesmen for the scientific users of the LAMPF facility. Because of its importance in the operations of the facility, the Users Group and its activities are described in more detail in a following chapter.

C. Program Advisory Committee

The Program Advisory Committee (PAC) is the primary determinant of scientific policy and scientific use of LAMPF. This committee examines research proposals, recommends acceptance, rejection, or modification on the basis of scientific merit and feasibility, and recommends priorities for proposals found acceptable. Its responsibility covers all proposals which require substantial beam time or other LAMPF resources. It is the indispensable *right arm* of LAMPF management insofar as the scientific program is concerned.

The PAC is appointed by the Director of LAMPF in his capacity as scientific leader of the research facility. He also acts as Chairman of the PAC, as recommended in the guidelines set down in the Users Group. Membership consists of the LAMPF Director, his Deputy, and at least nine additional members of the scientific community appointed for three-year terms. The PAC includes two nonvoting representatives of the Division of Physical Research of the U.S. Energy Research and Development Administration (ERDA) and two from the National Science Foundation.

Half or more of the scientific members appointed to the PAC are selected from nominations made by the Board of Directors of the Users Group. Members are chosen with an eye toward maintaining a suitable balance in geographical and institutional distribution and in representation of the various scientific disciplines to be pursued at LAMPF. The present membership of the PAC is given in Table II.

A large fraction of the work of the PAC is done by subcommittees of three to five members; each member of the PAC typically serves on two subcommittees. Subcommittees cover the following special areas:

Nuclear Chemistry
Low-Energy Pions (LEP)
Neutrinos
High-Resolution Spectrometer (HRS)
Pion and Particle Physics (P^3)
External Proton Beam (EPB)
Nucleon Physics (Line B)
Stopped Muon Channel (SMC)
Energetic Pion Channel and Spectrometers (EPICS)

It can be noted that each of the above areas is associated with a specific experimental beam line. The subcommittees act as referees to recommend priorities, schedule beam time and available experimental equipment for this beam line, and to advise on the needs for additional equipment and instrumentation.

There are in addition two special subcommittees which are advisory to the PAC and do not necessarily include PAC members. These are:

Solid-State Physics Committee (5 members)
Biomedical Program Advisory Committee (8 members)

The Biomedical Committee deals entirely with problems in the biological and medical fields. They examine research proposals in these fields and recommend approval or other action. Their recommendations are reported, via the PAC, to the Director, LAMPF, for decision and action.

The PAC meets four times a year on the call of the Chairman, to consider recently submitted research proposals. The subcommittees usually meet first as working groups, to study proposals in their fields

TABLE II

MEMBERSHIP OF THE PROGRAM ADVISORY COMMITTEE (1977)

Louis Rosen, Director of LAMPF, Chairman
D. E. Nagle, MP-4, LAMPF, Deputy
G. A. Cowan, CNC-DO, LASL, Secretary

Stephen Adler, Institute for Advanced Study, Princeton University
George Bell, T-10, LASL
Felix Boehm, California Institute of Technology
John C. Cramer, University of Washington
Robert A. Eisenstein, Carnegie-Mellon University
Gerald T. Garvey, Argonne National Laboratory
Lee Grodzins, Massachusetts Institute of Technology
B. G. Harvey, Lawrence Berkeley Laboratory
John Huizenga, Nuclear Structures Laboratory, University of Rochester
Alan D. Krisch, University of Michigan
Ira L. Morgan, Columbia Scientific Laboratories, Austin, TX
Michael J. Saltmarsh, Oak Ridge National Laboratory
Ellis Steinberg, Argonne National Laboratory
Herbert Steiner, Lawrence Berkeley Laboratory
Morton M. Sternheim, University of Massachusetts
Erich Vogt, University of British Columbia
Robert E. Welsh, College of William and Mary
Joseph Weneser, Brookhaven National Laboratory

George Rogosa, Division of Physical Research,
U. S. Energy Research and Development Administration
Marcel Bardon, National Science Foundation
Howard Pugh, National Science Foundation

L. E. Agnew, MP-7, LAMPF
A. A. Browman, MP-DO, LAMPF
D. R. F. Cochran, MP-DO, LAMPF
D. C. Hagerman, MP-DO, LAMPF
E. Knapp, P-DO, LASL
S. Koczan, MP-8, LAMPF
T. M. Putnam, MP-DSO, LAMPF

ex-officio
nonvoting

and make recommendations to the PAC in general meeting, for action on these proposals.

D. Administrative and Technical Services

The administrative chores of LAMPF are handled in the MP-Division Office (MP-DO) under the guidance of Rosen, MP-Division Leader, assisted by a staff to whom the several functions are assigned as indicated in Table I. One major function is operation of the accelerator, a complex electronic system requiring a highly trained organization of experts for planning, scheduling, maintenance, and continuous development. Another aspect is coordination of the research programs of the scientific users with the requirements and capabilities of the accelerator and its beam facilities. User coordination includes evaluation of experimental proposals, resolution of special problems, and scheduling of beam use. An office which centralizes User Group activities and provides administrative services is part of the responsibilities of the Division Office. The essential functions of budget planning and fiscal reporting are also the direct responsibilities of the Division Leader.

Most of the groups listed under MP-1 through MP-14 provide supervision of technical aspects of the Facility. Some are directly related to the linac itself, some cover beam-handling support systems and some deal with permanently located experimental facilities. However, titles of groups do not restrict the activities of individual group members. Many cross group boundaries to solve overlapping problems. The basic responsibility of all the technical staff is to expedite wherever possible the research programs of the user scientists. Some of the most essential groups are those in direct support of the experiments. Furthermore, the challenge of using pions for the irradiation of human cancer has added much incentive to the support staff. The most recently formed group, MP-14, is aimed at the design and development of compact meson-producing accelerators which, hopefully, could be used for a wider approach to the treatment of cancer. This work is supported by the National Cancer Institute.

E. LAMPF Policy Board

The LASL Director has his own independent source of information and advice on the policy, plans, and performance of LAMPF. This is the LAMPF Policy Board (LPB) which was initiated in 1968 by the then Director, Norris Bradbury. Meetings were held at approximate six-month intervals during the design and construction phase. Since 1971 the Board reports to the present Director, Harold Agnew, and meetings are held annually at the Director's call. The present membership of the LPB is:

H. L. Anderson, University of Chicago, Chairman
Robert E. Anderson, School of Medicine, University of New Mexico
Peter D. Barnes, Carnegie-Mellon University
E. V. Hungerford, University of Houston
T. A. Tombrello, California Institute of Technology

The Policy Board has consistently emphasized the National Facility aspect of LAMPF and the needs of the scientific users of the facility. Its advice has been helpful in promoting the development of the Users Group, in minimizing security restrictions for foreign users and visitors, in procurement of suitable housing for users, and in several other aspects. It has had significant influence in strengthening theoretical support in nuclear physics, both in the LASL T-Division and at LAMPF.

F. Financial Record

LAMPF is one of the few large accelerator facilities supported by the AEC for which the cost of construction was essentially as initially estimated. The design and construction costs as estimated in the Construction Project Data Sheet of October 30, 1964 were $55 000 000. A postponement by the Congress of the dates of authorization of funds beyond the planned and scheduled dates resulted in rearrangement of the schedule and an increase in the cost estimate by $1 000 000. The linac was brought into preliminary operation on June 9, 1972 within this revised cost estimate of $56 000 000. Certain additions beyond the scope of the original plans and estimate, which were authorized during the next two years, brought the total to $57 000 000. A breakdown of construction costs for major LAMPF components is shown in Table III.

The budgets for operation and for capital equipment and other costs associated with research instrumentation have also been within the initially planned range. There have been no budgetary surprises, either during the construction or in the operations phase. A record of the operations costs for the years prior to and following completion is given in Table IV, which also shows projections of major items into the future.

The early success of the LAMPF program, its fiscal responsibility, and the ambitious plans for research and applications have resulted in recognition where it counts — in the budget authorizations. Although it is always difficult to persuade the Federal budget authorities to support a program with rising cost estimates, the record of LAMPF shows that the budgets have met most of the needs of this growing laboratory which has shown a rapidly increasing level of research activity.

TABLE III

SUMMARY OF CONSTRUCTION COSTS FOR MAJOR LAMPF COMPONENTS

Design of Buildings and Site	$ 3 305 000
Construction of Buildings and Site	28 650 497
Design of Accelerator	4 112 000
Construction of rf System	6 574 072
Construction of Accelerator Structures	6 157 795
Construction of Injector System	719 426
Construction of Switchyard	4 206 506
Instrumentation and Controls	2 950 893
Other Equipment Items	323 811
TOTAL	$57 000 000

TABLE IV

FINANCIAL RECORD OF LAMPF[a]

($ in Thousands)

Fiscal Year	1969	1970	1971	1972	1973	1974	1975	1976[b]	1977	1978	1979
Personnel (full-time eq.)	95	117	148	169	196	276	314	340	333	366	373
Operations: Actual	3 682	5 250	6 000	7 239	9 296	11 808	14 450	23 326	19 710	----	----
Request./Project.	3 989	5 250	8 000	9 000	13 600	15 200	17 500	24 100	20 600	24 010	26 370
Capital Equip: Actual	505	1 450	1 700	1 710	2 100[c]	1 600	1 855	1 952	1 670	----	----
Request./Project.	634	1 559	1 700	1 922	2 100	2 300	1 910	2 880	2 200	2 400	2 600
Accelerator Improvements:						600	500	115	475	500	500
General Plant Projects: Actual	12	40	0	15[d]	150	250	190	60	----	----	----
Requested							120	500	500	500	500

---

[a] LAMPF Status Report, Louis Rosen, November 11, 1974, updated January 1977.

[b] FY 1976 figures cover 15 months.

[c] Includes $500k for HRS.

[d] Plus $146k for Isotope Production Facility.

CHAPTER 3

LAMPF USERS GROUP

The LAMPF Users Group was started in 1968 — four years before the scheduled date for initial operation — in order to provide a channel of communication between the Users and LAMPF management in planning the research facility. A general meeting of potential users was called for June 20, 1968, timed during a regional meeting of the American Physical Society at Los Alamos. Representatives of 70 universities and laboratories from outside LASL participated. Members of the LASL staff had anticipated the need for a users organization and supported it heartily. At this meeting committees were named to prepare a Charter, to nominate officers and to plan for a second meeting.

A. Organization and Charter

At the second Users Group meeting held January 16, 1969, a Charter[11] prepared in the interim was adopted, an Executive Committee of seven members was elected as prescribed in the Charter, and a Chairman delegated. The Charter described the membership of the Users Group as "open to practicing scientists and engineers," clearly allowing anyone with a valid interest in working at LAMPF to become a member. The Director of LAMPF appointed a Liaison Officer, L. E. Agnew, to act as secretary of the Executive Committee and to assist the new organization in all possible ways. At the first Executive Committee meeting a Technical Advisory Panel (TAP) was appointed "to collaborate with the staff of LAMPF in devising new experimental facilities and evaluating future developments." The Executive Committee also started a newsletter, to be edited by the Liaison Officer and published regularly as a report to the membership. The first newsletter was published March 21, 1969, with others at quarterly intervals in succeeding years.

Annual meetings of members of the Users Group are normally held in October or November of each year, for election of officers and transaction of other business. Statistical summaries of the LAMPF User Group activities are presented in Table V.

B. Incorporation and Officers

A decision to incorporate the Users Group was taken at the November 1972 annual meeting, and a set of By-Laws was approved. The incorporation of the LAMPF Users Group, Inc., became effective on January 1, 1973. The officers and Executive Committee of the Users Group elected for the year 1973 under the previous Charter became the "Board of Directors" of the Corporation. This Board of Directors consists of a Chairman, Chairman-elect, Past Chairman, and four other members elected by the membership. Two new members are elected each year for terms of two years, and one new Chairman-elect is elected each year for a term of three years. The Chairman-elect succeeds to the office of Chairman at the end of one year and to that of past Chairman at the end of two years. Elections to open positions on the Board of Directors are conducted by mail ballot prior to the annual meeting of the membership, which is held between October 15 and November 30 of each year. All terms of office begin January 1 of the year following election.

The Board of Directors meets as often as required to carry on the business of the Users Group. A Liaison Officer is appointed to the Board by the Director, LAMPF, who also serves as Secretary to the Board and as Editor of the Users Bulletin. In order to illustrate the scientific quality of the Users Group, as well as for historical reasons, lists of those members elected to Executive Committees under the Charter during 1969 to 1972, and to the Boards of Directors and Officers elected under the Articles of Incorporation By-laws from 1973 to 1976, are

TABLE V

SUMMARIES OF LAMPF USER ACTIVITIES

Date		Total Number of Users	Number LASL Users	Total Number Proposals
Spring	1969	173	50	
Fall	1969	325	90	
Spring	1970	364	99	
Fall	1970	461	100	
Spring	1971	510	121	73
Fall	1971	604	155	97
Spring	1972	630	167	115
Fall	1972			138
Spring	1973	737	178	142
Fall	1973			162
Spring	1974	830	188	181
Fall	1974	846	180	197
Fall	1975	871	183	241
Fall	1976	992	189	298
January	1977	1036	198	325

STATUS OF LAMPF RESEARCH PROPOSALS

January 1977

Completed	64
Active (approved, deferred, resubmitted)	191
Inactive (rejected, withdrawn, combined)	70
TOTAL	325

PARTICIPANTS IN USERS GROUP

January 1977

U. S. Universities	410
LASL	198
National or Government Laboratories	114
Foreign	156
Industry	57
Hospitals and Medical Centers	91
Honorary	10
TOTAL	1036

given in Table VI. For reference purposes the Articles of Incorporation of the LAMPF Users Group, and the By-laws, are attached as the Appendix.

C. Technical Advisory Panel

Under the By-laws, a Technical Advisory Panel (TAP) is appointed by the Board of Directors to collaborate with the staff of LAMPF in devising new experimental facilities and evaluating future developments. The TAP consists of 12 members each appointed for two years, with 6 new members added each year. Members of the Board, and a Liaison Officer appointed by the Director, LAMPF, are Members *Ex-Officio*. Present Membership is given in Table VII.

The TAP is the major working arm of the Users Group and the primary agency to transmit the needs of the Users to the attention of the LAMPF staff. They work in close cooperation with LAMPF and use their efforts to expedite the technical activities of the supporting staff.

D. User Working Groups

An important activity initiated by the Executive Committee as early as 1969 was a study program based on "Working Groups" of users, to study specific design problems which required analysis and development. Working Group meetings were called by LAMPF staff planners or by users and were scheduled and arranged by the Liaison Officer. During the following years these Groups became larger and more active; new groups were activated as new areas of interest developed. Chairmen assigned to each group were responsible for calling meetings, assigning tasks and reporting results. Recommendations made by the Working Groups were reported in the Newsletter. Dozens of working sessions of such groups helped to define the specifications and properties of the specialized instruments being developed by the LAMPF technical staff in preparation for experimental use. These studies have had a major impact on increasing the scope and quality of the research installations built at LAMPF. To illustrate the breadth of interest and the intense activity of users in these cooperative studies, a listing is given in Table VIII of some of these meetings, with their topics and chairmen, as they were published in the Newsletters.

TABLE VI

USERS GROUP EXECUTIVE COMMITTEES AND BOARDS OF DIRECTORS

1969

Chairman, Harry Palevsky, Brookhaven National Laboratory
Chairman-Elect, D. A. Lind, University of Colorado
Members
    R. P. Haddock, University of California at Los Angeles
    A. M. Poskanzer, Lawrence Berkeley Laboratory
    H. B. Willard, Case Western Reserve University
Liaison Officer, L. E. Agnew, LAMPF

1970

Chairman, R. P. Haddock, University of California at Los Angeles
Chairman-elect, G. C. Phillips, Rice University
Members
    I. L. Morgan, University of Texas
    R. A. Naumann, Princeton University
    B. J. Zeidman, Argonne National Laboratory
Liaison Officer, L. E. Agnew, LAMPF

1971

Chairman, G. C. Phillips, Rice University
Chairman-elect, K. M. Crowe, Lawrence Berkeley Laboratory
Members
    P. D. Barnes, Carnegie-Mellon University
    M. J. Jakobson, University of Montana
    J. E. Simmons, LASL
Liaison Officer, L. E. Agnew, LAMPF

1972

Chairman, K. M. Crowe, Lawrence Berkeley Laboratory
Chairman-elect, M. J. Jakobson, University of Montana
Members
    G. J. Igo, University of California at Los Angeles
    L. C. Northcliffe, Texas A&M University
    Chaim Richman, LASL
Liaison Officer, L. E. Agnew, LAMPF

1973

Chairman, M. J. Jakobson, University of Montana
Chairman-elect, V. W. Hughes, Yale University
Past Chairman, K. M. Crowe, Lawrence Berkeley Laboratory
Members
    R. E. Anderson, University of New Mexico Medical School
    R. J. Macek, LASL
    S. E. Sobottka, University of Virginia
    H. B. Willard, Case Western Reserve University
Liaison Officer, L. E. Agnew, LAMPF

TABLE VI

(CONTINUED)

1974

Chairman, V. W. Hughes, Yale University
Chairman-elect, H. L. Anderson, Fermi Institute
Past Chairman, M. J. Jakobson, University of Montana
Members
  R. E. Anderson, University of New Mexico Medical School
  R. M. Eisberg, University of California, Santa Barbara
  R. J. Macek, LASL
  S. E. Sobottka, University of Virginia
Liaison Officer, L. E. Agnew, LAMPF

1975

Chairman, H. L. Anderson, Fermi Institute
Chairman-elect, D. A. Lind, University of Colorado
Past Chairman, V. W. Hughes, Yale University
Members
  L. E. Agnew, LAMPF
  J. C. Allred, University of Houston
  R. E. Anderson, University of New Mexico Medical School
  R. M. Eisberg, University of California, Santa Barbara
Liaison Officer, H. H. Howard, LAMPF
Secretary/Treasurer, D. R. F. Cochran, LAMPF

1976

Chairman, D. L. Lind, University of Colorado
Chairman-elect, H. B. Willard, Case Western Reserve University
Past Chairman, H. L. Anderson, University of Chicago
Members
  L. E. Agnew, LAMPF
  J. C. Allred, University of Houston
  B. M. Preedom, University of South Carolina
  Paul Todd, University of Pennsylvania
Liaison Officer, H. H. Howard, LAMPF
Secretary/Treasurer, D. R. F. Cochran, LAMPF

1977

Chairman, H. B. Willard, Case Western Reserve University
Chairman-elect, J. C. Allred, University of Houston
Past Chairman, D. L. Lind, University of Colorado
Members
  B. M. Preedom, SIN, Villigen, Switzerland
  Paul Todd, Pennsylvania State University
  R. C. Minehart, University of Virginia
  R. A. Rebka, Jr., University of Wyoming
Liaison Officer, H. H. Howard, LAMPF
Secretary/Treasurer, D. R. F. Cochran, LAMPF

TABLE VII

TECHNICAL ADVISORY PANEL (TAP), 1977

Liaison Officer, H. H. Howard, LAMPF

1977	
Nuclear Chemistry	A. A. Caretto
Nucleon Physics Laboratory, NPL	George Glass
High-Resolution Spectrometers, HRS	G. I. Igo
Experimental Facilities	William Mayes
Neutrino Facility	Peter Nemethy
Muon Facility	R. J. Powers
1978	
Biomedical	E. L. Gillette
Solid-State Physics	A. N. Goland
Polarized Beams	M. McNaughton
Pion and Particle Physics, P^3	R. C. Minehart
Energetic Pion Channel and Spectrometers	R. J. Peterson
Low-Energy Pions	Klaus Ziock
TAP Subcommittees	
Long-Range Planning	D. A. Lind
Computer Services	R. E. Chrien
Cryogenic Targets	R. P. Haddock
New Muon Channel	V. W. Hughes

TABLE VIII

WORKING GROUP MEETINGS OF USERS AND LAMPF STAFF

	Topics	Chairmen
July 1969	Biomedical Applications	W. Langham and D. E. Groce
August 1969	Stopped Muon Channel	V. W. Hughes and H. Vogel
	Pion Channels	P. C. Gugelot
	High-Resolution Proton Spectrometer	B. J. Zeidman
	Nucleon-Nucleon Facility	J. E. Simmons
	Medium Energy Particle Physics	P.A.M. Gram and P. C. Gugelot
January 1970	Isotope Separator	B. Dropesky
April 1970	Pion and Particle Physics (P^3)	P.A.M. Gram
	Energetic Pion Channel and Spectrometer (EPICS)	P. D. Barnes
	High-Resolution Spectrometer (HRS)	N. Tanaka
	Nuclear Chemistry (At Gordon Conference)	E. Norris
January 1971	EPICS	P. D. Barnes
March 1971	HRS	N. Tanaka
April 1971	P^3	P.A.M. Gram
May 1971	EPICS	P. D. Barnes
	Biomedical	W. Langham
	Radiation Biology	P. Todd
June 1971	Nuclear Chemistry	B. Dropesky
July 1971	P^3	P. C. Gugelot
	Nucleon Physics Laboratory	J. C. Hopkins
	Low-Energy Pions	J. Amato and R. L. Burman
	Stopped Muons	V. W. Hughes
	EPICS	B. J. Zeidman
	Pion Therapy	D. E. Groce
April 1973	EPICS	S. E. Sobottka
	HRS	Harry Palevsky
July 1973	Theory Pion-Nucleus Scattering (Summer School)	H. Feshback
November 1973	LEP Channel	K.O.H. Ziock and B. M. Preedom
	HRS	N. Stein
	Nucleon Physics Laboratory (NPL)	D. Brown and J. E. Simmons
	EPICS	R. J. Peterson and S. E. Sobottka
	Biomedical Facilities	P. Todd
	P^3	G. Rebka and R. Minehart
	Slow Muon Channel	R. B. Perkins
	Nuclear Chemistry	B. Dropesky
	Computing Facilities	H. S. Butler
	Radiation Damage	W. Green
	Neutrino Facility	K. Lande
	HRS	Harry Palevsky and E. Flynn
April 1974	HRS (Washington, D.C.)	E. Flynn
	EPICS (Washington, D.C.)	H. A. Thiessen

TABLE VIII

(CONTINUED)

November 1974	Radiation Damage	W. V. Green
	LEP	B. M. Preedom
	Stopped Muon Channel	R. B. Perkins
	Nucleon Physics Laboratory	P. R. Bevington
	EPICS	S. E. Sobottka
	Nuclear Chemistry	B. Dropesky
	HRS	E. Flynn
February 1975	EPICS	H. A. Thiessen
April 1975	HRS	D. K. McDaniel
June 1975	EPICS	H. A. Thiessen
November 1975	Isotopes and Diagnostics	H. A. O'Brien
	Biomedical Facilities	E. L. Gillette
	EPICS	R. J. Peterson
	P^3	E. V. Hungerford
	Stopped Muons	B. Shera
	Radiation Damage	W. V. Green
	Neutrino Facility	K. Lande
	Nucleon Physics Laboratory	B. Dieterle
	Computing Facilities	H. S. Butler
	LEP Channel	B. Preedom
	HRS	D. K. McDaniels
	Nuclear Chemistry	B. Dropesky
April 1976	HRS	G. J. Igo
August 1976	EPICS	R. Eisenstein
November 1976	Computer Facilities	H. S. Butler
	EPICS	R. A. Eisenstein
	P^3	J. C. Allred
	Stopped Muons	Brooks Shera
	Radiation Damage	W. V. Green
	Nucleon Physics Laboratory	B. E. Bonner
	Neutrino Facility	Peter Nemethy
	Biomedical Facilities	E. L. Gillette
	Low-Energy Pions	E. E. Gross
	Nuclear Chemistry	C. J. Orth
	HRS	G. J. Igo
January 1977	Polarized Beam	E. P. Chamberlain

CHAPTER 4

PROCEDURES FOR RESEARCH EXPERIMENTS

A. Proposals and Approvals

Proposals for research at LAMPF are submitted in writing to the Director of LAMPF, at such times as he calls for proposals, following the form and content described in the LAMPF Users Handbook[12] published November 1974. Information is also available through the Users Office at LAMPF.

The proposal should indicate the scientific purposes and objectives of the experiment, an analysis of the expected data rates and backgrounds, an indication of the results and precision expected, an estimate of when the experiment will be ready, an estimate of the running time and beam requirements and a statement about the necessary auxiliary equipment and support required from LAMPF. A list of experimenters should be provided, with basic professional information sufficient to judge their experience and qualifications, and with an indication of the extent of participation of each.

Collaboration between outside research workers and the LAMPF research staff is encouraged by the LAMPF administration. Places on existing research teams can be made available to those desiring to gain pertinent experience. Each proposal should indicate the extent of collaborative participation planned and the magnitude of the several contributions.

A preliminary processing of each proposal is carried out by the LAMPF Director's Office, and all proposals which compete significantly for beam time or LAMPF resources are subjected to careful study and evaluation. However, the Director, with advice from the LAMPF administration, may authorize and schedule certain experiments such as satellite experiments which make no significant demand on LAMPF resources or for beam time. On occasion he may reorder priorities, or even provide beam time to a new experiment in response to changes in the experimental situation or new developments in physics. In the event of two or more proposals for essentially similar experiments, the LAMPF Director and his staff will make an effort to arrange for collaboration between the groups involved and request a revised proposal.

Proposals are numbered in sequence in the order received; this is a permanent identification number for future action and scheduling. On receipt, the LAMPF Office makes multiple copies of the Proposals, for distribution to members of the Program Advisory Committee (PAC). One copy is filed in the LAMPF library for general availability.

Each Proposal when submitted must include a one-page Summary which gives the title, names and affiliations of participants, and a statement of the purpose of the research and the method of procedure. These Summaries are published in the next available Newsletter; they serve to inform other Users of the planned experiment and avoid duplication. Lists of the Summaries are available in the Users Office and serve a useful purpose in providing an overall survey of the research program.

The primary basis for accepting or rejecting proposals and assigning beam time is the scientific merit of the research and the qualifications of the experimenters, as judged by the Director of LAMPF after careful evaluation and solicitation of recommendations by selected experts. His chief source of advice is from the Program Advisory Committee. His appointments to the PAC are based to a large extent on the recommendations of the Board of Directors of the Users Group.

The Program Advisory Committee, meeting with the Director, studies the proposals submitted and makes its recommendations, including the amount of beam time to be allocated. A proposal may be rejected or the Committee may advise certain modifications. Minutes are kept of all meetings and actions of the PAC, including all recommendations and the reasons for them. The PAC transmits its recommendations to the Director. On the basis of these recommendations and his own staff studies, the Director makes his decisions and transmits them to the applicants, including the authorization of beam time. If a proposal is rejected, or modifications suggested, the reasons are given in the letter.

For each approved experiment the LAMPF Chief of Operations appoints an Experiment Coordinator. He works with the experimenters in planning the details of the experiment, such as location in the beam line, dates and times of occupancy, support by the LAMPF technical groups, estimates of costs, running time, etc. The coordinator becomes the primary channel of information between the experimenters and the LAMPF organization. He follows the progress of the experiment, arranges for appropriate assistance, and sees that the work is both planned and performed in compliance with LASL operational and safety requirements.

During the Annual Meeting of the Users Group in October 1970, the LAMPF Director issued the first call for proposals for research experiments to be performed at LAMPF when it became operational. The call was made 20 months before the anticipated date of the first operation at 800 MeV to allow adequate time to consider and process the applications, and to provide time for experiments to be designed, built, and mounted in place. Information on the facilities and beam channels to be available at the start of operations, and the procedures for preparation of proposals had been published in a preliminary version of the Users Handbook (LA-4586-MS). The date of this first call was for April 1971 but later was extended to June 1971. The Program Advisory Committee (PAC) was called into service in June to make initial recommendations. The preliminary decisions of the Director on this first group of 70-odd proposals were announced in the Newsletter dated July 1971.

The number of proposals has grown steadily with time since the first call, along with an increase in the number of users. These numbers are listed in Table V, along with other statistical information relative to the research use of LAMPF.

B. Financial Support for Users

Users from Universities and other institutions must provide the bulk of the financial support for their scientists from sources other than LAMPF. Salaries and expenses of the participants, travel and shipping expenses, and rental for local housing, must be paid by the outside users. Users are expected to provide their own special experimental apparatus, detector systems and the associated circuitry, often including a trailer to house the control and data analysis electronics. In general, any instruments or equipment not available at LAMPF must be supplied by the User. If Users utilize LASL services for the design, fabrication, and maintenance of specialized equipment, or computing time, they are expected to reimburse LASL for costs. Charge rates, including direct expense and distributed overhead costs, are those currently in effect at LASL and apply equally to internal LASL groups for the same services.

Approved and scheduled experiments require advance planning and estimates of costs. Experimenters should work with the Experiment Coordinator assigned by LAMPF in estimating expenses, including a reasonable contingency, and arrange for a purchase order from their home institutions to cover the estimated expense in advance of their needs.

C. LAMPF Support

All major costs of operation of the accelerator are supported through the annual LAMPF budgets; Users are not levied charges for beam time. The LAMPF organization maintains a staff effort to explore and implement improvements of the accelerator and experimental facilities. It is LASL policy that all members of the LAMPF research staff devote roughly 50 per cent of their time to the improvement of the facility and the technical support of the users.

Certain major experimental facilities are provided by LAMPF as part of the general facility. These include several large instruments such as the High Resolution Spectrometer (HRS) and the spectrometers in the EPICS beam channel. They also include beam analysis magnets in the beam channels which provide separated beams of pions, muons, or nucleons. Some experiments are designed to utilize these "in house" instruments and are assigned time in the appropriate beam channels.

Users have access to a pool of equipment, the LAMPF Electronics Equipment Pool (LEEP). The total inventory in stock by Spring 1977 was over 2300 items of capital equipment with a total value of over $1 700 000. These include, as a descriptive sample: oscilloscopes, power supplies, voltmeters, amplifiers, pulse generators, delay circuits, magnetic tape drives, coincidence circuits, counter/timers, scalers, registers, etc. Users may request loans from this stock for the duration of their experiment. Requests are authorized by the Scheduling Committee and are provided by the LEEP Committee. This LEEP Committee is appointed by the Director of LAMPF to manage the stock of equipment and assignments to experimental groups. Inventory control is based on computer listing and analysis. The Users Group, through its Technical Advisory Panel (TAP), may recommend items for purchase and inclusion in the LEEP pool.

The LAMPF support staff erects and installs appropriate shielding and enclosures for the electronics and control station of the experiment. The experimenter is encouraged to provide his own trailer with electronics installed. However, some trailers may be made available by LAMPF. LAMPF will provide power, telephone, signal and control wiring to the control station. On-line computing facilities are available in limited supply, and a service organization can provide maintenance. It is also the intention of the LASL administration to provide adequate office, laboratory, and set-up space for users' needs.

A modest amount of direct financial support for experiments which have been assigned beam time may be provided by LAMPF in the form of an allowance prorated according to the amount of scheduled beam time. This allowance may be used to cover shop work, minor stores and consumables, and machine time at the LASL Central Computing Facility (CCF).

Certain other types of support are provided by LAMPF. They staff and run the Users Office which keeps records, publishes a Users Handbook and a quarterly Newsletter, arranges for housing accommodations and other needs of the Users. Graduate students assisting in experiments have been offered part-time jobs as Technical Assistants at LAMPF, to help defray living expenses and broaden their experience.

In consideration of the fact that the research facility is supported by Federal funds, each outside user must accept certain responsibilities. One requirement is that each non-LASL user sign an appropriate Guest Patent Agreement, which should be compatible with prior agreements the user may have with his home institution. Another requirement is that the user be properly registered with the LASL Personnel Office and accept any essential restrictions required for the control of personnel or government property. The Director of LASL will endeavor to minimize restrictions on the participation of foreign scientists, in conformity with present regulations. In 1974 the Atomic Energy Commission designated LAMPF as a "Category B" Facility, which liberalizes the approval of non-Soviet foreign visitors; such visitors require approval one week in advance from LASL. Soviet bloc visitors still need prior approval by ERDA which can be obtained through the LASL Security Office.

D. Scheduling and Equipment Committees

The technical problems of planning for and scheduling the use of the beams for experiments are handled by the LAMPF Scheduling Committee (LSC). This Committee of six members is appointed by the Director, LAMPF. The present chairman is D. C. Hagerman, Chief of Operations. This group takes recommendations of the Program Advisory Committee for each approved experiment, and fits them together into a schedule of use, with respect to time-sharing, beam intensity, beam energy, and other characteristics of the linac. The PAC divides its work between several subcommittees, each considering the experiments directed toward one of the beam channels. So the LSC also can simplify its task by considering the beam channels separately. The scientists and/or the Engineering Coordinator of each experiment being considered are usually called into the LSC meetings considering their requirements. The LSC also considers the needs of the several beam lines and provides an overall schedule of time sharing. Meetings of the LSC are held each week or more often if needed. Present membership of the LAMPF Scheduling Committee is:

D. C. Hagerman, Chief of Operations, Chairman
L. E. Agnew, MP-7 Group Leader
H. S. Butler, MP-1 Group Leader
D.R.F. Cochran, Assistant Division Leader
T. M. Putnam, Assistant Division Leader
D. E. Nagle, MP-4 Group Leader
A. A. Browman
S. P. Koczan

The Scheduling Committee has adopted a schedule of operations and maintenance based on 5-week cycles (35 days). The announced cycles for the coming year start on the following dates: February 20, March 27, May 1, June 5, July 10, August 14, October 9, and November 13. Each cycle includes 24 days of linac operation for experiments, 2½ days for maintenance, 6½ days for development, and 2 days for tune-up. The cycle structure includes 25 days of almost continuous 24-hour operation with only a few breaks for maintenance. The Committee reports the planned schedule and assignments of beam time to the experimenters frequently.

Another responsibility of the laboratory is the sharing of LAMPF-owned equipment between the experiments competing for beam time and space. The LEEP Committee consists of six members from LAMPF and one or more consultants assigned by the Technical Advisory Panel (TAP) of the Users Group. This Committee works closely with the Scheduling Committee to see that necessary equipment is made available to meet the scheduled beam-time dates for each experiment. The computer listing of items provides up-to-date information to the experimenters and to the Committees. The existing system of allocation has worked well, illustrated by the computer record that over 90% of the LEEP stock on the average has been assigned to users for several consecutive months of operations. Additions to the LEEP pool are also determined by the LEEP Committee, guided by known needs of up-coming experiments.

E. Funding for Experiments

Many experimental teams from universities obtain financial support for experiments through support contracts with ERDA or NSF. A contract is usually applied for in support of an individual experiment, and frequently the participants come from several universities. The application for contract support may be based on the Proposal submitted to LAMPF, but should also include details of expenses such as travel and transportation to LAMPF, construction of equipment, technical assistance, and usually an item of overhead costs for the sponsoring university. The cost budget will include anticipated charges at LAMPF, which requires preliminary discussions and estimates acceptable to LASL. Such requests for supporting funds are reviewed by the governmental agency involved and by other professional reviewers. Funds are handled by the User team involved, through their own home institutions.

Associated Western Universities offer partial support of costs for a few scientists from within their Association, when other funds are not available.

One difficult problem for some university scientists has been to obtain expenses for preliminary visits to LAMPF in order to plan for an experiment, prior to submission of a proposal. Some universities have no travel funds for staff members for such exploratory purposes. No general answer can be suggested in this case.

CHAPTER 5

THE ACCELERATOR

The meson facility consists of a high-intensity linear accelerator and the equipment required to utilize the resulting beams of particles and radiations for research experimentation. The linac is designed to provide simultaneous acceleration of protons and negative hydrogen ions. The maximum energy is 800 MeV and the maximum total beam intensity will eventually reach 1 mA. A large fraction of the resulting proton beam will be used to produce mesons, both pions and muons, and in both charge states. Positive and negative pions are strongly interacting particles which can produce a wide variety of nuclear interactions. As we will see, negative pions also have useful practical applications which may be of great value to medicine. The LAMPF installation will produce great intensities of pions, sufficient to collimate and focus them into beams for experimental and other uses. This type of facility which produces high intensities of mesons has been called a "meson factory." LAMPF is the highest intensity meson factory in operation or presently planned for the future.

A. Preaccelerators and Ion Sources

The particles attain their final energy through a sequence of steps starting at the ion sources, of which there are three, one for protons, one for negative hydrogen ions, and one for polarized hydrogen ions. Each ion source is located within the high-voltage terminal of a 750-keV Cockcroft-Walton type generator, and these units are located within three large electrically shielded bays in the Injector Building. The ion source bays are indicated in Fig. 3, and the Injector Building is clearly shown in the aerial photograph of the frontispiece.

Beams from the two ion sources presently in use go into a beam transport area which directs each one into the entry end of the linac without interference with the other. The beams are pulsed and timed to enter at preselected instants during the radiofrequency accelerating cycle of the linac. They are focused by magnetic lenses and stripped of off-focus peripheral ions in traversing slit systems, so each beam has the desired "injection emittance" to traverse the linac with minimal further losses.

The 750-keV Cockcroft-Walton high-voltage generators are of the voltage-multiplier design, built by Haefely, Inc., of Basel, Switzerland. The Haefely company has supplied high-voltage sets of this type to other laboratories in this country in recent years. The voltage-multiplier circuit uses solid-state rectifiers energized by 5-kHz transformers to charge a stack of capacitors in parallel and discharge in series, thus achieving a multiplication in voltage. The high-voltage terminals are enclosed in smoothly finished aluminum housings supported on insulating columns, to minimize sparking and corona from the terminals. The units ordered for LAMPF are rated at 1.0 MV at sea level but operate at 0.75 MV at the 7000-ft elevation of Los Alamos. One of these preaccelerators is shown in Fig. 4.

The initial proton ion source for the main proton beam was developed by Robert Emigh[13] of the LAMPF staff from designs of the Von Ardenne type first developed in East Germany and first applied in this country at Brookhaven, called the "duoplasmatron with expansion cup." (See Fig. 5.) This source has produced peak currents of over 200 mA during pulses of 500-μs duration and with a time duty factor of 6%.

The H^- ion source is of the charge-transfer type, in which a beam of protons traverses a channel filled with H_2 gas at low pressure. The H^- ions which are formed in the discharge column are pulled out by electric fields and focused magnetically to form a beam. The source used was developed by Paul Allison[14] of the LAMPF staff using a standard duoplasmatron proton source producing a 200-mA

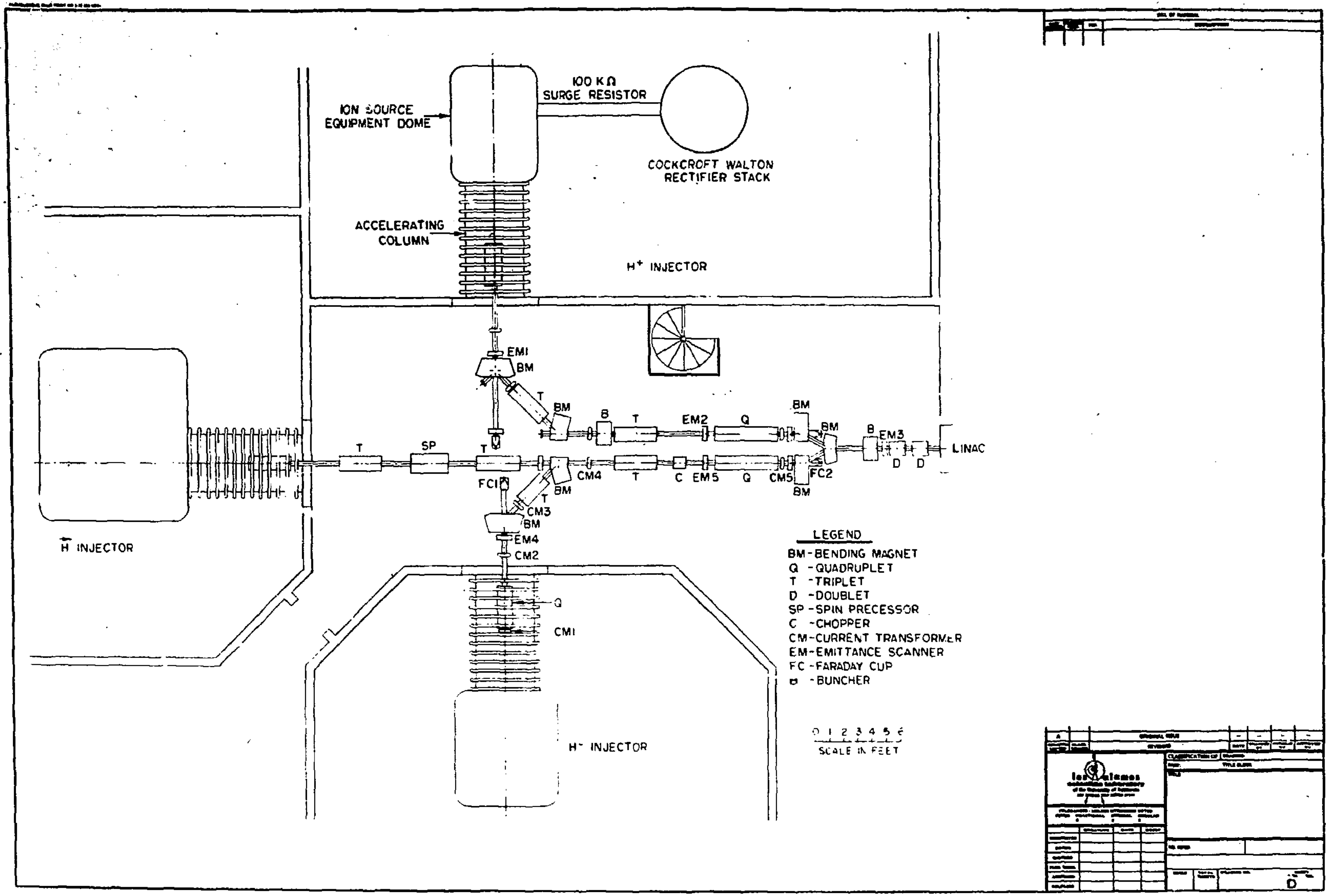


Fig. 3.
Injector Building.

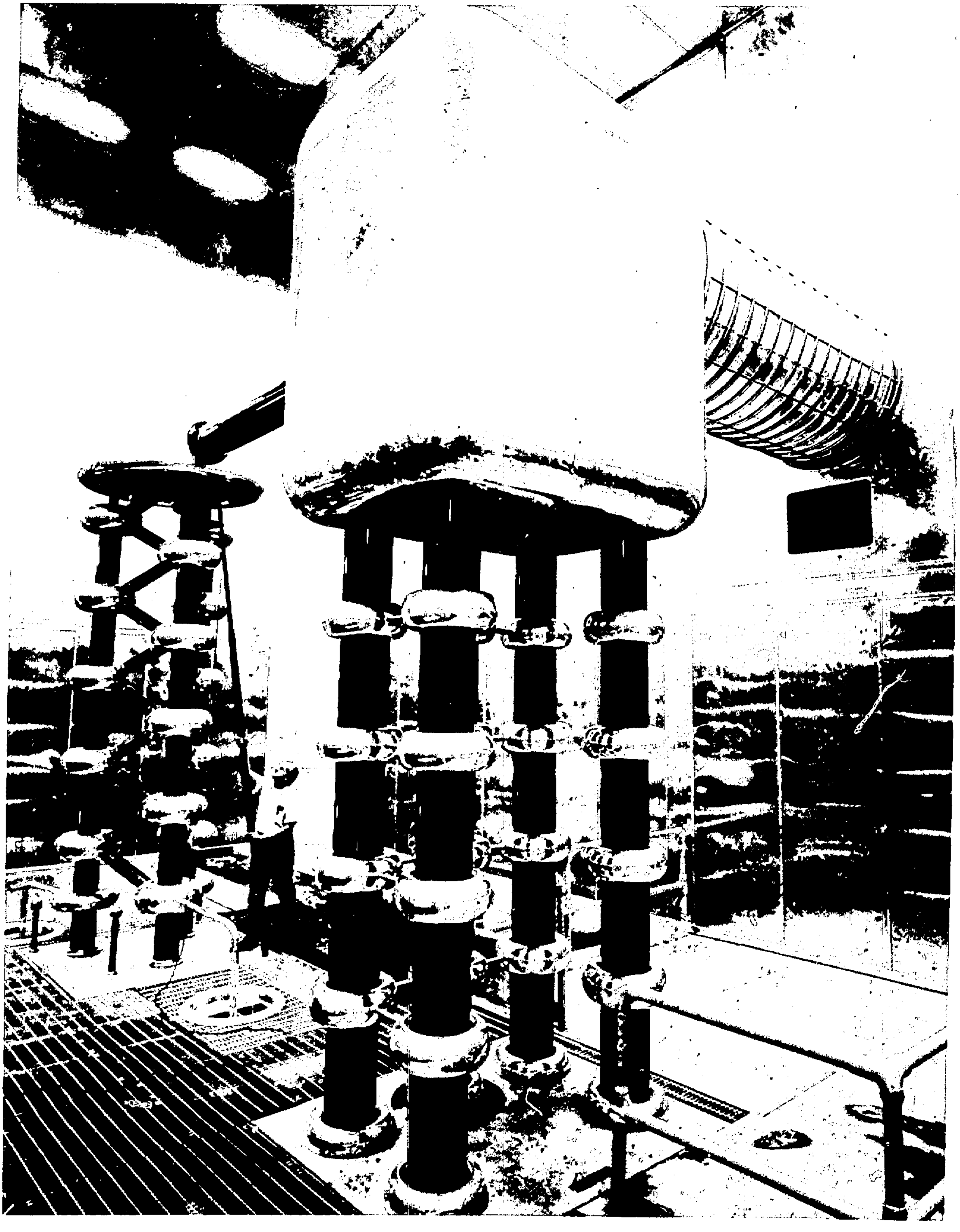


Fig. 4.
Cockcroft-Walton 750-keV Preaccelerator.

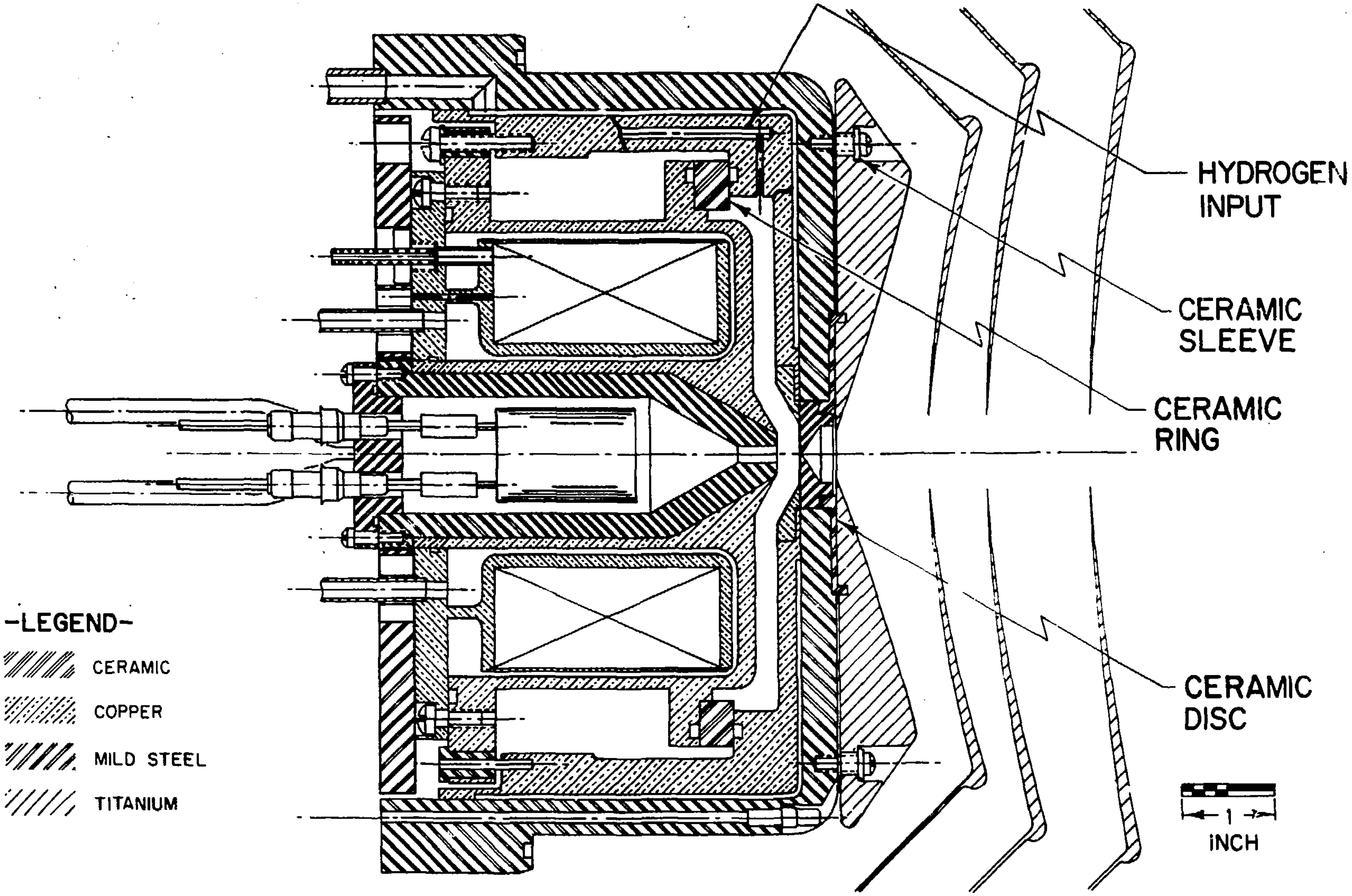


Fig. 5.
Proton ion source.

beam of H^+ ions at 15 kV; it yields an H^- ion beam of over 6 mA (see Fig. 6).

A polarized H^- ion source has been developed by J. L. McKibben and associates[15] at the LASL Physics Division, where it has previously been used for research with the Van de Graaff Generator. Ralph R. Stevens, Jr., of the LAMPF staff has adapted this type of source to fit within the high-voltage terminal of a Cockcroft-Walton unit. The 750-keV Cockcroft-Walton generator for the polarized ion source was installed and tested in October 1976. The polarized H^--ion source is now available for scheduled experimental use as requirements develop, alternating with the unpolarized H^- ion source.

B. Drift-Tube Linac

The first section of the linac is of the drift-tube type developed from the original Alvarez design. It uses four successive copper-lined tanks with drift tubes mounted along their axes to accelerate the beams from 750 keV to 100 MeV.

The first tank, of 3.26-m length, has 31 drift tubes and accelerates the beams from 0.75- to 5.4-MeV energy; the second is 19.7-m length, has 66 drift tubes and accelerates to 41 MeV; the third is 18.75-m length, has 38 drift tubes, and attains 72.7-MeV energy; the fourth is 17.9-m length, has 30 drift tubes and reaches the designed energy of 100 MeV. Total length including intertank spaces is 61.75 m or about 202.5 ft.

The linac cavity design effort was led by Don Swenson[16] who came to LAMPF from the MURA laboratories in Madison where he had worked with others on a similar linac design. The MURA design was adopted at LAMPF without much change, using the MESSYMESH computer program which solves the electromagnetic field equations within the linac tank and includes the effects of the axial holes in the drift tubes. The drift-tube linac development was further aided by paralleling developments in two other laboratories of similar linacs which were in process of design and construction during the same period between 1966 and 1970. These were for 200-MeV injectors for the AGS synchrotron at Brookhaven and for the 400-GeV accelerator at the National Accelerator Laboratory (now the Fermi Laboratory). Consultation between the three groups was frequent and design improvements in one laboratory were often utilized in the others. The three designs had the same features of copper-clad steel tanks, quadrupole magnets mounted within drift tubes for focusing, and the same frequency of about 200 MHz. The basic design is illustrated in Fig. 7, and the installation in the tunnel is shown in Fig. 8.

The most significant improvement of the drift-tube linac originating at LAMPF was the invention by Ed Knapp and Don Swenson in June 1967 of the "post coupler" for tuning and stabilizing the drift-tube structure. Knapp and others had developed tuned resonant structures for the side cavities used for coupling the accelerating cavities of the main 800-MHz linac and had noted the excellent stability and low losses of the $\pi/2$ resonant side cavities. The two designers tried various shapes of coupling systems which would have the same resonant effects at 200 MHz in coupling between successive drift tubes. They conceived and developed a resonant stem with eccentric nosepiece inserted from the side of the tank which could, by insertion to a chosen depth and rotation, be tuned to produce a similar $\pi/2$ resonance and which did not dissipate power. This technique has improved the stability of the drift-tube linac by a factor of 100 or better.

The radio-frequency power system for the 100-MeV drift-tube linac operating at 200-MHz frequency is based on the use of the RCA 7835 triode power tube, which was known to be capable of delivering short pulses at 5-MW peak power. In the LAMPF installation, one such triode is used to provide rf power for each of the last three tanks. After considerable development of the containment cavity structure supplied by Continental Electronics Corp., this power tube has given good service at LAMPF; tube lifetimes of the order of 10 000 hours have been obtained. The only significant development problem was with the plate modulator for the power triode. Don Hagerman and Tom Boyd of the LAMPF staff conducted the development. The 5-MeV unit was installed first and was operated for the first time on July 1, 1970. The remaining three tanks were assembled the following year, and operation at 100-MeV energy and 1-mA beam current was obtained in June 1977.

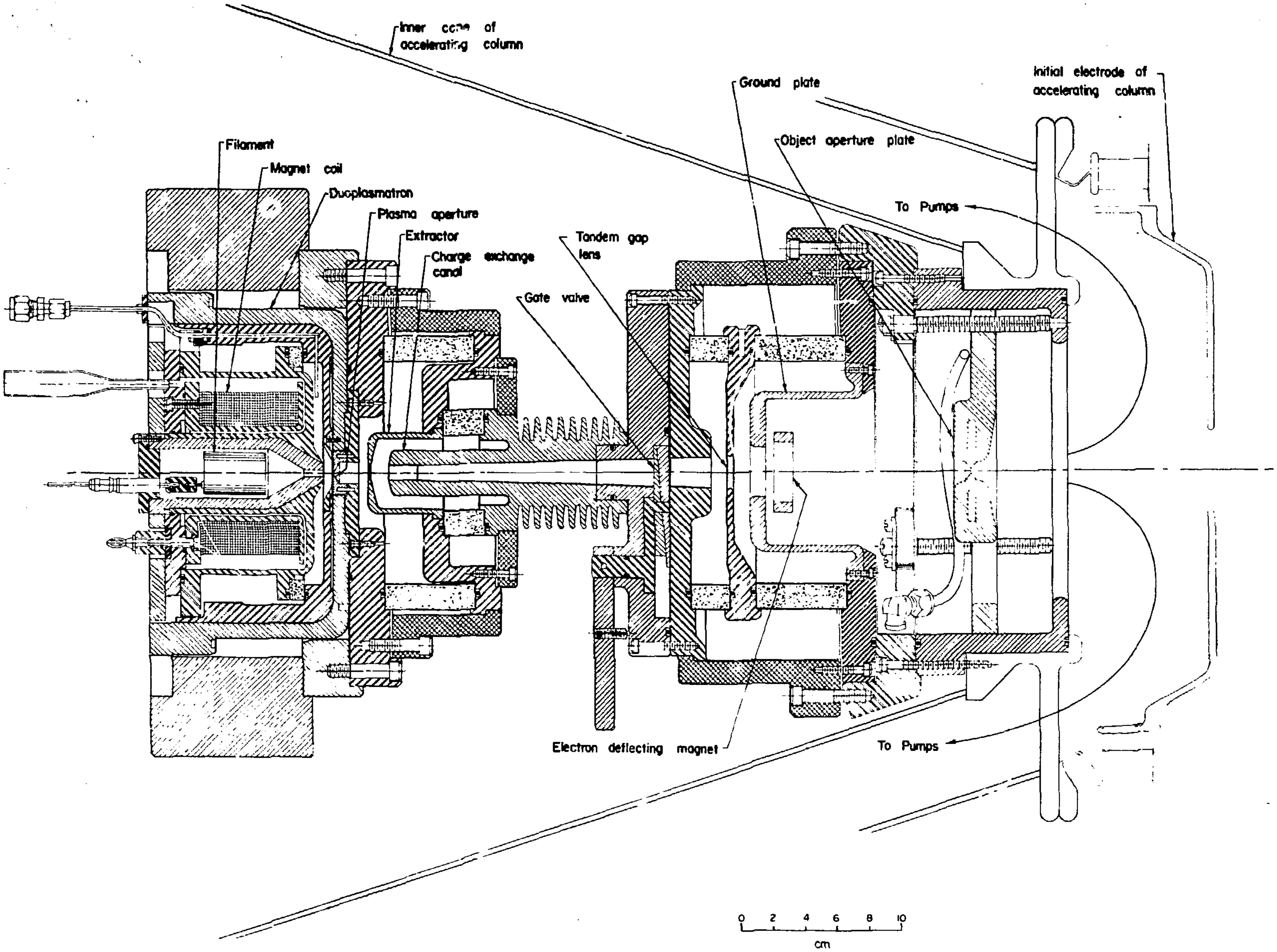


Fig. 6.
Negative hydrogen ion source.

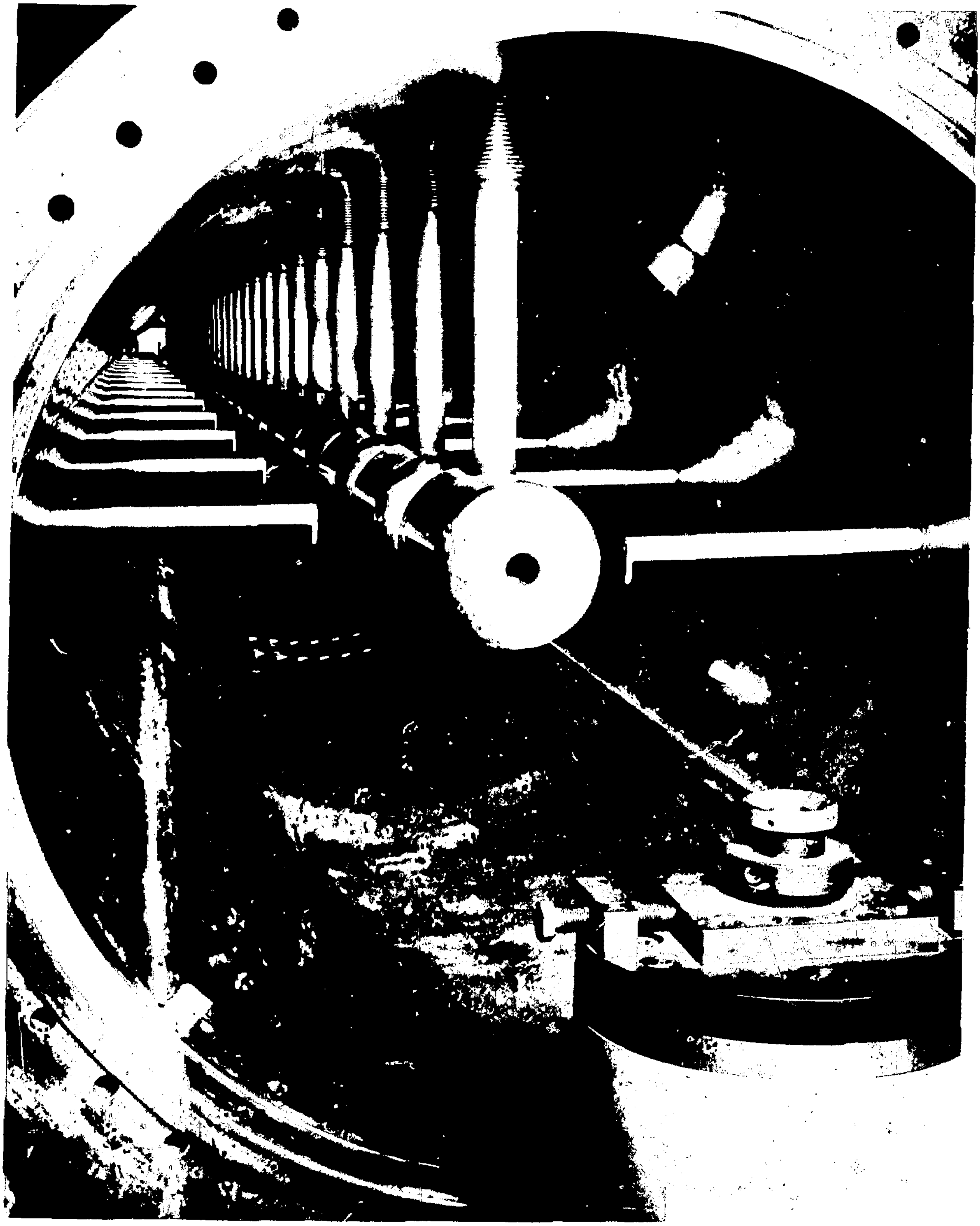


Fig. 7.
Drift-tube linac, interior view of electrodes.

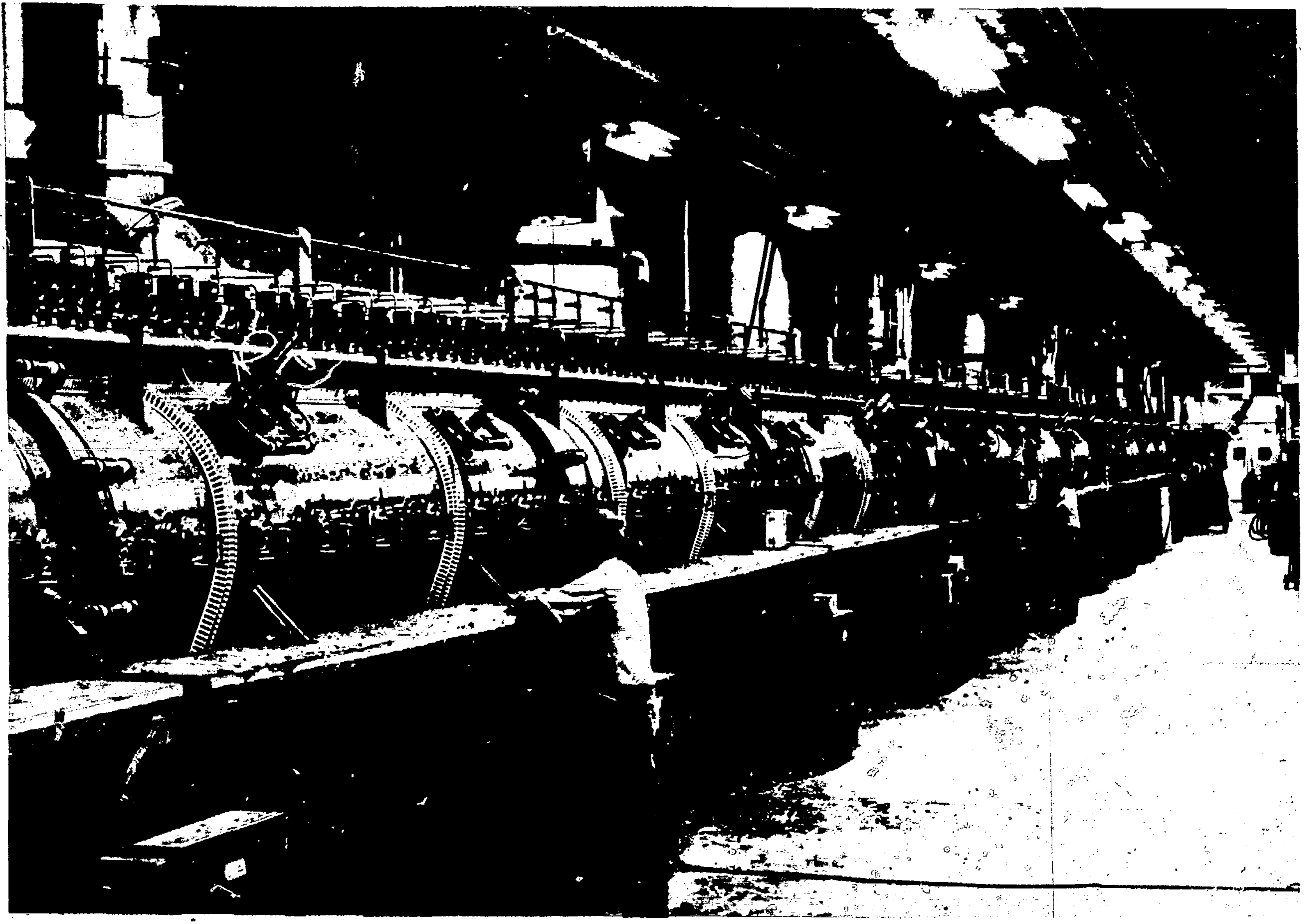


Fig. 8.
Drift-tube linac in tunnel.

C. Side-Coupled-Cavity Linac

The main section of the linac is a side-coupled-cavity system developed at LAMPF over the years 1963 to 1970 and was the culmination of a long series of studies and tests on waveguide structures to be used at 800-MHz frequency. The development at LAMPF that led to the side-coupled cavity started from concepts originally proposed at Harwell which involved tightly coupled resonant systems. The LAMPF designers chiefly concerned were E. A. Knapp and D. E. Nagle, assisted by a team including B. Knapp, W. J. Shlaer, and J. M. Potter.

The unique feature of the LAMPF linac is the use of an external resonant cavity operating in the $\pi/2$-mode, which is coupled by slots to each successive pair of resonant cavities between adjacent drift tubes. This coupling system provides efficient coupling, the necessary phase shifts, and very small power losses. By applying small physical distortions externally to these cavities in tune-up operations, a mechanism of precision fine tuning is also provided. The physical spacing between centers of resonant cavities increases steadily with the increasing velocity of the particles, so each of the nearly five thousand individual cavities has a different length. Copper forgings are machined to form the individual half-cavities. And a group of such half-cavities with their side-coupling units is assembled into a section between 8 and 10 feet in length and brazed into a solid vacuum-tight structure in an electric-heated, hydrogen-purged furnace. A total of 352 such accelerating tank sections was built for the half-mile-long linac, each with differing dimensions. The mechanical engineering team which designed the procedures and fabricated the cavity system was led by H. G. Worstell.

The cavity sections described above are the units which are mounted on piers in the linac tunnel, coupled with flexible vacuum bellows, provided with vacuum pumps at frequent intervals, and supplied with radio-frequency power at 800-MHz frequency from the power supplies located in cubicles along the tunnel. Various beam-handling devices are mounted between sections, such as quadrupole focusing magnets, beam sensors, and other control systems. A typical section of cells is shown in Fig. 9, and a portion of the installation in the tunnel is shown in Fig. 10.

The virtues of the side-coupled linac have been recognized by other designers including commercial manufacturers of linacs for X-ray systems. The principle was never patented and so became available to all. Several commercial firms now make electron linac X-ray units based on this design, with rated energies between 4 MeV and 18 MeV.

Another important requirement in the development of the side-coupled-cavity linac was to provide the radio-frequency power for excitation at 800 MHz. D. C. Hagerman was in charge of this program. At the start, the most suitable type of power amplifier unit was a source of argument between linac experts; some believed in a coaxitron-type triode power tube; others favored klystrons, although none had yet been built at the required frequency for the peak pulsed power of 1 MW needed for the linac application. Another possibility was a crossed-field amplifier called the "amplitron." At LASL, development contracts were placed with commercial firms for all three types of amplifiers, and testing programs were set up. T. J. Boyd played a key role in this engineering development.

Following a long and harrowing experience with prototype tubes which included many failures, an acceptable klystron made by Varian was received and tested late in 1968, and a decision was made to adapt this amplifier and abandon further development of the others. This klystron (the VA-862) produces 1¼-MW pulses of rf power at 800 MHz with a time duty factor of up to 12%. Orders were placed with Varian for 45 klystrons and with Litton for 25 of the same type. The number used in the side-coupled-cavity installation is 44; others are carried as spares.

The control system for phase and amplitude of the 800-MHz linac is a unique development by R. A. Jameson[17] of the LAMPF staff. It uses feed-back signals from pickup loops, which are compared with reference voltages and develop error signals that are fed back to the driving amplifier. One such system controls amplitude; another controls phase. To obtain the needed precision, wide-band-width circuits and absolute standards for amplitude and phase were developed. Precise tuning is obtained by turning on one unit at a time and tuning to perfection before proceeding to the next unit.

In service the klystron power systems have performed well. Tube lifetimes have averaged over

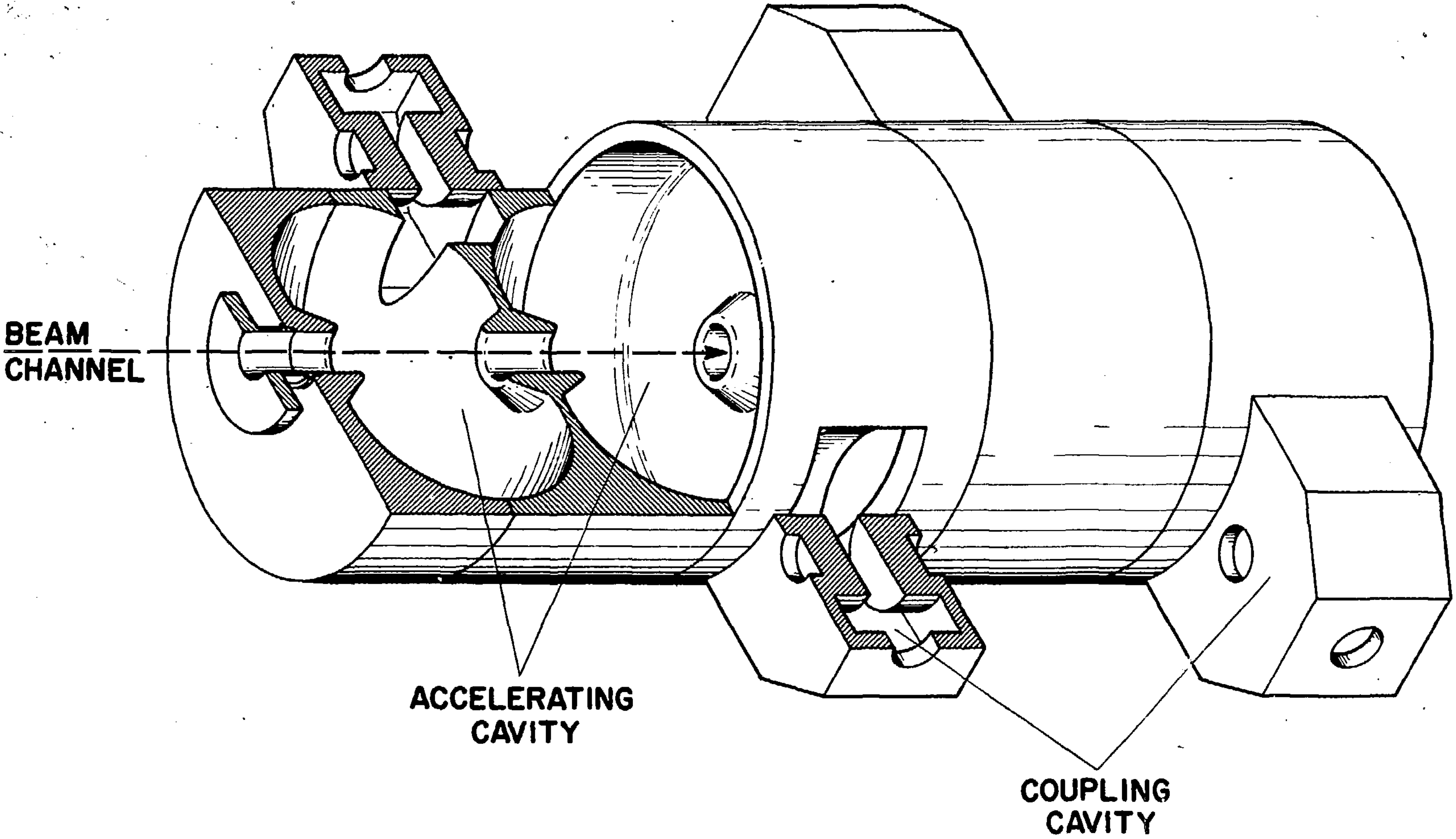


Fig. 9.
Side-coupled-cavity linac, cutaway section.

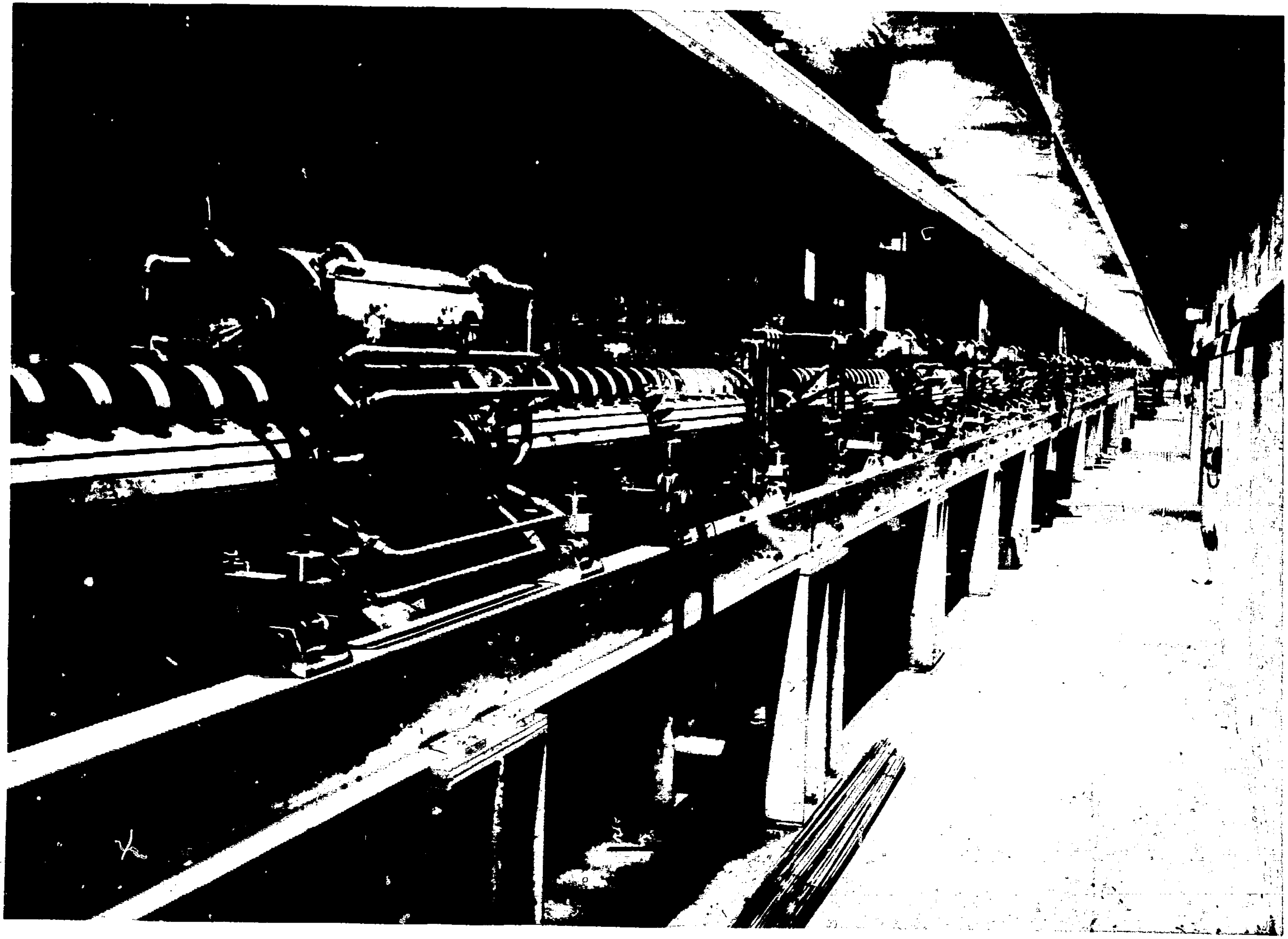


Fig. 10.
Side-coupled-cavity linac in tunnel.

10 000 hours, and the rebuilding of used tubes for reuse has proved to be practical.

D. Beam Switchyard

At the end of the linac the beams enter a beam switchyard in which a variety of focusing and deflecting magnets and other beam-handling equipment is located. The beams are separated, focused, and diverted into their chosen beam runs through channels in a thick stack of iron and concrete shielding, and into several shielded experimental areas. D.R.F. Cochran led the group responsible for development of the switchyard and experimental areas. The experimental facilities are largely contained in a cluster of sites around and beyond the beam switchyard. Deflection magnets provide simultaneous but separated beams of protons and H^- ions. A proton beam goes nearly straight ahead into Line A, and the H^- beam is deflected to the north by 30° into Line X. Also in the switchyard a beam-splitter magnet can divert a fraction of the main beam to the south into a channel leading to the Weapons Neutron Research Area. The experimental areas downstream of the switchyard are shown and identified in Fig. 11.

Line X provides H^- ion beams for stripper targets in the channels leading into Lines B and C. These produce proton beams which are further collimated, focused, and directed into experimental areas. One such converted proton beam provides protons for the Neutron Physics Laboratory and the Nucleon-Nucleon Laboratory in Beam Area B. Another more highly collimated beam is the input to the High Resolution Spectrometer in Beam Area C.

The main beam entering Beam Area A goes through Target Cells A-1 and A-2, each of which supplies scattered or secondary beams for two major experimental installations. The reduced-intensity beam is refocused and then proceeds on into Target Cell A-5 which supplies negative pions to the Biomedical Research Facility, on through an Isotope Production Area where major amounts of radioactivity are produced, and finally into Beam Stop A-6, beyond which the neutrino facility is located. A critical problem involved the development of magnets which can withstand extremely high radiation intensities. Alex Harvey was responsible for devising magnets with mineral insulation for high-radiation-level environments.

The research facilities described above can be identified in Fig. 11. More detailed descriptions of the specialized experimental installations are given in following sections. A stack of iron and concrete shielding surrounds the beam channel from the end of the linac, through the switchyard, through Beam Area A including Target Cells A-1 and A-2, through Target Cell A-5, and on into the Beam Stop A-6, in an essentially straight line. This entire area is serviced from above by a movable crane and shielded transport system called "Merrimac," see Fig. 12.

Merrimac is a large movable carriage mounted on four B-52 wheel assemblies with pneumatic tires which roll on top of the long stack of concrete shielding blocks and can transport radioactive items within a box shielded by iron and lead plates to a hot laboratory located above the end of the linac tunnel. Above each of the areas to which access is desired the top concrete and iron blocks can be moved apart horizontally to open a port beneath the shielded carriage of Merrimac. Then disconnect systems and hoists can be used to raise equipment up into the shielded box which is transported to the hot lab. Connect-disconnect systems are provided for electrical power, cooling water, and other services, for the magnets and other beam handling devices used in the beam line, all controlled remotely. This arrangement provides a flexible handling system for a wide variety of items and equipment which might become radioactive in service, extending along the entire stretch of beam channel in which beam intensities are highest.

E. Control System

LAMPF was the first major accelerator to adopt full computer control as an essential element. The concept of a control system organized about an on-line digital computer appeared very early in the planning of LAMPF. A preliminary study of feasibility by R. A. Jameson and H. S. Butler was dated 1963. Tom Putnam joined the LAMPF design group in early 1964 and accepted responsibility for the computer control system. This includes programmed control of the accelerator, switchyard, and

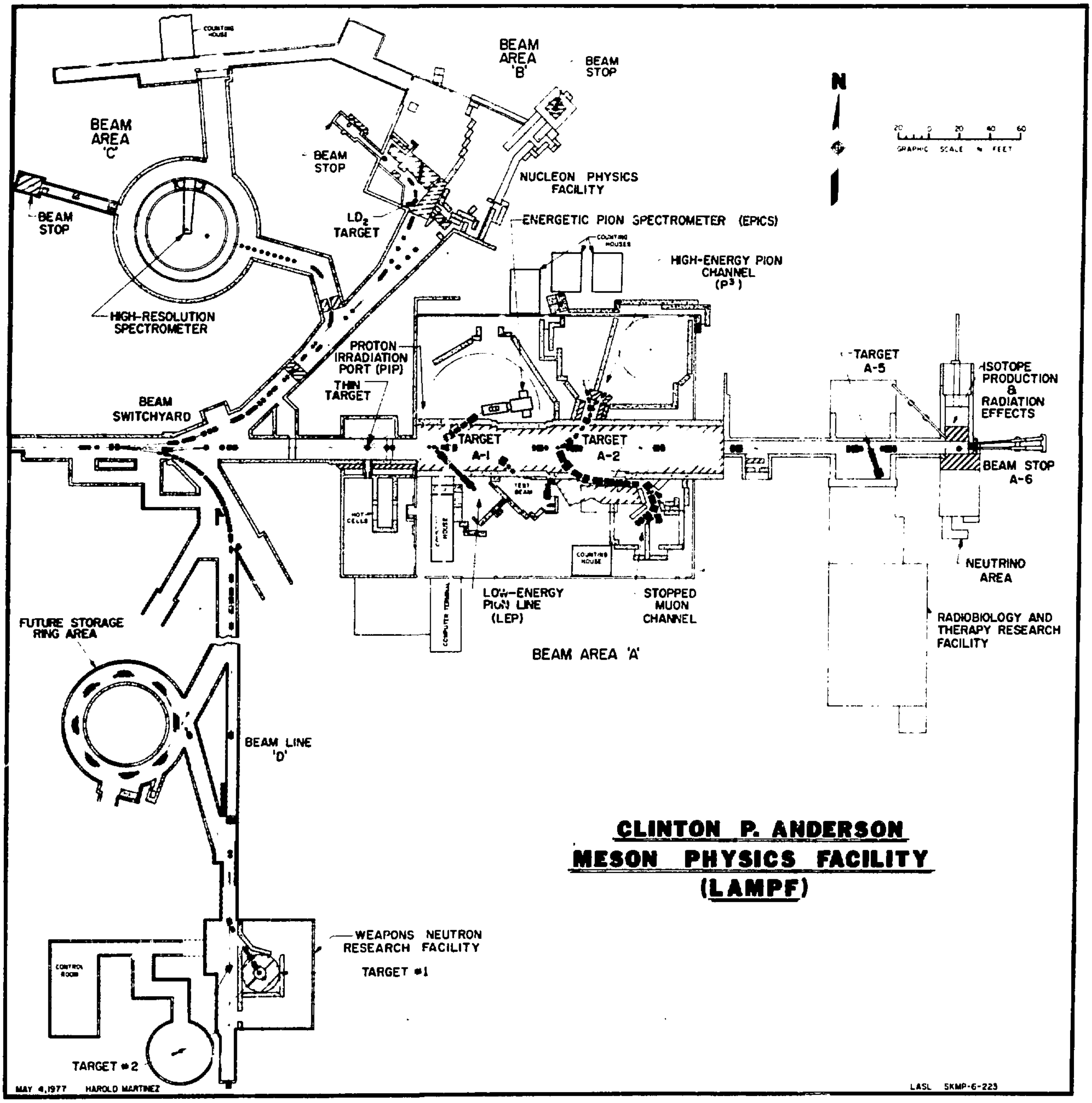


Fig. 11.
Experimental areas.

most beam lines through a centralized control station. In order to be able to tune up and test individual subsystems such as the 44 klystron power supplies, the separate ion sources, etc., a large number of manual control modules are located throughout the linac system. These local controls can be used for testing, replacement of components, and for local monitoring. Control can then be switched to the central computer for routine operations.

The computer control system has worked well in service. Among its many advantages are:

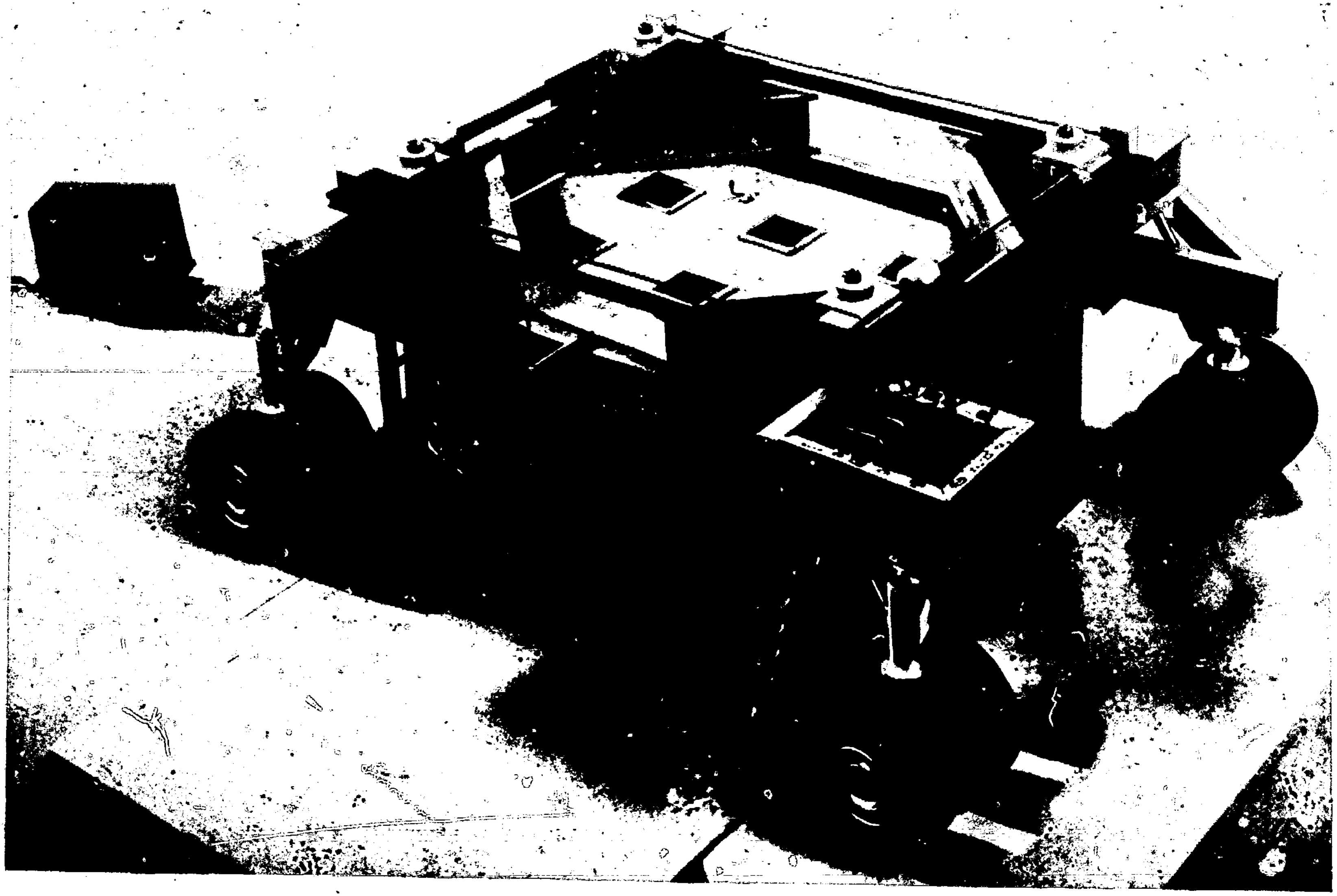


Fig. 12.
Merrimac Transporter.

1. convenience of controlling thousands of elements from one location,
2. ability to display data about status and performance, in graphical or tabular form,
3. ability to convert raw data to a more readily interpretable form by computer calculations performed through predesigned programs,
4. ability of the computer system to search rapidly and automatically for optimum adjustments of parameters,
5. convenience of automatic storage of various parameters and records,
6. convenience of local computational facility for use as an aid to machine tuning.

Several hundred application programs have been prepared and are in routine use. Continued study and use widens understanding of how to expand the range of use of the computer. Computer memory and other hardware has been expanded continuously and now has a memory of 128 000 words. Much of this capability can also be used for applications to research experiments and other activities, if desired.

Computerized operations and maintenance procedures reduce downtime of the accelerator. Regular reporting of equipment malfunctions through the computer provides statistical and historical data which is valuable for analyses of reliability. A central control system monitors all signals and shows any deviations from standard settings.

The cost of the computer system is about 10% of the total capital cost of installation. This seems a small price for the flexibility and capability for expansion available in the computer-based system. It is unlikely that this complex accelerator could be tuned and controlled successfully without such a computer-based system. H. S. Butler, the present Group Leader of MP-1, was at the forefront of the computer control system for the accelerator.

F. Linac Performance

The time sequence of the accelerator consists of 120 pulses/s, each one about 500 μs long, giving a macro duty cycle of 6%. If desired in the future it is possible to increase pulse length to 1000 μs and the duty cycle to 12%. Each pulse has a microstructure consisting of a 0.25 ns burst every 5 ns. The energy spread of the beam from the sources is no greater than 0.3% (FWHM), and the transverse phase space is approximately $\pi/3$ mrad-cm. When accelerated to 800 MeV the energy spread is $\pm 0.2\%$, and the beam dimensions can be controlled by focusing magnets from a minimum of 2 mm to a size as large as any chosen target. For example, the optimum beam spot size at the A-1 target for the EPICS channel is 2.0 cm horizontally and 0.2 cm vertically.

It is possible to manipulate beam intensity and pulse sequence at the ion sources from the central console, to match requirements of experiments. Both the H^+ and H^- beams are accelerated simultaneously, the H^- micropulses being timed to enter the linac at an instant one-half cycle of the radio-frequency later than the H^+ micropulses. When the polarized H^- beam is used, it replaces the unpolarized H^- beam during the odd half-cycles. The radio-frequency power supplies which provide rf power to accelerate the ions are also switched on and off at a duty cycle sufficient to match the ion sources. The parameters of the H^+ and H^- beams are given in Table IX.

TABLE IX

PROTON AND H^-—BEAM PARAMETERS

Beam Energy	800 MeV, continuously variable	
Energy Spread	±0.2%	
Beam Intensity (present):	H^+ = 100-μA average H^- = 6-μA average	Accelerated simultaneously
Beam Intensity (future):	H^+ = 1-mA average H^- = 100-μA average H^- (polarized) = 0.1-μA average	Accelerated simultaneously
Pulse Structure:		
Macropulse Length	500 μs	
Repetition Rate	120 Hz	
rf Microstructure	0.25-ns pulses with 5-ns separation 5-ns separation	
Duty Factory	6%	

CHAPTER 6

RESEARCH INSTALLATIONS

During the first year of operation of LAMPF for research, in 1974, the mode of operation used a negative hydrogen ion beam (10 μA of H^- at 5% macroscopic duty factor) which was split in the switchyard by stripping part of the beam to positive ions for delivery to Area A (Meson Physics Area), with another part diverted for simultaneous delivery to Area B (Nucleon Physics Laboratory). A diagram of the LAMPF experimental areas is given in Fig. 11. Development of the experimental areas was carried on largely by L. Agnew and R. Macek.

These low-beam intensities were necessitated largely by the incomplete state of shielding for experimental studies, which in turn was the result of lack of sufficient funds to equip the research laboratories in the early years of operation. Low intensities were also important to avoid build-up of radioactive intensity along the linac and in the switchyard during the early years, while beam controls were still under development. Nevertheless, the available intensity was sufficient to initiate a considerable number of experiments in Areas A and B and to start experimentation on the biological applications of negative pions. A study of the Users Bulletin covering 1974 shows that 68 experiments were provided with beam and 4 experiments completed during this phase, which involved a total of 16 500 beam hours.

During the year 1975 and on into 1976 the facility was shut down to allow time for a major maintenance program which included realignment of the linac, as well as installation of many new research experiments and shielding for the experimental areas. This rebuilding of the linac allowed an increase in the operating intensity level by 10 times, to an average current of 100 μA. Since the facility resumed operations in September 1975, the originally planned mode of operation has been used, in which H^+ and H^- beams are accelerated simultaneously. The main proton beam goes straight ahead through Area A, while a smaller beam(~6-μA average) of H^- ions is diverted to the north for delivery, after stripping to protons, to Areas B and C (see Table IX for beam parameters).

A. Meson Physics Area — Experimental Area A

Most of the precision experiments using mesons are located in the Meson Physics Area. The main proton beam from the switchyard goes through this area, traversing several targets to generate secondary pion beams. Two target locations, A-1 and A-2, provide four secondary pion beams, two to the right and two to the left, which enter shielded areas inside which are the experimental instruments. The meson channels themselves are permanently assembled arrays of deflecting and focusing magnets, slit systems, and other devices to produce the type and quality of meson beam desired. The arrangements of these four experimental facilities are shown in Fig. 13.

1. Low-Energy Pion Channel (LEP)

This channel is designed to provide beams of $\pi^\pm$ particles from about 20- to 300-MeV energy, which covers the resonance region. It is intended to service a variety of research studies in nuclear structure, nuclear chemistry, elementary particle physics, and biomedicine. The design features include good momentum resolution, a small (achromatic) spot size for stopped pion experiments and for total absorption counter experiments, and high-intensity beams at moderate resolution. To facilitate meeting a range of experimental requirements, the final spot size and divergence are variable over a factor of 20. The general beam parameters are given in Table X.

The LEP channel is formed of four rectangular bending magnets which deflect in the vertical plane; the magnets are oriented to have 60° bends and

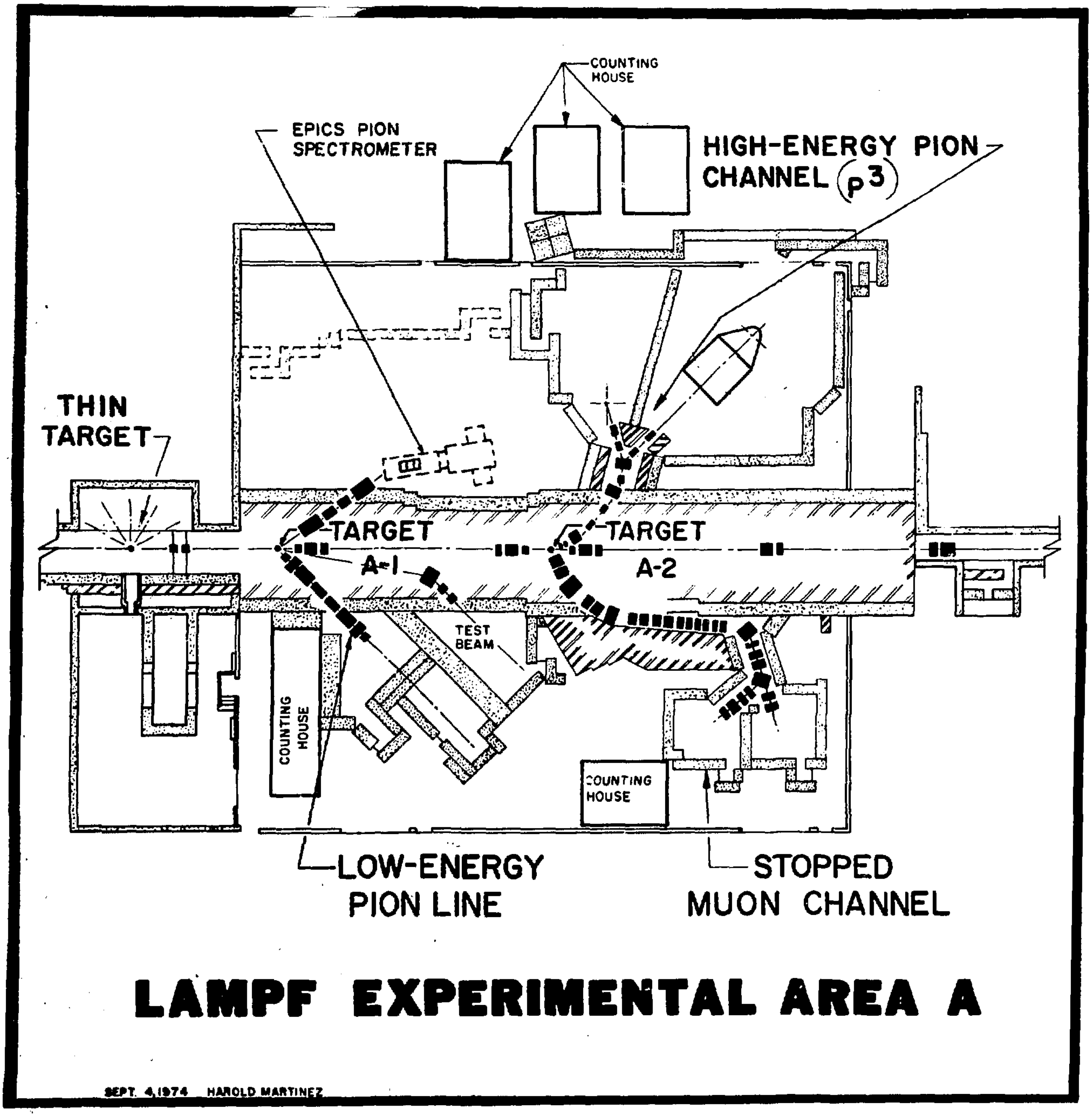


Fig. 13.
Experimental Area A.

TABLE X

PARAMETERS OF THE LOW-ENERGY PION BEAM (LEP)

Energy Range	20-300 MeV
Flux (3-cm-thick C target)	π^+ at 100 MeV: 1.9×10^7 ($\Delta p/p = \pm 0.05\%$) or 1.5×10^9 ($\Delta p/p = \pm 2\%$)
Resolution	$\Delta p/p = \pm 0.05\%$ (max)
Momentum Bite	up to ±2%
Solid Angle	10-20 msr
Beam Emittance	$(\pm 0.13\text{ cm} \times \pm 40\text{ mr}) \times (\pm 1.5\text{ cm} \times \pm 125\text{ mr})$
Beam Waist Spot Size and Divergence	$\Delta p/p = 0.1\%$: size = ±0.13 cm, div. = ±30 mr $\Delta p/p = 1.0\%$: size = ±0.7 cm, div. = ±30 mr $\Delta p/p = 5.0\%$: size = ±3.4 cm, div. = ±45 mr

symmetrical beam entrance and exit angles. Two sets of quadrupole focusing magnets are used, one set at the entrance and one at the exit of the vertical dispersion system; the quadrupoles have 10-in. bores, 16-in.-long iron cores, with maximum field strengths of 5 kG. A plan view of the LEP channel illustrating the shielding arrangement is shown in Fig. 14, and an elevation is shown in Fig. 15. Some representative beam-waist spot sizes and angular divergences are included in Table X. The fluxes given in the table are calculated assuming a 3.0-cm-thick carbon production target and 1-mA proton beam.

2. Energetic Pion Channel and Spectrometers (EPICS)

EPICS provides a complete system for high-resolution, two-arm spectrometer experiments. It includes a high-resolution beam channel, a particle separator for reducing backgrounds, a scattering chamber at the focal spot of the beam channel, a spectrometer pivoted about this target location, and detection systems at the outputs of the spectrometers. Plans include adding a second spectrometer on the same pivot. See layout of the channel in Fig. 16 and details of the first spectrometer in Fig. 17. It is intended for nuclear structure experiments using either positive or negative pions for the bombarding particles, and is equipped for rapid change of targets, automatic scanning through spectrometer angles, and a fast data-acquisition system. Design and contruction of EPICS and other large spectrometer systems was done by A. Thiessen, J. Spencer, and K. Tanaka.

The pion production target in the main beam is planned to be a block of graphite of 3-cm thickness although it can be of any chosen thickness and material. The pion channel accepts particles scattered in the horizontal plane at 35° production angle. The beam-analysis channel has four bending magnets which disperse and recombine the beam in the vertical plane, with slit systems at beam crossover points and an electrostatic separator to eliminate unwanted protons and other particles. Performance characteristics of the channel are shown in Table XI.

The initial low-momentum spectrometer arm illustrated in Fig. 17 has a momentum range from 100 to 680 MeV/c. This permits a variety of experiments such as elastic and inelastic pion scattering, and the study of certain two-particle interactions which can be performed with one spectrometer. Ultimately a second, high-momentum spectrometer (1000 MeV/c) will be installed to increase the range

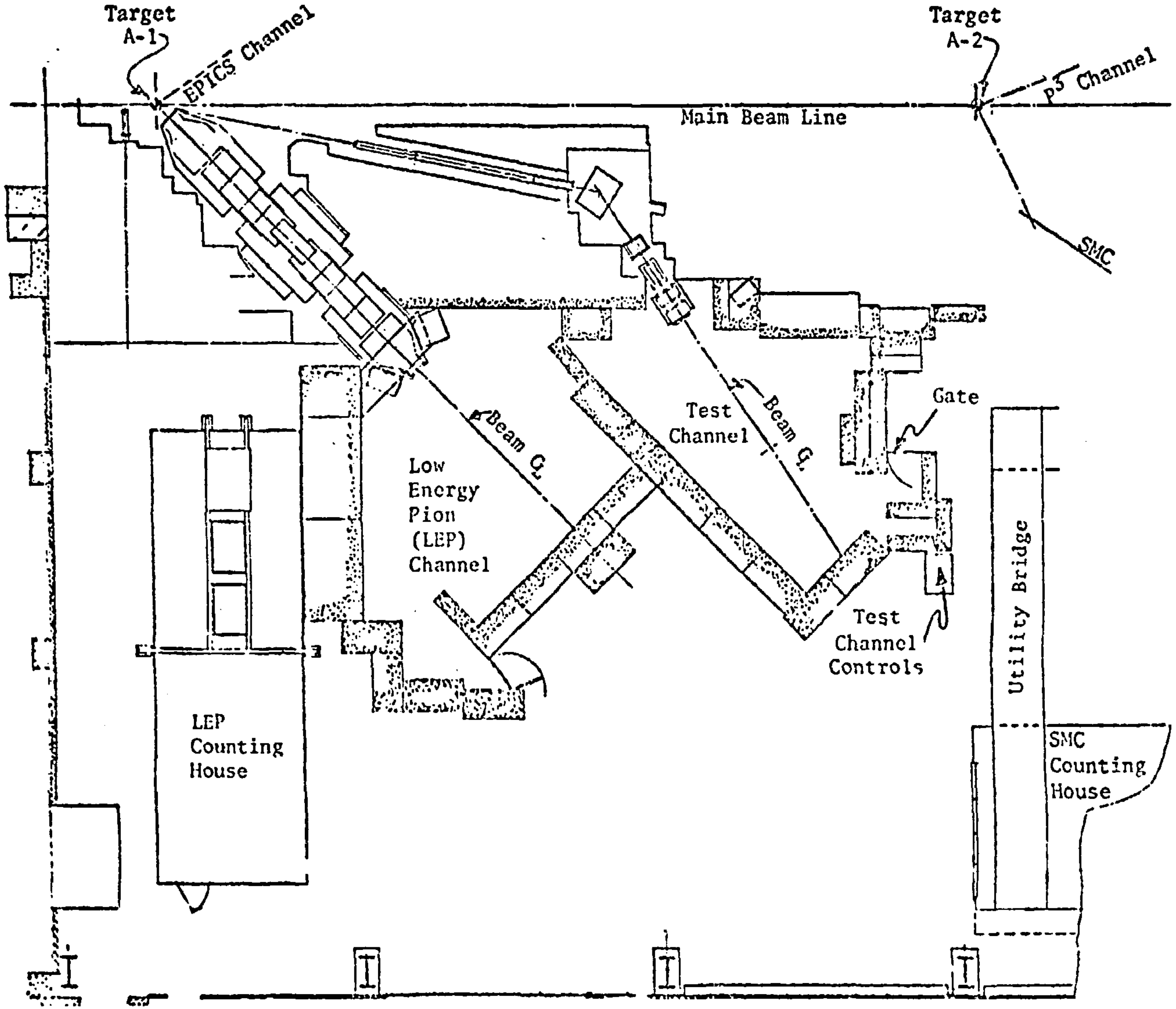


Fig. 14.
Low-Energy Pion Channel, plan view (LEP), and test channel cave layout.

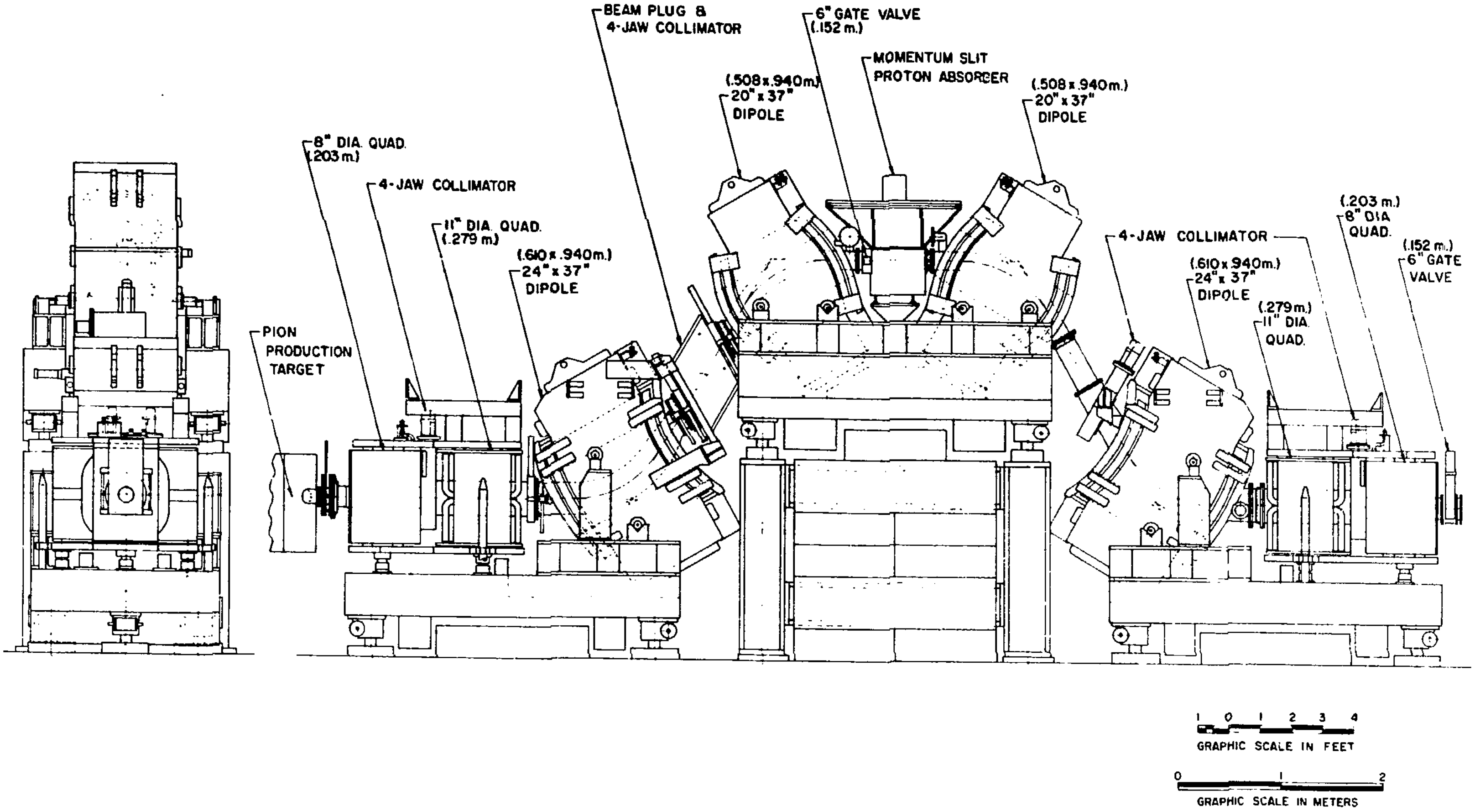


Fig. 15.
Low-energy Pion Channel, elevation (LEP).

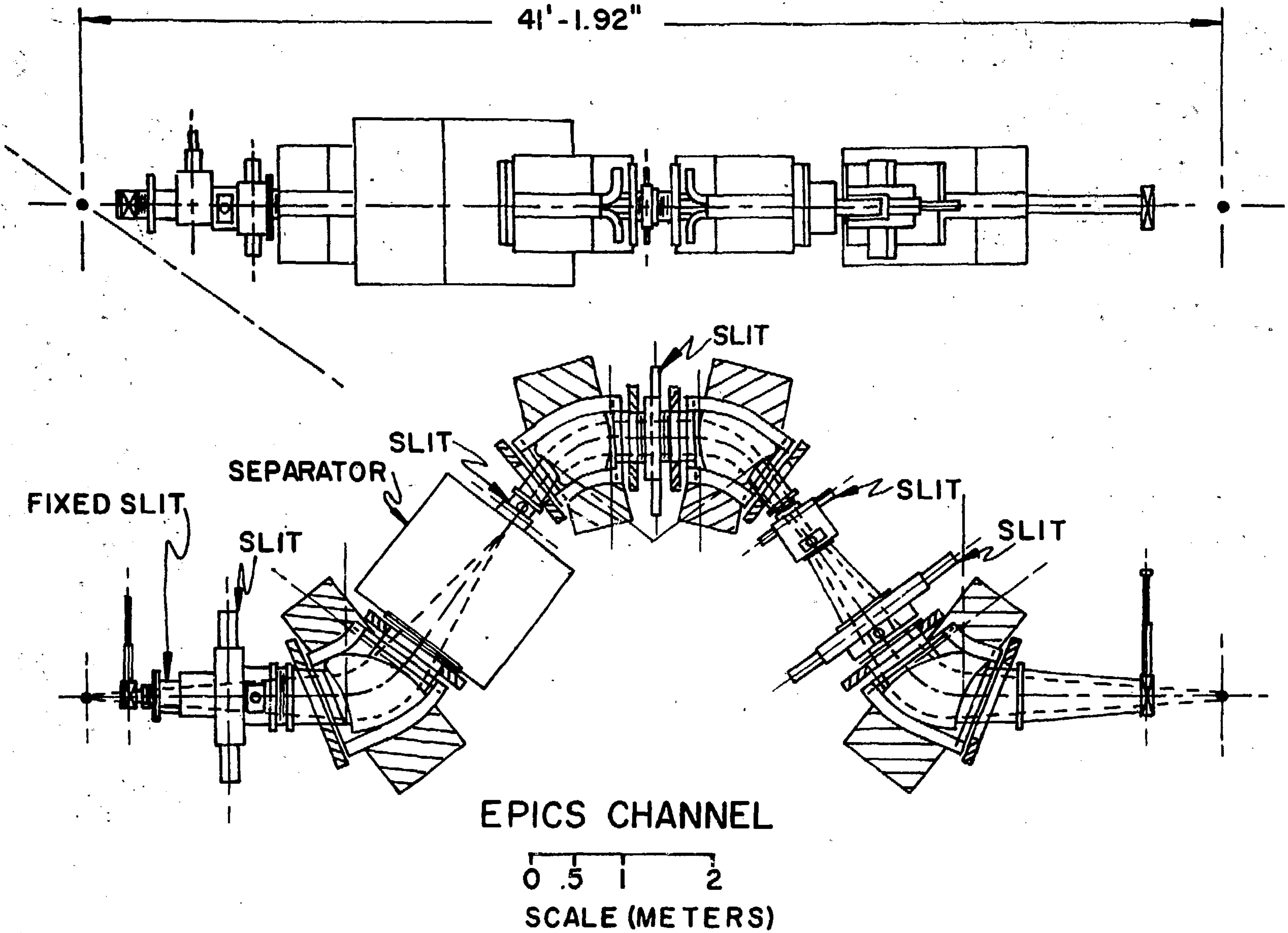


Fig. 16.
Energetic Pion Channel (EPICS).

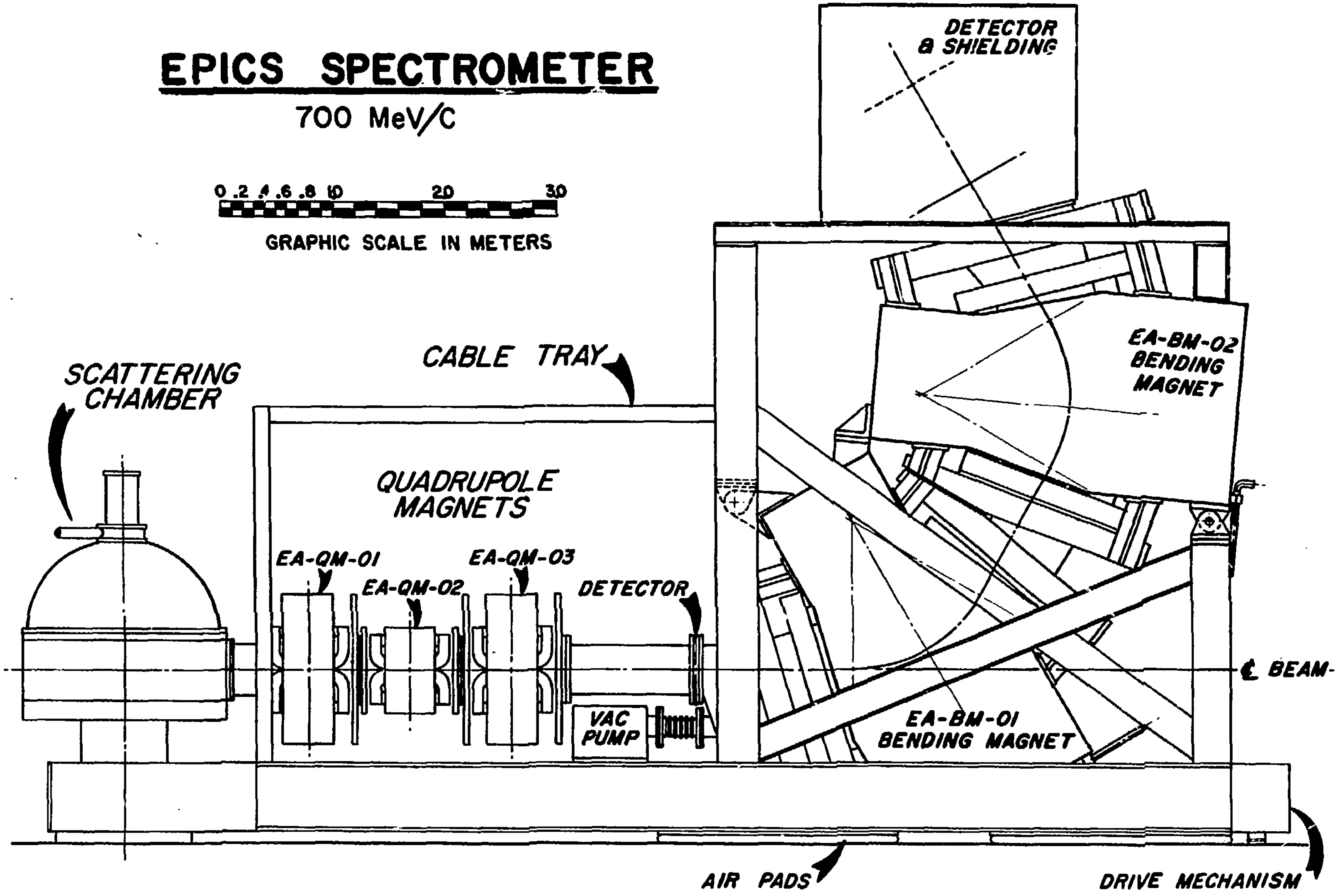


Fig. 17.
EPICS Spectrometer.

TABLE XI

EPICS PION CHANNEL AND SPECTROMETER

	Channel	Initial Spectrometer
Range	50-300 MeV	100-680 MeV/c
Flux at 1 mA	$4 \times 10^8\ \pi^+/s$	$0.5\ \pi^+/min/\mu b/sr$
Resolution	2.4×10^{-4}	3×10^{-4}
Solid Angle: $\Delta\Omega$	2.5 msr	10 msr
$\Delta p/p$	±1%	±5%

and type of experiments. This will allow study of the reactions: (π,π'), (π,p), (π,π'p) and (π,pp) over the full energy range, and of (π,d) and (π,T) reactions at lower energies.

3. Stopped Muon Channel (SMC)

This channel provides beams of low-energy muons useful in experiments in which they can be stopped in targets or detectors. One example is the use of μ^+ beams for experiments on muonium; another is μ^- beams for muonic X-ray studies. The channel has a pion-collection portion, a pion-decay section, and an analysis system in which muons of specific momenta can be selected for experimental use. A switching magnet at the output allows the muons to be directed into one or the other of two experimental caves. See Fig. 13.

The primary target in the main beam is a carbon target 6 cm thick. The pion-collection channel views the target at 65° in the horizontal plane, with a pair of large aperture quadrupole magnets to collect a wide angular spread of low-energy pions. Bending magnets of wide aperture and a long sequence of quadrupoles provide distance for some of the pions to decay, and forms a large-diameter muon beam. The muons selected are those which decay in the backward mode, which are the slowest. The analyzing system has a 70° deflection magnet, additional focusing quadrupoles and a final switching magnet to produce either of two beams. The performance characteristics of the channel are given in Table XII.

The stopped muon flux detected depends in part on the size of detector used. For example, if the muon momentum band selected is at 100 MeV/c, and a carbon moderator having a 35-MeV energy loss is used before the stopping target, then the number of muons stopped in a 100-mg/cm^2 target is $4 \times 10^5\ \mu/s$ with 1-mA protons. The total muon flux on the target would be $13 \times 10^5\ \mu/s$ in this case.

4. Pion and Particle Physics Channel (P^3)

This channel provides a flexible, general purpose pion line capable of transmitting the highest energy pions which LAMPF can produce. It is intended for both nuclear reaction and elementary particle experiments. The channel is basically a two-bend channel augmented with a third bend which will switch the beam between two spatially separated experimental areas (see Fig. 18). Both beams can be made achromatic. To provide high intensity, the production angle is forward, at 20°, and the collecting quadrupole is placed as close as possible to the beam line. For flexibility in rearrangements the channel is built with magnets of conventional design (i.e., rectangular dipoles and standard 8-in.-aperture quadrupoles). A brief list of typical performance characteristics is given in Table XIII.

TABLE XII

STOPPED MUON CHANNEL

Range	0-165 MeV
Flux (Positive Muons)	$6 \times 10^7\ \mu^+/s$ (at 60 MeV)
Stopping Flux (Negative Muons)	$1 \times 10^7\ \mu^-/g/s$
Purity	1% π: <1% e
Polarization	0.8
Spot Size	5 cm × 10 cm

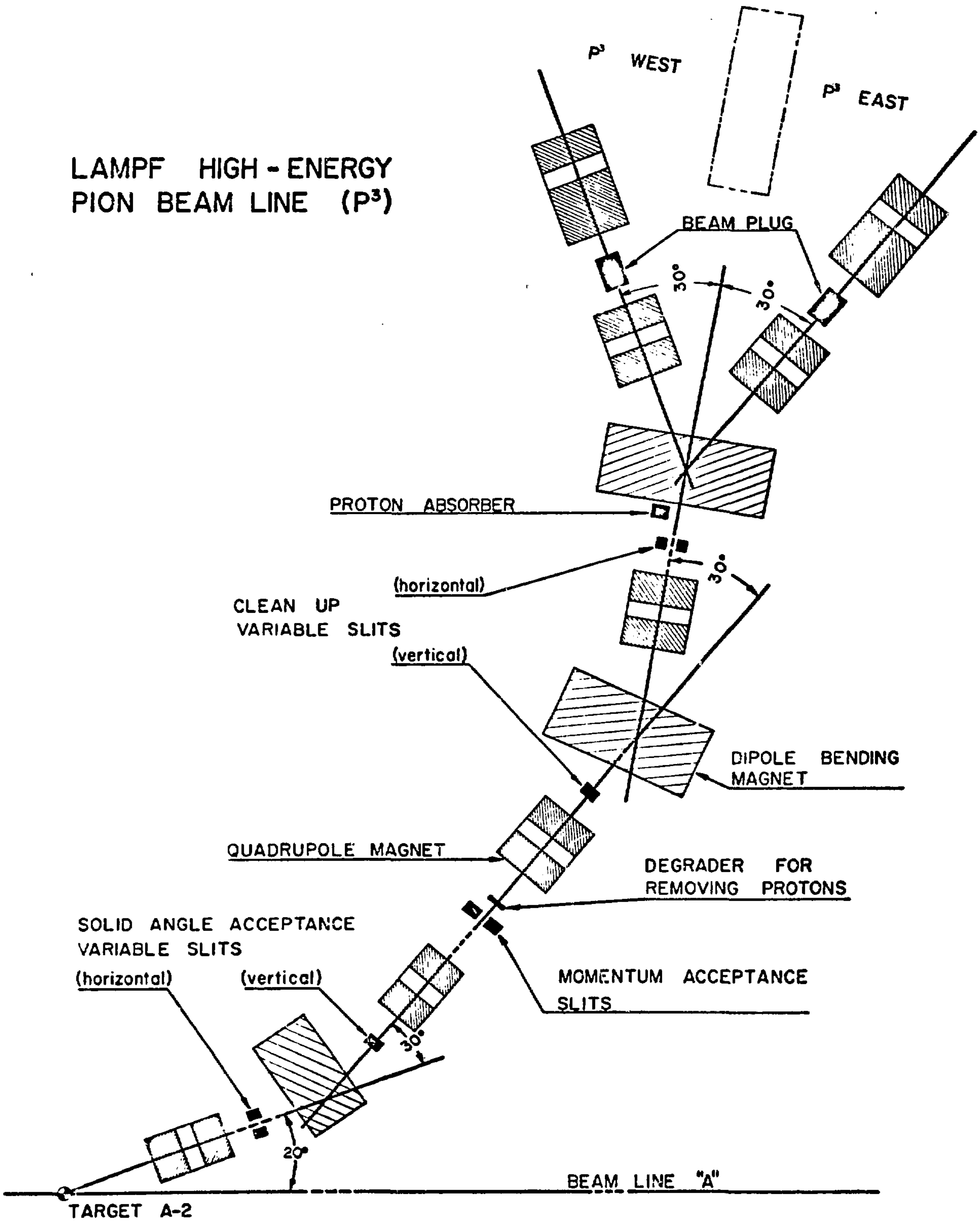


Fig. 18.
Pion and Particle Physics Channel (P^3).

TABLE XIII

HIGH-ENERGY PION CHANNEL (P^3)

Range	100-600 MeV
Flux	3×10^9 π^+/s (at 400 MeV)
Resolution	2.5×10^{-3}
$\Delta p/p$	5%
Emittance	30 mr-cm

B. Nucleon Physics Laboratory — Experimental Area B

The beam of H^- ions diverted into Beam Line X at the switchyard traverses first a partial stripper foil which strips the electrons from some of the H^- ions to form an input proton beam for Line C. The remaining H^- beam continues and traverses another stripper foil to produce a proton beam in Line B which supplies the Nucleon Physics Laboratory (NPL). See Fig. 19. The objectives are to provide high-quality beams of protons of variable energy, and also neutrons of good energy resolution, to be used for nucleon-nucleon research.

1. Neutron Beams

A major portion of the H^- beam which is stripped of electrons provides a proton beam which is focused and directed against a liquid deuterium (LD_2) target to produce neutrons. The proton beam passes through a number of bending and quadrupole focusing magnets which control spot size on the target to a size of 1.5 cm by 2.0 cm or smaller. The emerging proton beam is deflected horizontally by other magnets and refocused to provide beam spots at two nuclear chemistry stations downstream of the last bending magnet.

The neutrons observed from a 10-cm-thick LD_2 target, with a 1-μA-average proton beam at 800 MeV, in the forward direction (0°), and in a 4-cm-diam aperture located 6 m from the target, were measured to have an intensity of 5×10^5 n/s. The energy of the neutrons was 795 MeV and the resolution was ±13 MeV (FWHM). A background of lower energy neutrons associated with pion production results in a low-energy tail on the neutron spectrum. The neutron spot size is variable but is typically 10 cm^2 at 6 m from the LD_2 target.

Neutron beams can be formed by collimation at 0°, 7°, 14°, 20°, 27°, and 37° from the proton beam direction at the LiD_2 target. These beams provide lower energy neutrons; also, the proton beam energy can be varied in the linac between 300 and 800 MeV. Neutron beams at the larger collimation angles are partially polarized; those at 27° are calculated to have a polarization $P = 0.35$.

2. External Proton Beam (EPB)

That portion of the H^- which is not stripped and used for neutron production goes straight on down Line EPB where it enters a shielded cave in the Nucleon Physics Laboratory and can be used either as an H^- beam or stripped to a proton beam. Quadrupole focusing magnets are used to adjust spot size at various locations for experimental targets. Usually this external proton beam provides a pencil beam of about 3-mm diam and with an energy resolution of ±3.5 MeV at 800 MeV. The size of the beam is predominantly determined by the size of the hole in the stripper used to form the EPB H^- beam. Intensities are limited at present but can be increased if required with further shielding of the cave and the beam stop.

With use of the polarized H^- ion source in the future, the EPB will provide about 15 nA of polarized protons with $P = 0.9$. First delivery of a polarized beam was made in April 1977.

C. High-Resolution Spectrometer (HRS)

Experimental Area C houses the high-resolving-power spectrometer facility and its associated beam line, as shown in Fig. 20. The optics of Beam Line C and of the HRS have been designed to give a momentum resolution on the order of 2.4×10^{-5}, an angular resolution of $\pm 10^{-3}$ rad for a momentum acceptance of 2%, and a solid angle acceptance of 3.6 msr. As a result, the spectrometer should be able to resolve nuclear levels separated by as little as 30 keV at 800 MeV when operating at full design resolution. Using a target thickness of 10 mg/cm^2, which is consistent with such a resolution, and a proton current of 10 μA, a counting rate on the order of 1/s/(nb/sr) should be possible.

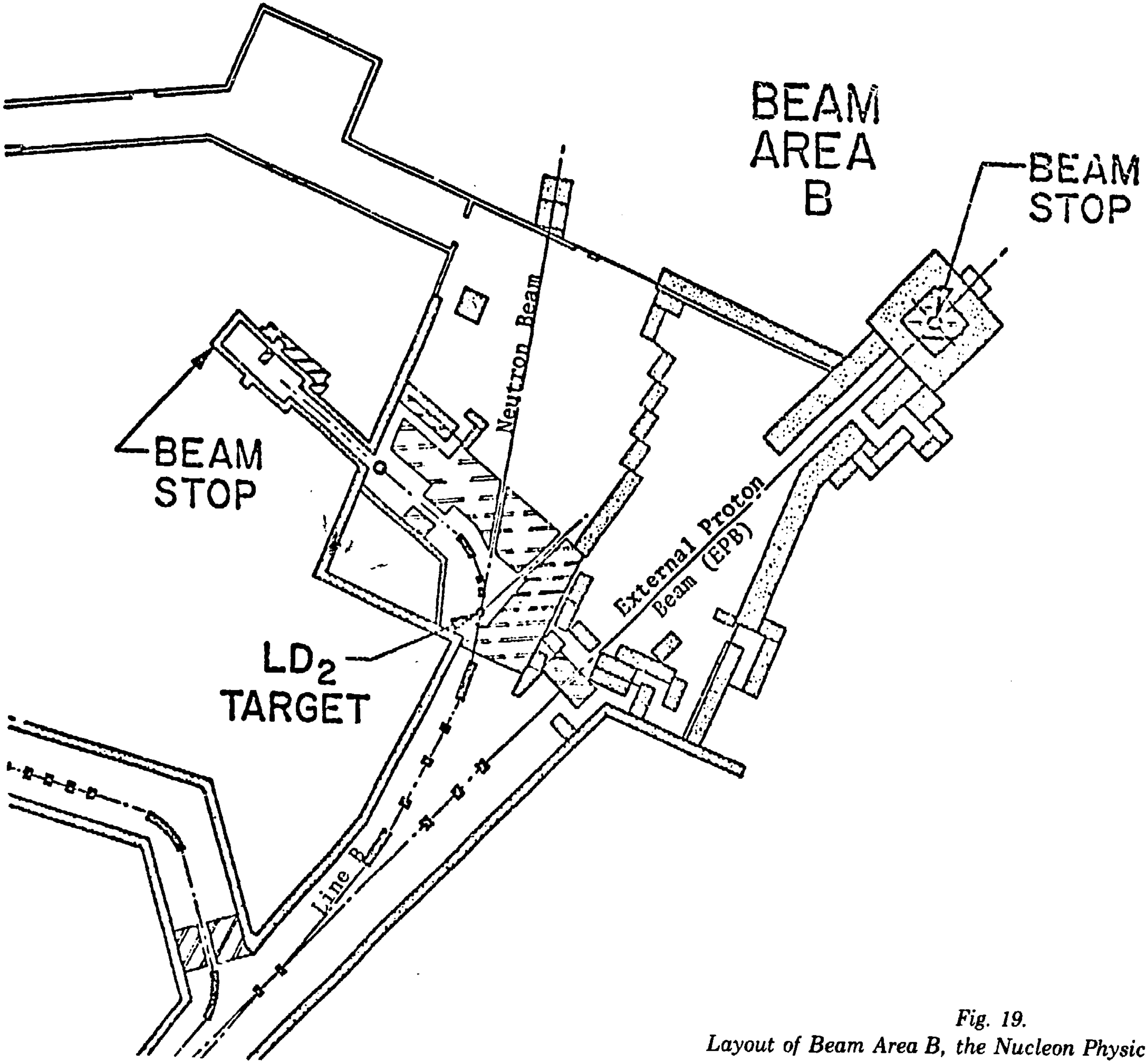


Fig. 19.
Layout of Beam Area B, the Nucleon Physics Laboratory.

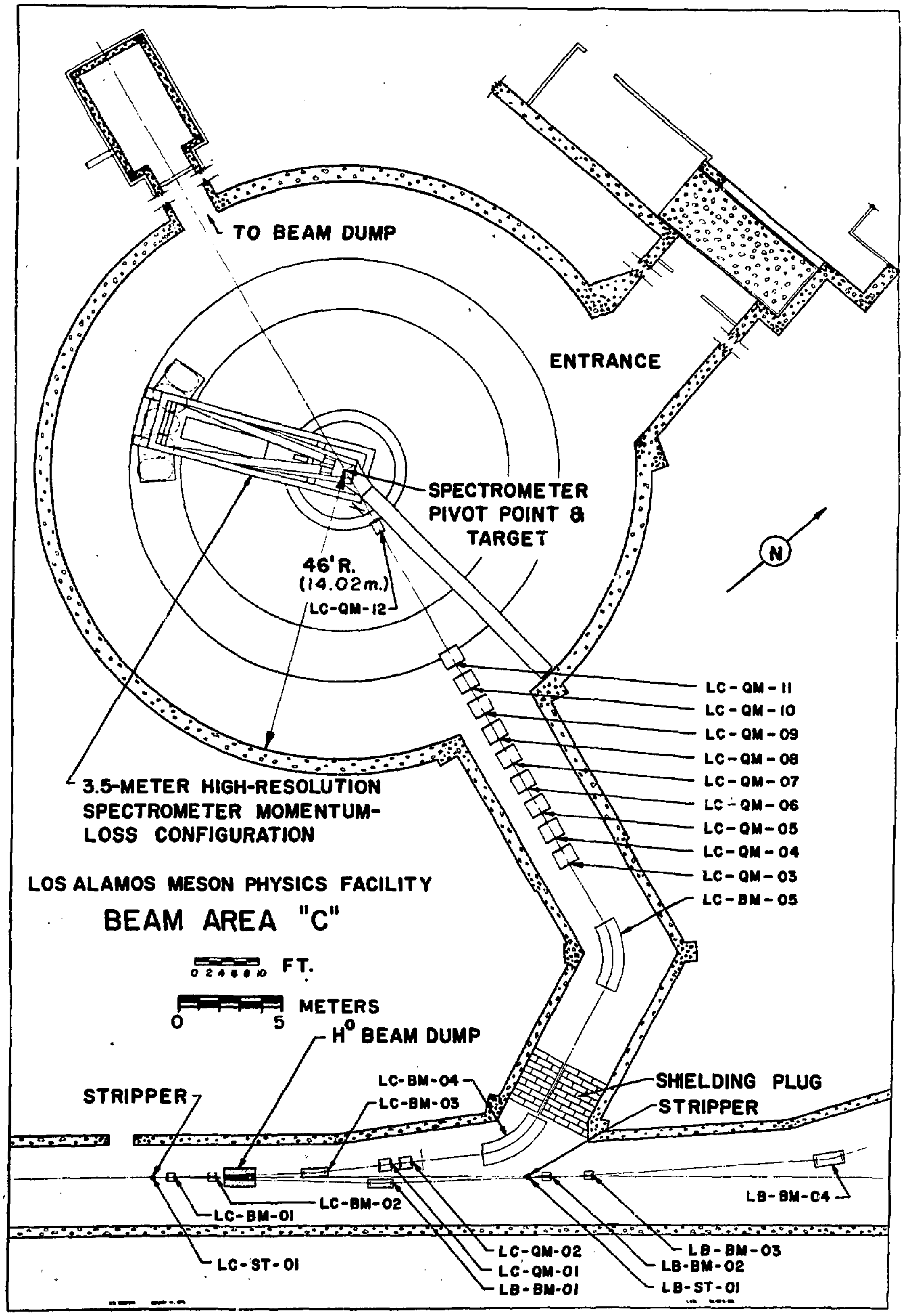


Fig. 20.
Experimental Area C.

The research capability covers a broad range of possibilities for both particle physics and nuclear structure research. Several possibilities are: a) the study of nuclear reaction mechanisms over a broad range of incident energies; b) high-resolution nuclear spectroscopy involving proton pick-up reactions; c) pion or kaon production reactions leading to discrete final nuclear levels; d) proton-produced reactions which are complementary to those obtained using pions which are of particular interest at LAMPF.

The HRS spectrometer consists of a large aperture quadrupole lens followed by two 75° bending magnets, known as the "QDD" system. The bending magnets are in the vertical plane, arranged to rotate as a unit around a pivot at the location of the spectrometer target. The detector and the time-of-flight electronic identification system are located on the top of the spectrometer carriage above the pivot. The entire spectrometer rotates about a vertical axis at the pivot and is enclosed within a hemispherical dome of 14-m radius, which is covered with earth fill for shielding. A sectional sketch of the HRS facility is shown in Fig. 21. Specifications of Beam Line C and the HRS spectrometer are given in Table XIV.

TABLE XIV

SPECIFICATIONS OF LINE C AND HRS

Incident Proton Beam

1. Energy variable in steps from 100-800 MeV.
2. 0.1 π cm mr phase space for 96% of the beam and 0.3 π cm mr phase space for 99% of the beam.
3. Momentum spread of $\Delta p/p = 0.26\%$.
4. Maximum average proton current of 10 μA.
5. 50- to 100-nA average polarized proton current.
6. Maximum dispersion at full phase space = 40 cm/%.

QDD Spectrometer

1. Central radius of curvature = 3.5 m.
2. Solid angle = 3.6 msr.
3. Maximum induction = 19 kG.
4. Momentum acceptance = 4%.
5. Momentum resolution = $\pm 1.5 \times 10^{-5}$.
6. Angular resolution = ±0.8 mr.
7. Range of scattering angles = 10-168° and 0-10° with reduced intensity.
8. Flight path ≈ 19.5 m.
9. Dispersion $<\Delta X/\Delta p> = 18.25$ cm/%.

D. Thin Target Area

This facility is located in Beam Line A just upstream of the Area A shielding wall. It is designed to allow on-line studies of nuclear reactions induced by 800-MeV protons. The mechanisms of high-energy nuclear reactions, and the de-excitation of highly excited nuclei, will be studied by utilizing dE/dx and time-of-flight techniques to measure the energy spectra, angular distributions, and total yields of a large number of both stable and radioactive nuclear reaction products such as ^{11}C, ^{12}C, and ^{13}C.

A scattering chamber in the main beam line vacuum pipe contains a remote target retractor and positioning mechanism that can hold four targets. The arrangements are shown in Figs. 22 and 23. These will be thin targets of less than 10^{-4} radiation lengths thick. The scattering chamber has outlet pipes emerging at seven angles which lead to detection instruments behind a shielding wall. The angles are: 20°, 45°, 60°, 90°, 120°, 135°, and 160°. Drift-tube detectors have been installed in several of the outlet pipes, with silicon detectors and suitable electronic recording circuits.

The limitation of this area is that access is through the switchyard and is possible only when the accelerator is turned off.

E. Nuclear Chemistry Facilities

The nuclear chemistry program emphasizes such reactions as spallation, fission, and fragmentation. These phenomena are observed primarily in the high-energy proton beam or from high-energy neutrons. Studies include the decay properties of nuclides well away from the β-stability line produced in proton and neutron reactions. However, there is also interest in reactions involving charge exchange between pions and muons and complex nuclei, so it is also important to provide exposures to pion and muon beams.

There are four stations for exposure of chemical samples to beams, two in proton beams, one in the

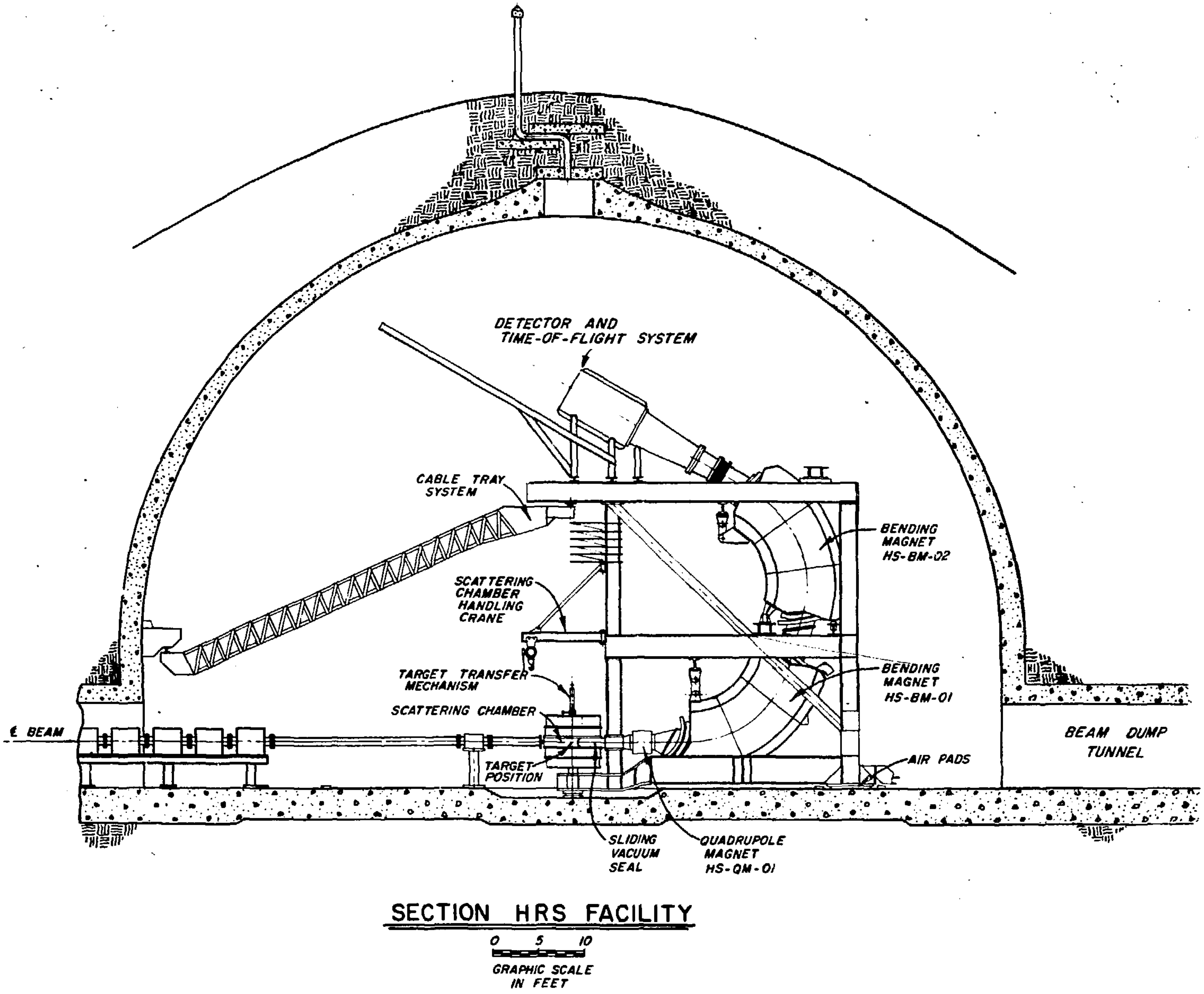


Fig. 21.
High-Resolution Spectrometer, elevation (HRS).

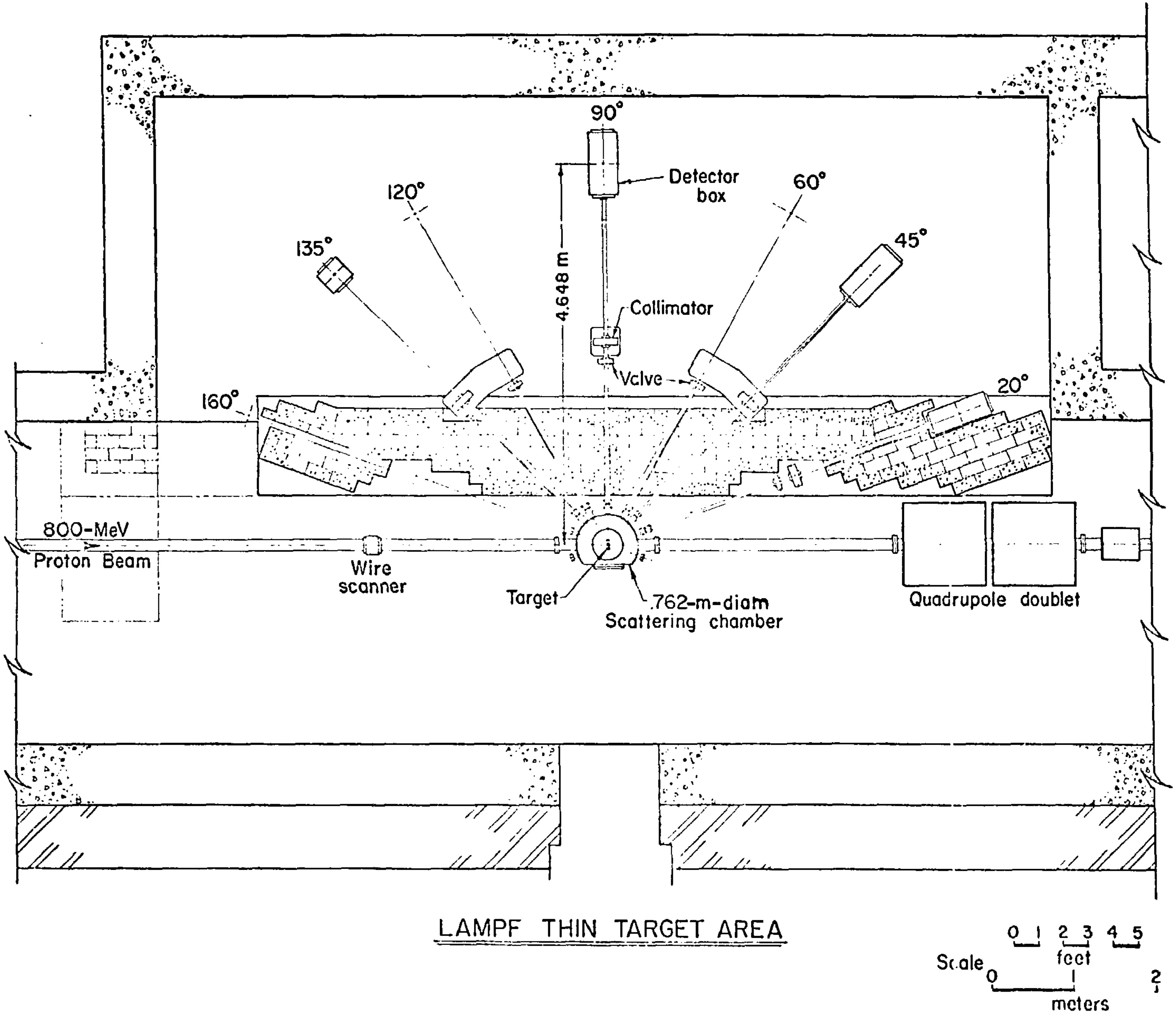


Fig. 22. Thin target area, plan view.

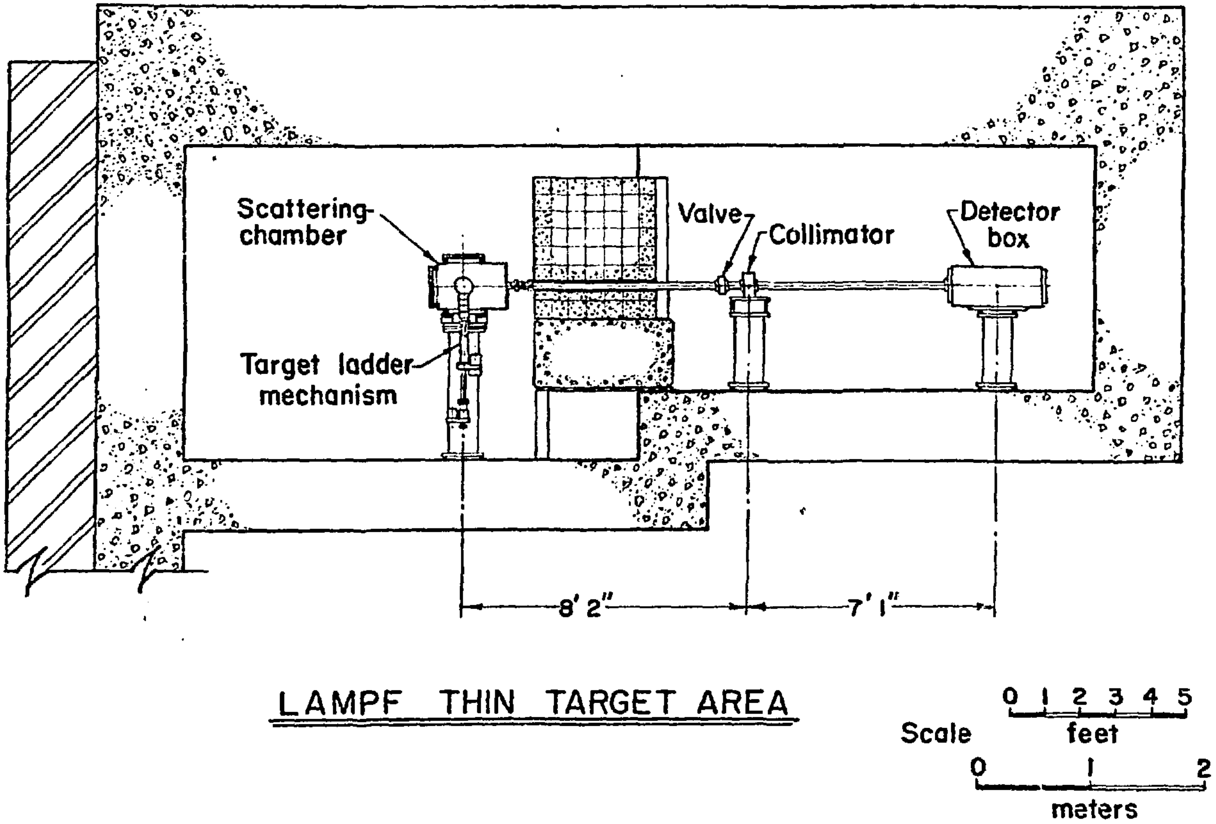


Fig. 23.
Thin target area, elevation.

neutron flux at the beam stop, and one in a pion channel. These stations are connected by pneumatic "rabbit" tubes to the hot-cell of the nuclear chemistry building. The locations of tube terminals are shown in Fig. 24. These stations are:

1. Low-intensity station in proton beam of Area B, 600-800 MeV, 10 μA.
2. High-intensity neutron station inside cooled target area, at Beam Stop A, neutrons of 15-MeV average, 0.5 mA.
3. Thin Target Area, 600- to 800-MeV protons, spallation studies, 0.1-mA beam.
4. Pion Channels, 50-600 MeV, up to $10^{10}\pi^+$/s.

F. High-Intensity Applications Areas

1. Radioisotope Production Facility

The Isotope Production Facility provides the mechanisms to prepare substantial quantities of spallation-produced radionuclides, primarily for applications in nuclear medicine. Also, a variety of "rare" nuclides will be prepared to support research studies in nuclear medicine, geochemistry, agriculture, metallurgy, nuclear weapons, etc.

The isotope facility is located at Beam Stop A, at the far end of the main beam run where the residual beam has the highest intensity. At this point the beam has traversed the switchyard, the Thin Target Area, the scattering targets in Experimental Area A, the meson-producing target in the Radiobiology Target Area, and possibly other

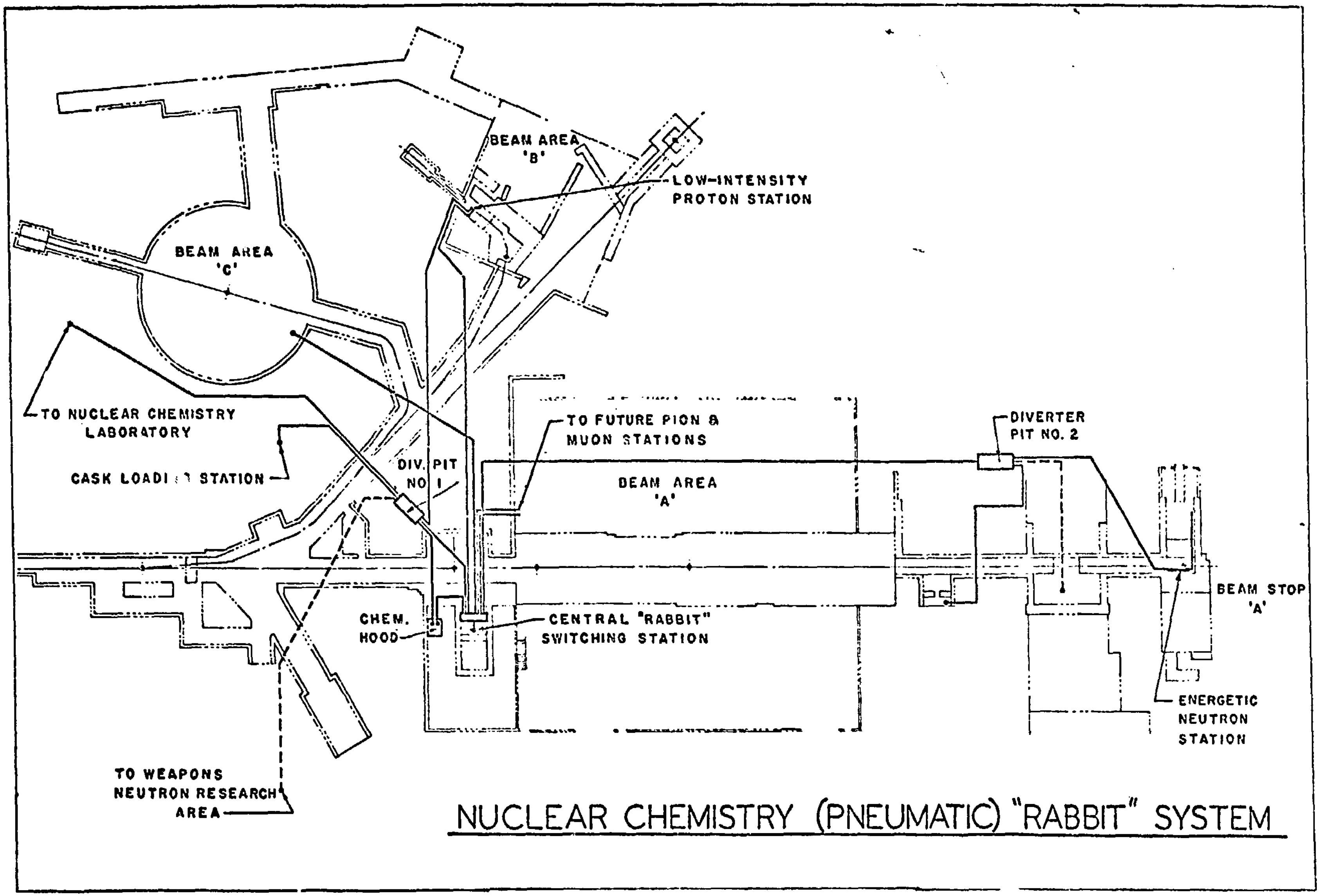


Fig. 24.
Radiochemistry pneumatic tube stations.

targets. Estimates are that the beam reaching Beam Stop A may have about 90% of original energy and 40-50% of original intensity. It will be enlarged by scattering in the targets and by defocusing magnets to a size of 15 cm by 15 cm, to reduce heating effects on isotope production targets and at the Beam Stop. This residual beam, even at present intensities, has the highest beam power of all accelerators now operating above the meson threshold.

The facility has a set of four independently operated target "stringers," capable of expansion to twelve such units in the future. See Fig. 25. Each stringer is a 26-ft-long beam with a target-containing chamber at the end which is water cooled. The stringer can be remotely driven horizontally through a slot in the shielding, and retracted into an area where the target chamber is removed and transferred to a shielded cask for transport to hot-cell facilities elsewhere. No hot-cell facilities exist in this area.

Yields for some of the isotopes of current interest in nuclear medical applications, such as ^{82}Sr, ^{123}I, ^{126}I, and ^{127}Xe, have been calculated from studies at the Space Radiation Effects Laboratory in Virginia. A program is in progress for production of these and other isotopes on the hundred-gram scale.

2. Radiation Effects Facility

A region close to the Main Beam Stop is allotted to a chamber within which samples can be exposed to the neutron flux. The neutrons arise mainly from evaporation processes. However, the spectrum is harder than from a fission source and is accompanied by a gamma flux of about 1% that in a reactor core. These characteristics make the facility attractive for studies of radiation effects on materials used for fast-breeder controlled thermonuclear reactors. The flux of 15-MeV neutrons, at 0.5-mA proton beam intensity, is estimated to be between 10^{13} and 10^{14} n/cm^2/s at the location of the exposure chamber. This should be sufficient to provide valuable information on radiation effects on materials.

The Radiation Effects Facility is adjacent to the Radioisotope Production Facility. The distinction is that exposure to neutrons for radiation studies does not require insertion of the sample into the proton beam. For radiation studies the samples are inserted just outside the main beam stop. However, as for isotope production targets, the sample chamber is provided with water-cooling, gas withdrawal, and remote removal to a shielded shipping container.

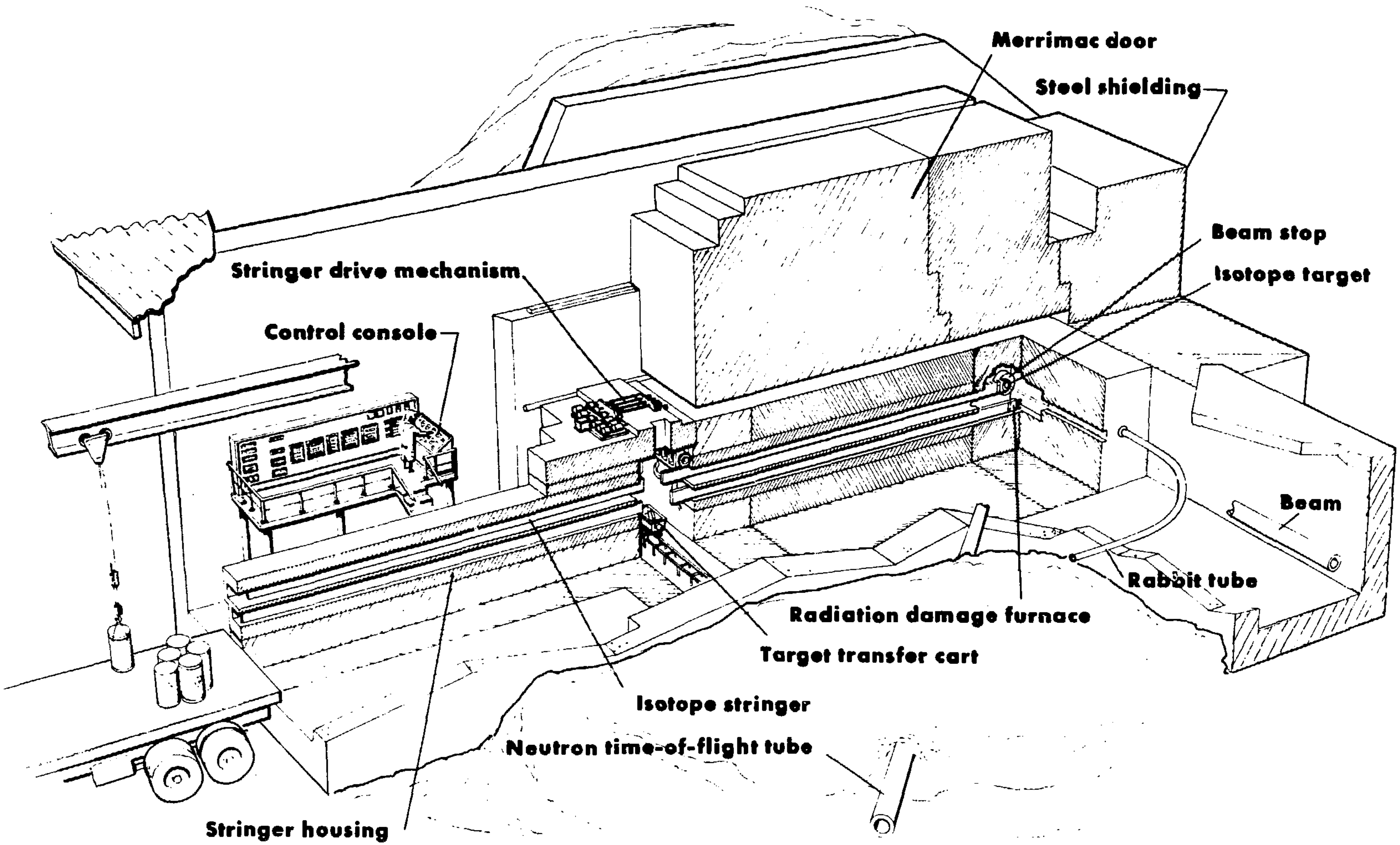
More recently, a radiation effects facility was installed in the main beam just upstream from the A-1 target. This location permits the study of radiation damage which is uniform across the beam area and at intensity rates over ten times greater than achievable in any nuclear reactor.

3. Neutrino Facility

The residual beam at Beam Dump A, in the main proton line, may be as large as 0.5 mA of 700-MeV protons. This represents an attractively intense source of electron-neutrinos. A facility consisting mainly of stacked steel shielding has been designed to allow use of this neutrino source.

The mechanisms for production of neutrinos are well known and yields can be calculated with some confidence. The primary process is muon decay: $\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$. The energy spectrum of the electron-neutrinos extends from 0 to 53 MeV, with a peak around 35 MeV. This energy is high enough that reactions with electrons, nucleons, and nuclei can all be observed, but there will be no muon or pion production to produce background effects. Thus, reactions that are difficult to observe in the GeV energy range may be studied at LAMPF neutrino energies. Calculations suggest that, for a residual proton beam of 1/3 mA, the number of μ^+ decays into neutrinos will be 2×10^{14}/s and at a distance of 8 m from the target the flux will be about $3 \times 10^7 \nu_e$/s-cm^2.

A building (room) shielded with steel plates, which is available for installation of neutrino experiments, is located about 8 m south of the beam dump. A thick (0.8-m-thick) movable steel block adjacent to the beam dump will allow convenient tests of beam-associated background levels (see Fig. 26).



ISOTOPES PRODUCTION FACILITY

Fig. 25.
Isotope Production Facility.

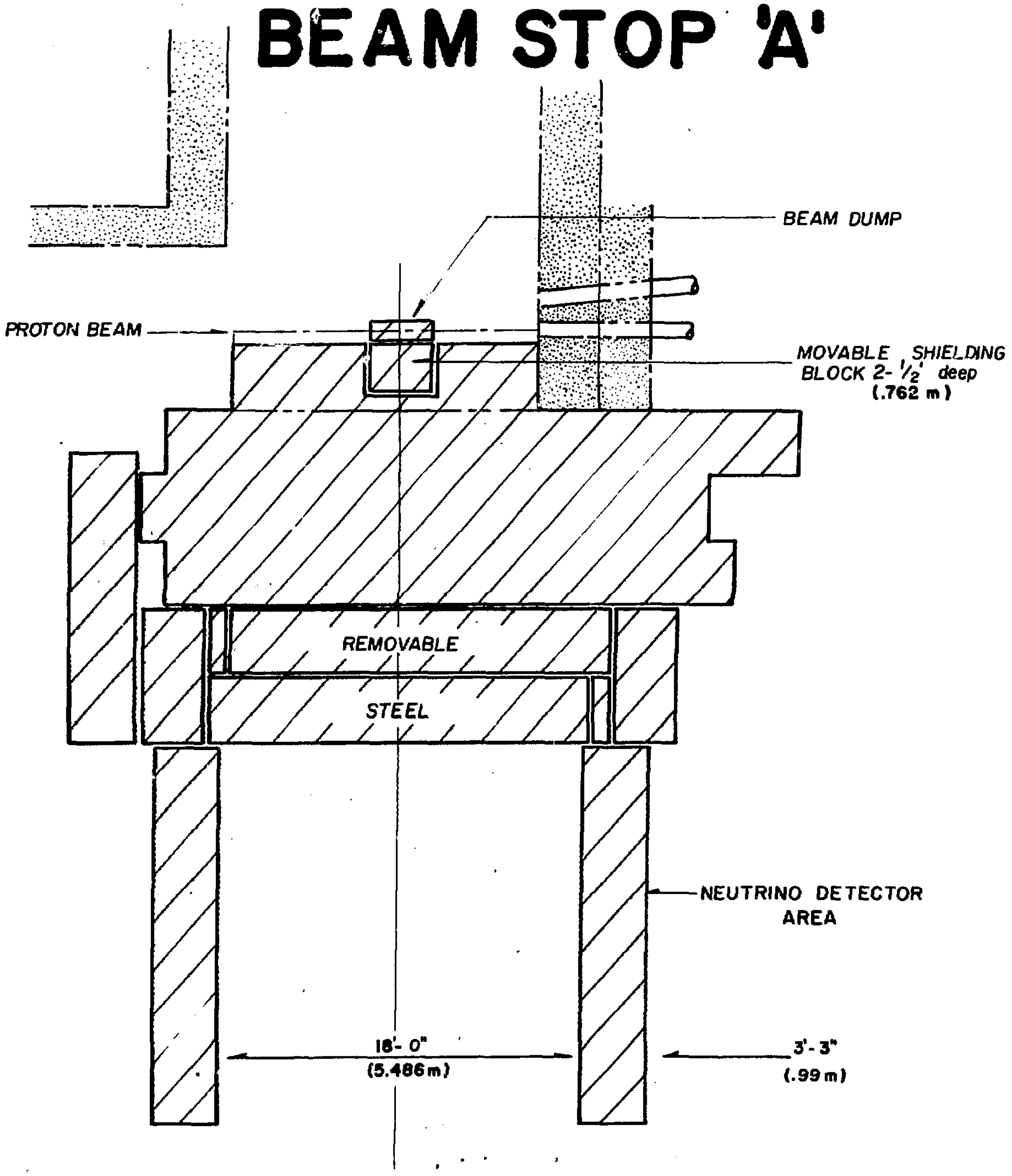


Fig. 26.
Neutrino Facility, top view.

CHAPTER 7

PRACTICAL APPLICATIONS

LAMPF is a multiple-use facility which allows many experiments to be conducted simultaneously, with minimal interference between them, and which has surplus beam intensity available to be used for a variety of practical applications at the same time. Recognizing this fact, LAMPF organized the first practical applications group at a major accelerator facility, headed by E. A. Knapp and J. N. Bradbury. During the first years of operation several of these applications have been exploited and many more are planned for the future. Perhaps the most exciting development is the application of negative pions to the management of cancer. A joint effort to evaluate the possibilities of cancer treatment is under way at present, funded by the National Cancer Institute and staffed from the University of New Mexico Medical School and LASL. Other applications apply to medical instrumentation, such as highly efficient X-ray systems using electron linacs based on the LAMPF linac design, and an electrosurgical tool developed by members of the LAMPF staff. Still other applications involve radioisotope production and use, and the utilization of other secondary radiations such as muons, neutrons, and neutrinos.

A. Biomedical Facility

Nuclear physicists have known for years of the special property of negative mesons, on slowing down in matter, of 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) have energies of 5 to 20 MeV and ranges in light matter such as tissue of only a few microns. This concentration of ionization at the end of the range of a pion beam is many times greater than the ionization peak at the end of range of protons or light-charged particles (the Bragg peak). See Fig. 27. This differs from positive pions which are not attracted by positively charged nuclei and decay into muons. Such a concentration of ionization was known to medical therapists to be potentially useful in the treatment of deep-seated tumors. Fowler and Perkins[18] calculated the characteristics of an accelerator capable of pion therapy as early as 1961. However, until LAMPF was conceived none of the existing meson-producing accelerators could produce sufficient intensities to make an application possible.

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

Rosen spent several years convincing the medical community that pions might provide a worthwhile method of treatment of cancer. One of his first steps was publication of a paper[19] in December 1968, presenting his calculations of radiation dosage. Some of his early supporters in the medical profession were Dr. Max Boone of the University of Wisconsin, Dr. Robert Stone of the University of Oregon Medical School, and Dr. Henry S. Kaplan of Stanford University. The Atomic Energy Commission was informed of the possibilities and supported further efforts to speed up the planning. Rosen also described the opportunity to the Joint Committee on Atomic Energy at several Hearings in February 1967, April 1969, and March 1970. Dr. John R. Totter, Director, Division of Biology and Medicine of the AEC, welcomed the early planning and requested proposals to stimulate the development. A formal proposal was prepared by Dr.

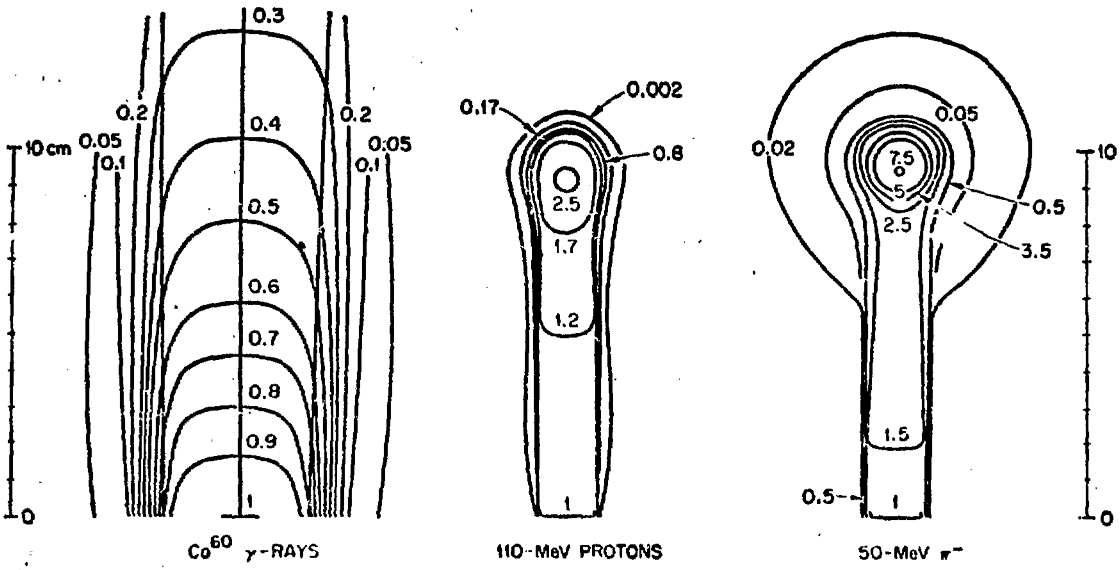


Fig. 27.
Isodose distributions around beams of gamma rays, protons, and negative pions in tissue, showing the greater localization in depth of dose produced around the stopped negative pions.

Wright H. Langham, in the LASL Health Research Division, and sent to the AEC in September 1970.

A parallel proposal for support of a program of research aimed at developing techniques for the treatment of animal and human tumors was submitted to the National Cancer Institute under the direction of Dr. M. M. Kligerman. The result is a jointly supported program involving the Division of Biology and Medicine of ERDA, the National Cancer Institute, the University of New Mexico Medical School, and the Health Research Division of LASL. Arrangements agreed to in the contract with the National Cancer Institute provide that the NCI will determine the use of the Biomedical Facility for half-time, and that proposals from other investigators for research to occupy the other half-time are to be authorized by a committee similar to the PAC used by LAMPF for physical experiments.

The residual proton beam in Area A is refocused after passing through the research targets in Area A, and traverses another target in the Biomedical Target Area. This area is specifically designed for remote handling of the target, valves, and magnets. See Fig. 28. Pions scattered at an angle of about 70° are collected by large quadrupoles and deflected by magnets to the side and down into a treatment room in the Biomedical Building. The pion channel illustrated in Fig. 29 shows the wedge-type energy degrader, collimators, and other devices to produce a controlled negative pion beam. The negative pions are projected downward across a treatment table quite similar to those used in hospital X-ray treatment rooms. Adjacent control facilities behind shielding partitions allow an operator to vary the energy, physical dimensions, and depth of penetration. The beam can be scanned in energy to cover a vertical depth of exposure within a patient, and can be controlled in size to match the transverse dimensions of a tumor.

The Biomedical Building includes offices, laboratories, animal staging areas, patient staging areas, simulator devices for tests, and many other support facilities. An overall view is shown in Fig. 30.

B. Experimental Projects

In addition to the pion cancer therapy project, there are many other opportunities for practical applications at the experimental level. Several facilities provided at LAMPF lend themselves to applications as they might arise:

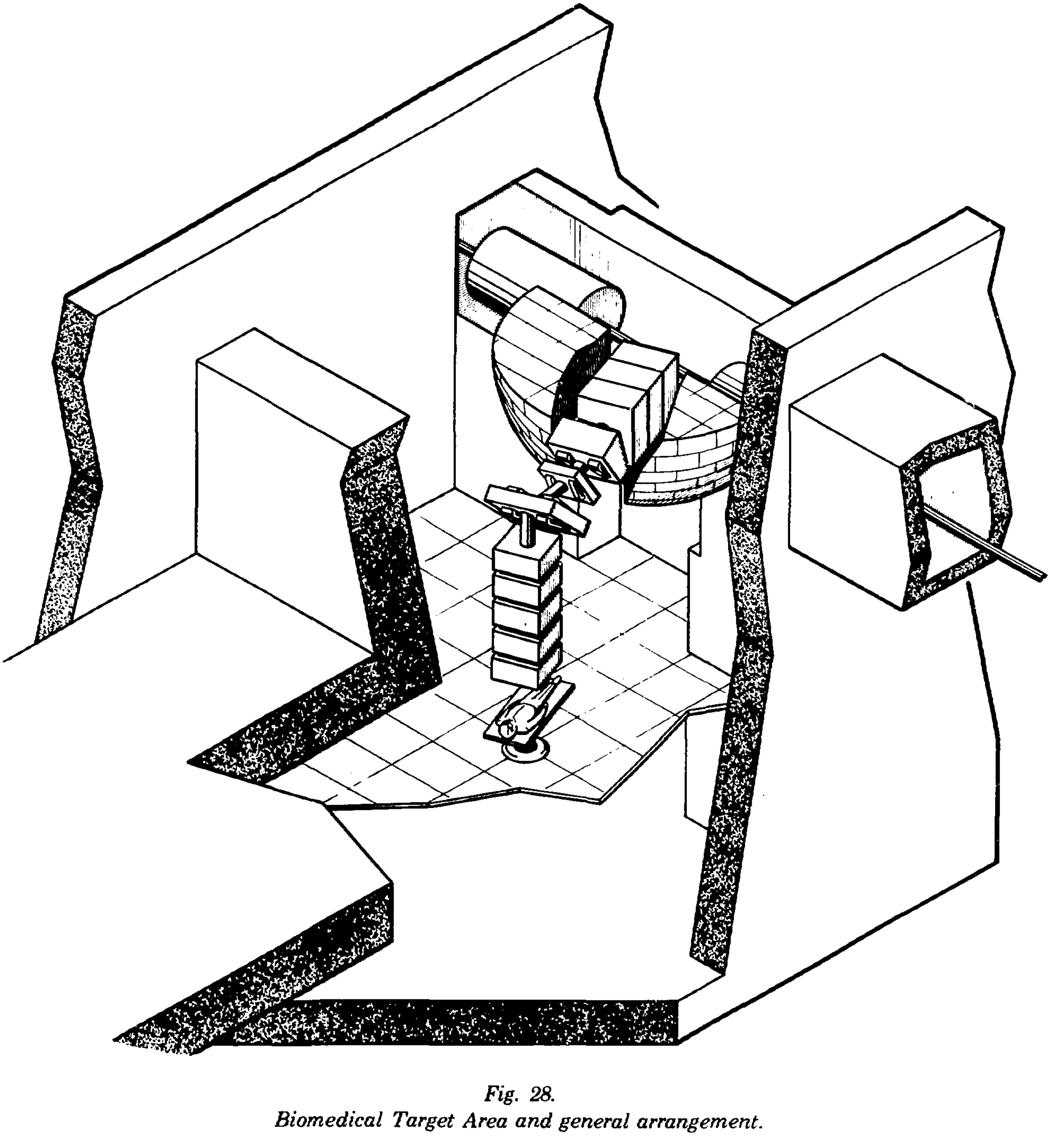


Fig. 28.
Biomedical Target Area and general arrangement.

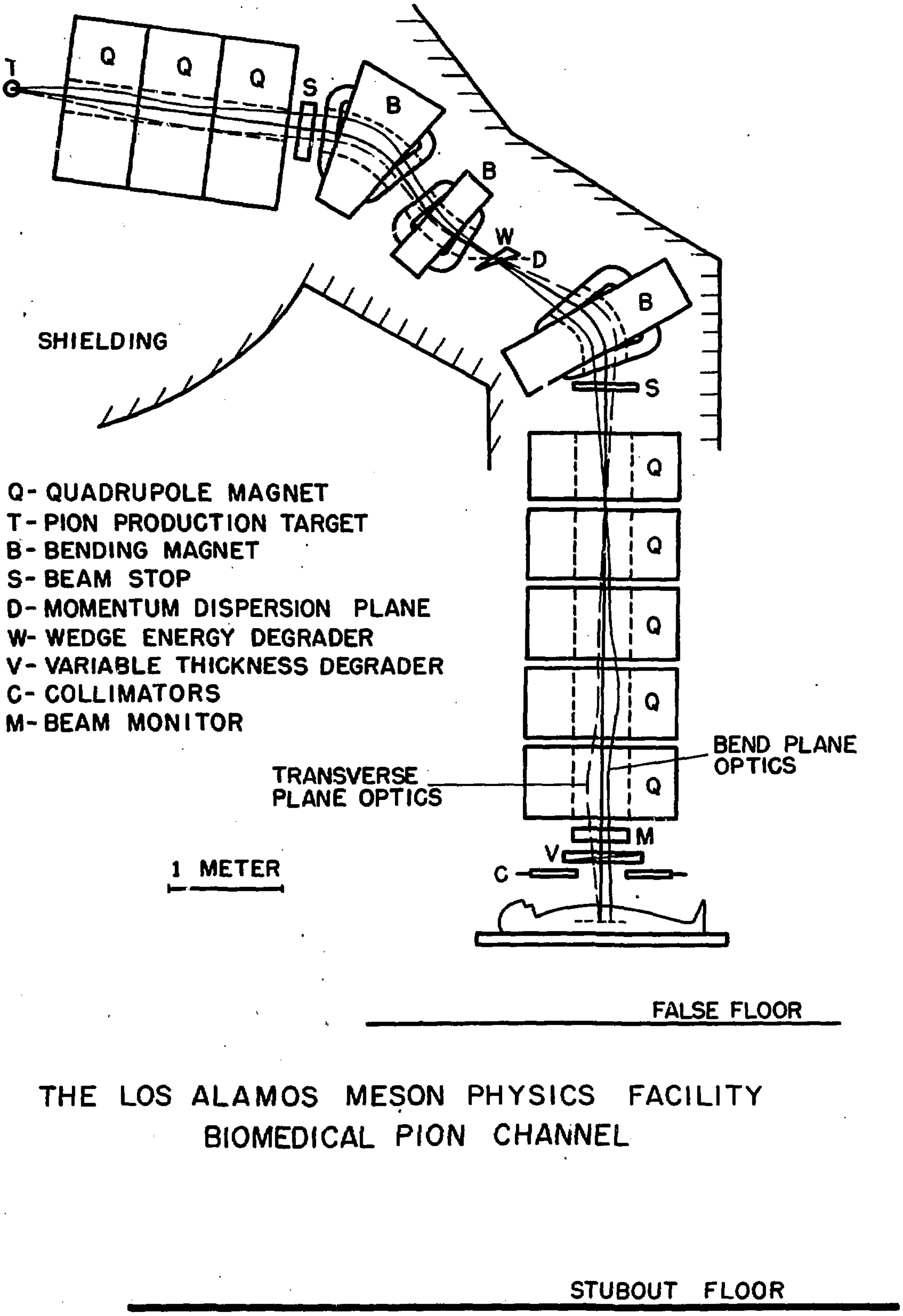


Fig. 29.
Biomedical Pion Channel.

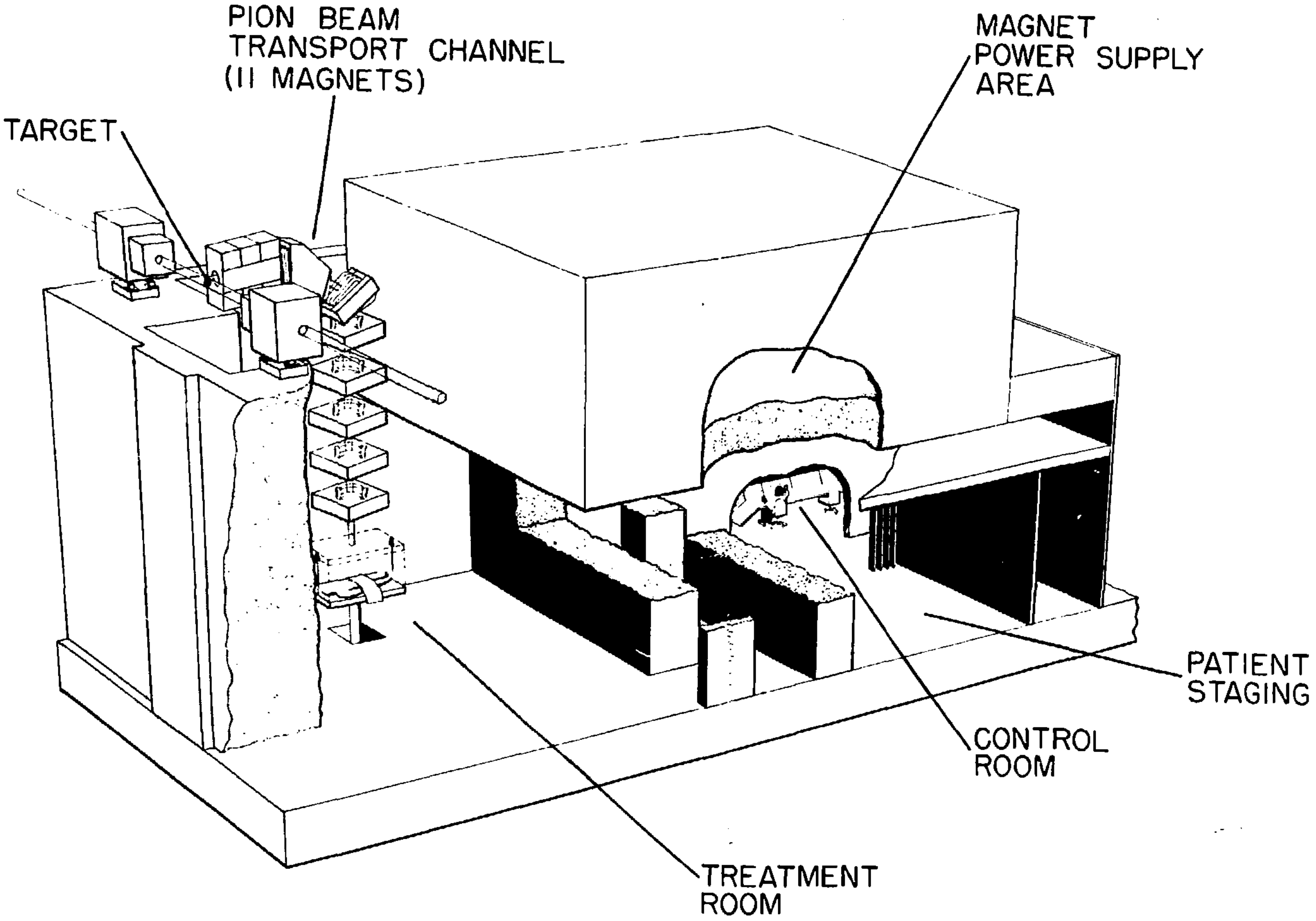


Fig. 30.

Pion Radiation Therapy Facility.

1. Radioisotope Production Facility

The surplus proton beam intensity in Area A at the Beam Stop is many times larger than the total from all accelerators now operating at energies above the meson threshold. This installation obviously will become a major source of radioisotopes to be used in other scientific fields. Of particular interest are the radionuclides used for diagnosis and treatment in medicine. In the last chapter the arrangements provided for exposure of samples to the beam in remote-handled, cooled target chambers were described.

2. Radiation Damage Studies

Neutrons from the main beam stop have an energy spectrum and sufficient intensity to be useful for studies on the radiation-damage effects on materials used for reactor cores, especially for fast-breeder and controlled thermonuclear reactors. Recently, use of the direct proton beam for radiation-damage studies has been proposed. This technique shows promise in giving a quick test for radiation-damage properties of materials used in reactor cores, etc.

3. Neutron Beams

The neutrons of known and controllable energy, both at 90° and in the forward direction at targets in the Nucleon Physics beam in Area B, might well have a variety of applications in other fields of physics, such as the physics of the solid state.

4. Muonic X Rays for Analysis

Muonic X rays have proven to be a very useful elemental analysis tool. For high-Z elements they also have an isotopic discrimination capability. The important feature of this type of analysis is that it is nondestructive, similar to neutron activation or the technique of X-ray fluorescence. Muonic X rays provide a technique which allows development of an accountability system based on direct physical measurement which is nondestructive and requires samples of only a few grams of fissionable material.

The physical principle is as follows: Low-energy, negative pions produced in a scattering target (carbon or copper) are captured in a beam transport system and allowed to decay in flight (half-life about 20 ns) into negative muons. The muon comes to rest in the surrounding matter of the sample and is captured by a nearby nucleus of the sample into a loosely bound atom consisting of that nucleus and the muon. The μ^- has much the same properties as an electron except that its mass is 200 times that of the electron. The atom which is formed is similar to a hydrogen atom, with one orbiting muon and other muonic orbits empty. The single muon cascades down to the more tightly bound muonic orbits with the de-excitation energy being given off as muonic X rays. The muonic X-ray energies are characteristic of the element and precisely calculable. So, the measured spectrum of muonic X rays identifies the element of the sample. In the case of heavy elements such as fissionable ones, the X ray will even distinguish between isotopes. After the muon reaches the lowest orbit it decays ($T = 2.2\ \mu s$) or interacts with the nucleus.

Muonic X rays are quite energetic. since the muon is so heavy. For example, in ^{208}Pb the K X-ray transitions for the electron system are about 75-keV energy; the same transition energy for a muon with the same nucleus is 200 times greater or about 15 MeV. Since muonic X rays are so energetic they are also penetrating, allowing the analysis of bulky samples. Furthermore, the muons themselves are penetrating; a 200-MeV muon beam has a range of 12 cm in Pb, for example. So the muons can penetrate large or dense samples.

The X rays are observed in a high-resolution germanium detector located at the side of the sample being irradiated by the muons. A coincidence-anticoincidence system is used with counters which identify the muon which attaches to the target nucleus with the X ray which results.

Preliminary data supports the contention that this technique is feasible, and a program preparing for the analysis of real samples is being developed. The electronic sensitivity of the detectors and the calculational capabilities are being refined to improve the discrimination for isotopes.

Another possible application of muonic X rays is for diagnostic applications in medicine.

C. Technology Transfer

1. Side-Coupled-Cavity Linacs for X-Ray Systems

The concept of the side-coupled waveguide structure for linear accelerators has been widely accepted and used by commercial producers of medical and other X-ray systems. This structure results in much higher electric field gradients than earlier linac structures, such that higher final energies can be obtained in relatively short structures. This in turn allows the linac to be mounted on gimbals when used as the electron beam source for an X-ray system, a decided advantage for clinical use in hospitals. Six to eight producers of X-ray systems have adopted this technique and have developed and marketed X-ray units based on the side-coupled waveguide structure. Several hundred units are now in service, in the energy range of 4- to 18-MeV X-rays.

2. Electro-Surgical Tool

A team of LASL scientists, including J. D. Doss from LAMPF, has developed a special surgical tool which cuts and cauterizes blood vessels instantly, using electrical heating for the cautery. Development is proceeding with the collaboration of surgeons at the University of New Mexico Medical School and the Los Alamos Medical Center.

3. Thermal Treatment of Tumors

The use of radio-frequency waves to generate high temperatures in superficial tumors is being explored by a team of LAMPF scientists (J. D. Doss) and physicians from the local medical schools. One early success is the apparent cure of a nonmalignant tumor on the trunk of an elephant at the Albuquerque Zoo.

4. Tumor Diagnostic Studies

Electronic skills of the LAMPF staff are also being applied to the diagnosis of breast cancer. A temperature measuring and recording instrument developed at LAMPF is presently under test by physicians at the University of Arizona Medical School, Tucson, Arizona.

D. Weapons Pulsed Neutron Facility

An application more appropriate to the mission-oriented aspects of LASL than to basic scientific research is the use of high-intensity short pulses of neutrons which can be obtained from the linac beam. Much of this work will be classified for security reasons and it will be performed in a separate guarded building with no connection to LAMPF except the underground tunnel through which the beam enters the building. See location of Beam Line D in Fig. 10. A fraction of the main beam will be diverted to the south in the switchyard and will traverse a tunnel into the special laboratory. Future plans call for collecting the proton beam in a storage ring in a single turn to form a short pulse which will produce a pulse of neutrons on striking a target. The expectation is a broad spectrum of neutron energies with a peak at 1 to 2 MeV, in pulses at a repetition rate of 120 pulses/s and with intensities of 10^{12} n/s in each pulse.

Some of the applications of this pulsed neutron beam are:

1. Measurement of cross sections needed for weapons design, vulnerability, calculations and evaluation of diagnostics.
2. Tests of weapon design codes for simple systems.
3. Simulation experiments on complex weapon systems, a) as a test of vulnerability and, b) to provide input to weapons codes.
4. Measurement of shock-wave and hydrodynamic data (as a supplement to Phermex).
5. Neutron and proton radiography (as a nondestructive test of weapons components and systems.
6. Detector calibration (for underground test and other uses).

REFERENCES

1. "Relevance of Particle Accelerators to National Goals," Louis Rosen, Science **173**, 490 (1971).
2. "The Clinton P. Anderson Meson Physics Facility (LAMPF)," Louis Rosen, Proc. Nat. Acad. Sci., **70**, 603 (1973).
3. "Origins and History of the Los Alamos Meson Physics Facility," M. Stanley Livingston, Los Alamos Scientific Laboratory report LA-5000 (June 1972).
4. Schedule 44, Construction Project Data Sheet, "Los Alamos Meson Physics Facility," August 1963.
5. "Meson Factories," Louis Rosen, Physics Today, **19** (December 1968).
6. "High Intensity Proton Accelerators," Yale internal report Y-12 (October 1964).
7. "Proposal for Mc^2 Isochronous Cyclotron," Oak Ridge National Laboratory report ORNL-3540 (November 1, 1963).
8. "Proposal to the U.S. AEC for ... a Cyclotron for the Production of Large Fluxes of Mesons," J. R. Richardson, K. R. McKenzie, B. T. Wright, D. H. Stork, and R. P. Haddock, July 1960.
9. "Bethe Panel Report on Meson Factories," H. A. Bethe, Chairman, Office of Science and Technology Report (March 1964).
10. Schedule 44, Construction Project Data Sheet II, "Los Alamos Meson Physics Facility," October 30, 1964.
11. The Charter is presented in Ref. 3 as Appendix C.
12. "LAMPF Users Handbook," Los Alamos Scientific Laboratory Publication No. 9MP-DO-1-UHB (November 1974).
13. "The LASL High-Duty-Factor Ion Source," C. R. Emigh and D. W. Mueller, Proc. 1968 Proton Linear Accelerator Conf., Brookhaven National Laboratory report BNL-50120, Pt. 1, p. 293 (May 20, 1968).
14. "Performance of the LAMPF H^- Injector," P. W. Allison, E. A. Meyer, D. W. Mueller, and R. R. Stevens, Jr., Proc. Symposium on Ion Sources and Formation of Ion Beams, Berkeley, CA, October 22-25, 1974, LBL-3399 (1974).
15. "Source of Polarized Negative Hydrogen Ions," G. P. Lawrence, G. G. Ohlsen, and J. L. McKibben, Phys. Letters, **38B**, 594 (March 3, 1969).
16. "Generation of Geometrical Dimensions for Drift-Tube Linacs," D. A. Swenson, Los Alamos Scientific Laboratory, unpublished data, MP-3/DAS-1, June 29, 1967.
17. "Design of RF Phase and Amplitude Control for a Proton Linac," R. A. Jameson, T. F. Turner, and N. W. Lindsay, IEEE Trans. of Nucl. Sci. NS-12, **3**, p. 138 (June 1965).
18. "Possibilities of Therapeutic Application of Beams of Negative Pi-Mesons," P. H. Fowler and D. H. Perkins, Nature **189**, 525 (1961).
19. "Possibilities of Using Negative Pions in Radiotherapy," L. Rosen, Nucl. Applications **5**, 379 (December 1968).

APPENDIX

ARTICLES OF INCORPORATION

OF THE

LOS ALAMOS MESON PHYSICS FACILITY USERS GROUP, INC.

Article I - NAME

The name of the corporation is the Los Alamos Meson Physics Facility Users Group which may be abbreviated to "LAMPF Users Group".

Article II - PURPOSES

The purpose of the corporation is to promote the advancement of science as follows:

a) To provide a channel for the exchange of information among scientists interested in working at LAMPF and between scientists and the LAMPF administration.

b) To provide a means for facilitating involvement of scientists and engineers in specific projects at LAMPF.

c) To provide an entity responsive to the representations of its members for offering advice and counsel to the LAMPF management on operating policy and facilities.

d) To provide a legal entity responsible to its members for providing services which will promote the most effective utilization of the LAMPF for the common good and general welfare of human society.

e) To provide a legal entity which will have the flexibility and adaptability to do anything necessary to aid scientists, particularly those from institutions other than LASL, to use the facility.

f) To represent, when feasible and desirable, the membership in contracts with other parties.

g) To make, perform, and carry out contracts of every kind, as the purposes of the corporation shall require, with any person, firm, association, corporation, government or governmental agency or instrumentality.

h) To acquire property, real or personal, by gift, purchase, devise or bequest, and to hold and dispose of such property as the purposes of the corporation shall require.

i) To act as trustee under any trusts incidental to the principle objects of the corporation, and to receive, hold, administer, and expend funds and property subject to said trusts.

j) To borrow, assess fees, or otherwise raise money as needed for accomplishing its purposes.

k) To erect, lease, reserve, or buy living accommodations as found to be needed or desirable to facilitate access of its members to the research facility or to organized meetings concerning the same.

l) To have all the capacity to act possessed by natural persons as are necessary and proper to accomplish its purposes.

Article III - NONPROFIT AND NONPOLITICAL CHARACTER

a) This corporation is organized under the provisions of Chapter 15, Article 14 of the laws of the State of New Mexico pertaining to nonprofit corporations. It will not afford pecuniary gain, incidentally or otherwise, to its members. No part of net funds acquired by the corporation from any source will be used for the benefit of private interests such as designated individuals, or persons controlled directly or indirectly by such private interests, except that reasonable compensation may be paid for services rendered to or for the corporation affecting one or more of its purposes.

b) This corporation will have no capital stock and will pay no dividends or other pecuniary remuneration directly or indirectly to its members as such.

c) This corporation, its incorporators, directors, and officers will not discriminate, in the admission of its membership, administration of its affairs or dealings with others, on the basis of race, color, religion, sex, or national origin.

d) This corporation is nonpolitical and will not directly or indirectly participate or intervene in political campaigns on behalf of, or in opposition to, any candidate for public office.

Article IV - DURATION

The period of duration of this corporation shall be one hundred (100) years unless sooner terminated or extended as provided by law.

Article V - REGISTERED OFFICE

The registered office of this corporation in the State of New Mexico will be located at Los Alamos, New Mexico 87544. The name of the registered agent in charge thereof is ________________.

Article VI - INCORPORATORS

Article VII - DIRECTORS

The first board of directors will be constituted by seven (7) members whose names and addresses and tenures are as follows:

Article VIII - OFFICERS

a) The officers of the group shall be a Chairman, Chairman-Elect, and Secretary/Treasurer.

b) Each officer will perform such duties as usually are incident to the office to which he has been elected or appointed and such other duties as may be imposed upon him by the board of directors of the membership of the group.

c) Vacancy in any office shall be filled for the balance of the term thereof by a person appointed by the board of directors.

Article IX - COMMITTEES

The board of directors, or the group, by resolution of its members shall determine from time to time the number and identity of committees.

Article X - BY-LAWS

The group shall adopt such by-laws as are necessary for its government, and may amend or repeal the same as provided for therein.

Article XI - TERMINATION

If, upon termination of this corporation, there shall be assets (except for special designated funds held in escrow) such assets shall be delivered as a contribution to another organization which shall be exempt from taxation under provisions of Section 501(c) of the Internal Revenue Code (or as it may hereafter be amended).

IN WITNESS WHEREOF, we the incorporators hereunto set our hands and seals this ________day of

____________________, 1972.

LOS ALAMOS MESON PHYSICS FACILITY USERS GROUP, INC.

BY-LAWS

Article I - MEETINGS

Section 1. Place of Meeting

Meetings of the members and of the board of directors of this group may be held at a place designated by the board of directors or by a majority vote of a quorum of the membership with notice given as provided in these by-laws.

Section 2. Annual Meeting of Members

An annual meeting of the members shall be held in each calendar year between October 15 and November 30. The election of members to the open positions on the board of directors, one of which shall be designated chairman-elect, will be conducted prior to the annual meeting as provided in these by-laws.

The first board of directors shall be the current executive committee of the LAMPF Users Group chartered on January 16, 1969 at Los Alamos, New Mexico with the addition of the past-chairman of said group and the liaison officer of the said group also serving. The term of the first board shall be from the adoption of these by-laws until December 31, 1972.

For the first elected board of directors the terms of office shall be one year for the past-chairman, two years for the chairman, three years for the chairman-elect, two years for two members, and one year for two members. The chairman-elect will succeed to the office of chairman and the chairman will succeed to the position of past-chairman at the end of one year.

Section 3. Notice of Annual Meeting of Members

At least ten (10) and not more than thirty (30) days prior to the date fixed by Section 2. of this Article for the holding of annual meeting of members, notice of the time and place of such meeting shall be mailed as hereinafter provided to each member entitled to vote at such meeting. Notice of the meeting shall state the matters to come before the membership so far as known.

Section 4. Delayed Annual Meeting

If for any reason the annual meeting of the members shall not be held on the day hereinbefore designated, such meeting shall be called on the earliest convenient date thereafter provided that the notice for such meeting shall be the same as herein required for the annual meeting originally scheduled, namely not less than ten (10) nor more than thirty (30) days notice.

Section 5. Order of Business at Annual or Delayed Annual Meeting

a) Reading notice and proof of mailing notice or of publication.
b) Approval of minutes of the last preceding meeting.
c) Report of Chairman.
d) Report of Chairmen of Committees.
e) Report of Secretary/Treasurer.
f) Announcement of results of the election of directors.
g) Transaction of other business mentioned in the notice or from the floor.

Provided that, in the absence of any objection, the presiding officer may vary the order of business at his discretion.

Section 6. Special Meeting of Members

A special meeting of the members may be called at any time by the chairman, or by a majority of the board of directors or by fifty (50) members of the membership. The method by which such meeting may be *called is as follows: Upon* receipt of a specification in writing setting forth date and objects of the proposed special meeting signed by the chairman, or by majority of the board of directors, or by fifty (50) members of the membership as the case may be, the secretary or an assistant secretary shall mail the notices or otherwise communicate the same requisite to such meeting.

Section 7. Notice of Special Meetings of Members

At least ten (10) and not more than thirty (30) days prior to the date fixed for the holding of any special meeting of members, notice of the time and place and purposes of such meeting shall be communicated *as hereinafter provided*, to each member entitled to vote at such meeting. No business not mentioned in the notice shall be transacted at such meeting.

Section 8. Organization Meeting of the Board of Directors

At the place of holding the annual meeting of members and immediately following the same, the board of directors as constituted upon final adjournment of such annual meeting shall convene for its annual meeting for the purpose of appointing officers and transacting any other business properly brought before it.

Section 9. Regular Meetings of the Board

Regular meetings of the board of directors shall be held not less frequently than annually at such place as the board shall from time to time determine. No notice of regular meetings of the board shall be required.

Section 10. Special Meetings of the Board

Special meetings of the board of directors may be called by the chairman or a majority of the board of directors at any other time by means of any convenient communication of the time, place, and purpose thereof directed to each director at his usual or otherwise known address, and action taken at such meeting shall not be invalidated for want of notice if such notice shall be waived as hereinafter provided.

Section 11. Notice and Mailing

All notices required to be given by any provision of these by-laws shall state the authority pursuant to which they are issued (as, "by the chairman" or "by order of the board of directors" or "by order of the membership", as the case may be).

Section 12. Waiver of Notice

Notice of the time, place, and purpose of any meeting of the members or of the board of directors, may be waived by any communication indicating assent by the respective member or director or by failure to object at the meeting.

Article II - QUORUM

Section 1. Quorum of Members

Present in person or by proxy of members representing at least ten (10) percent of the membership of this association shall constitute a quorum of the members.

Section 2. Quorum of Directors

At least fifty (50) percent of the directors shall constitute a quorum.

Article III - VOTING, ELECTIONS, AND PROXIES

Section 1. Who is Entitled to Vote

Each member or member organization is entitled to one vote as herein provided.

Section 2. Proxies

No proxy shall be deemed effective unless signed by the member and filed with the group. The proxy may specify over the signature of the member the duration (not to exceed two (2) years) for which it shall remain in effect. A proxy shall extend to all meetings of the members occurring within the specified duration unless sooner withdrawn in writing by the member.

Section 3. Election by Mail

The board of directors may choose to conduct voting and election by mail. Ballots must be sent to the members no later than five (5) weeks before the next annual or special meeting of the members. In order for a ballot to be counted its envelope must be signed by the member and received at the business address of the LAMPF Users Group not less than one (1) week before the next annual or special meeting.

Article IV - BOARD OF DIRECTORS

Section 1. Number and Term of Directors

The business, property, and affairs of this group shall be managed by a board of seven (7) directors provided that the membership shall have the power to increase the number not to exceed twelve (12). Each director shall hold office for the term for which he was elected and until his successor is elected and qualified. The term of the director designated as chairman-elect, who will succeed to the office of chairman at the end of one year, shall be three (3) years. All other directors shall be elected for a term of two (2) years, provided that nothing herein shall be construed to prevent the election of a director to succeed himself. All terms of office begin January 1 of the year following election.

Section 2. Power to Make By-Laws

The membership shall have power to make or alter any by-law or by-laws including the fixing and altering of the number of directors.

Section 3. Power to Appoint Officers and Agents

a) The board of directors shall have power to appoint officers and agents as the board may deem necessary for transaction of the business of the group. Such appointed officers and agents may be removed by the board of directors whenever, in the judgment of the board, the best interests of the group will be served thereby.

b) The board of directors at its first meeting of the year will appoint a Liaison Officer from the staff of LAMPF with the concurrence of the LAMPF Director. It will be the duty of the Liaison Officer to act as secretary/treasurer of the group.

c) The board of directors shall submit to the LAMPF administration names of members for consideration as members of LAMPF's Program Advisory Committee (PAC) whenever there are positions open because of reason of membership rotation.

Section 4. Power to Fill Vacancies

The board shall have power to fill any vacancy in any office. In the event that a post on the board of directors should be vacated during the board's term in office, the board shall appoint a member of the LAMPF Users Group to fill the unexpired term. If the vacated post should be that of chairman-elect, the name of the person appointed shall appear on the ballot at the next annual election as a candidate for the office of chairman.

Section 5. Delegation of Powers

For any reason deemed sufficient by the board of directors, whether occasioned by absence or otherwise, the board may delegate all or any powers and duties of any officer to any other officer, director, or member, but no officer or director shall execute, acknowledge, or verify any instrument in more than one capacity.

Section 6. Power to Appoint Committees

a) The board of directors shall appoint committees, standing or special, from time to time, from the membership including the board members and confer powers on such committees and revoke such powers and terminate the existence of such committees at pleasure. It may also terminate at will the term of individual members of such committees.

b) The board of directors will appoint each year a nominating committee consisting of five (5) members of the LAMPF Users Group, but not including any members of the board of directors, who are charged with the duty of nominating a slate of candidates for the chairman-elect and the other elective positions on the board of directors. 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 board of directors. 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 board of directors prior to two (2) months in advance of annual meeting.

c) The board of directors will appoint a Technical Advisory Panel (TAP) from the membership. The chairman of the board of directors will act also as chairman of the 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 members of the board of directors and the liaison officer are to be members ex-officio.

Section 7. Power to Require Bonds

The board of directors may require any officer or agent to file with the group a satisfactory bond conditioned for faithful performance of his duties.

Section 8. Compensation

The directors, officers, and committee members shall serve without pay. The compensation of agents, employees or consultants may be fixed by the board.

Article V - OFFICERS

Section 1. Officers

The officers of the group shall consist of a chairman, chairman-elect, and secretary/treasurer.

Section 2. Duties of Officers

a) Chairman--The chairman shall preside at all meetings of the membership of the group and the meetings of the board of directors. He shall enforce due observance of the constitution and by-laws. He shall perform duties as directed by the group or board of directors or as his office may require. He will be an ex-officio member of all committees in which he is not an appointed or elected member. He shall succeed to the position of past-chairman at the end of one year.

b) Chairman-Elect--In the absence of the chairman, the chairman-elect shall perform the duties of chairman. Otherwise he will provide assistance in conducting the affairs of the group as requested by the chairman. He shall succeed to the office of chairman at the end of one year.

c) Secretary/Treasurer--The secretary/treasurer shall keep a complete and accurate record of the proceedings of the meetings of the group and of the meetings of the board of directors. He shall, unless other committees are appointed to fill any of the following functions, maintain a file of correspondence of the group, and keep an accurate record of all members of the group, showing the name and address of each. He will request nominations, send and tally mail ballots, and keep the membership informed by means of newsletters of new developments at the facility. He shall receive all money belonging to the group and shall keep an accurate record of all receipts and expenditures. He shall report verbally the state of the treasury at each meeting of the board of directors, and to the membership at least once a year by a written report. He shall make no payments except as authorized in the budget or in the minutes of meetings of the board of directors. He shall submit his books for verification or audit to a bookkeeper or accountant specified by the board if so requested by the board.

Article VI - EXECUTION OF INSTRUMENTS

Section 1. Checks, etc.

All checks, drafts and orders for payment of money shall be signed in the name of the group and shall be signed by the chairman or secretary/treasurer or such other officers or agents as the board of directors shall from time to time designate for that purpose.

Article VII - MEMBERSHIP

Section 1. Membership

The membership is open to practicing scientists and engineers and organizations of scientists and engineers. The qualifications for membership and their voting or nonvoting status shall be determined by the board of directors with concurrence of the membership. Following the drawing up of an original membership list, new members will be added by action of the board of directors 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.

Article VIII - AMENDMENT OF BY-LAWS

Section 1. Amendments. How Effected.

These by-laws may be amended, altered, added to, or repealed 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.

Certificate

I certify that I am the duly appointed, qualified, and acting secretary of the Los Alamos Meson Physics Facility Users Group, Inc., a nonprofit corporation, and that by a special mail ballot the membership decided by a two-thirds majority of those voting that the above and foregoing by-laws are adopted.

Secretary

☆ U.S. GOVERNMENT PRINTING OFFICE: 1977—777-018/124