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LA-4899-PR

A PROGRESS REPORT

MASTER

Quarterly Status Report on the
Medium-Energy Physics Program
for the Period Ending January 31, 1972

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87544

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This report presents the status of the LASL Medium-Energy Physics program. The four most recent reports in this series, all unclassified, are:

LA-4571-MS
LA-4692-MS

LA-4753-MS
LA-4850-PR

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A Progress Report
UC-28

ISSUED: April 1972

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Medium-Energy Physics Program
for the Period Ending January 31, 1972

Compiled by

Eleanor Dunn

NOTICE

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I. SUMMARY

As of 1 January, MP-Division was reorganized to permit, over the next year, an orderly transition from accelerator design and construction to operations, maintenance and research. The new organizational structure is given below.

Engineering Support

The production and testing of klystrons and modulators continues on schedule. Klystrons and their ancillary equipment have been installed in Cluster Buildings B through F. Klystron lifetime tests have now accumulated 77,700 high-voltage hours.

<u>Group Designation</u>	<u>Supervisory Personnel</u>	<u>General Responsibilities</u>
<u>MP-1</u> (Electronic Instrumentation and Computer Systems)	T. M. Putnam, Group Leader (until 4/1/72) R. A. Gore, Group Leader (effective 4/1/72) H. S. Butler, Alternate Group Leader D. R. Machen, Assistant Group Leader R. F. Thomas, Assistant Group Leader	Electronic instrumentation and computer-based data acquisition systems. Support all groups, including LAMPF users.
<u>MP-2</u> (Accelerator Operations)	D. C. Hagerman, Acting Group Leader R. F. Warner, Alternate Group Leader	Accelerator operations and light maintenance
<u>MP-3</u> (Practical Applications)	E. A. Knapp, Group Leader	Practical applications of LAMPF and LAMPF technologies.
<u>MP-4</u> (Nuclear and Particle Physics)	D. E. Nagle, Group Leader C. R. Emigh, Associate Group Leader	Basic research responsibility for all such research in MP Division and for coordinating the MP program with all other users.
<u>MP-6</u> (Experimental Areas)	D.R.F. Cochran, Group Leader R. J. Macek, Alternate Group Leader M. T. Wilson, Associate Group Leader P. R. Franke, Assistant Group Leader	Maintain and manage experimental area, including remote handling, targets, beam dumps, effluent control, isotope production, and cryogenic operations.
<u>MP-7</u> (Secondary Beam Lines)	L. E. Agnew, Group Leader H. A. Thiessen, Alternate Group Leader	Maintain and improve secondary beam lines
<u>MP-8</u> (Engineering Support)	T. J. Boyd, Group Leader H. G. Worstell, Alternate Group Leader	Electrical and mechanical engineering, (including drafting), metronics laboratory, klystron repair, and improvements to accelerator.
<u>MP-9</u> (Accelerator Systems Development)	R. A. Jameson, Group Leader D. A. Swenson, Associate Group Leader R. R. Stevens, Assistant Group Leader	Development of advanced concepts for improvement of accelerator reliability and capability.

D. Nagle will continue as Alternate MP-Division Leader, in addition to his duties as MP-4 Group Leader.

Associate Division Leader for Operations - D. Hagerman
(Hagerman will have overall responsibility for accelerator operations, maintenance and development activities in Groups MP-1, MP-2, MP-8 and MP-9. He will also be the Chief of Operations with responsibilities outlined in the Guidelines for Users of LAMPF.)

Associate Division Leader for Practical Applications - E. Knapp

Assistant Division Leader for Facility Planning and Budget Control - P. D. Edwards

Assistant Division Leader for Safety - T. Putnam

Furnace brazing of the 805-MHz side-coupled structures is nearing completion and the installation of these structures is proceeding on schedule.

Tank conditioning and high-power testing of the combined 805-MHz rf systems and the installed accelerator sections are proceeding on schedule.

The hardware associated with the transition region has been installed and tested and placed in service.

Engineering support for the experimental area continues to receive substantial emphasis.

Accelerator Systems Development

A reorganization of installation and commissioning procedures for the 805-MHz accelerator systems was made. New tuning procedures were developed and proved satisfactory. A detailed schedule was prepared for all remaining accelerator installation, and all activities were on schedule at the end of this quarter.

Operation was suspended during the month of December for installation and alignment of the transition region. Beam was transmitted through the transition region for the first time on 19 January 1972, with very small loss.

Three 60-h continuous runs were made before shutdown. Beam was available ~ 30% of the time for investigation of the ΔT technique for adjusting module-to-module fields.

Work was initiated on development of control circuits for decoupling phase and amplitude interactions in the 201.25-MHz accelerator.

A major series of experiments was completed during the shutdown to study the properties of the ion beam extracted from the accelerating column. At design conditions, the beam size extrapolated to the last electrode was 1.03-cm radius with 14.6-mrad envelope divergence. Analysis of these experiments continues; the goal is to select a beam for use in the initial 800-MeV tests and to design suitable scrapers to realize this beam.

A technique was developed for rapid enhancement of the injector hydrogen ion pumps using argon. The reduction in conditioning time is very significant.

After a detailed review, the design goal for the initial H^- injector to be used for experiments at LAMPF was fixed at 100-200 μA . Development work was continued of several versions of the ion source.

The Cockcroft-Walton for the H^- injector was put into operation.

Electronic Instrumentation and Computer Systems

The computer control system was made available for accelerator operations on a 24 h/day basis. The continuing program of improvements in the injector and 201-MHz areas and in the Central Control Room will be scheduled at times which do not conflict with operations.

Most of the control equipment and power supplies for the dome of the H^- injector were ordered.

The installation and wiring of control chassis in the transition region was a major activity. Controls for the equipment along the H^+ section were essentially finished while those along the H^- section are 50% complete.

All of the electrical wiring associated with the control system in the 805-MHz area was completed. The quad-magnet power supplies were installed and wired. The receiving inspection of steering-magnet power supplies was concluded. The channels were calibrated.

The criteria for the control systems in the switchyard were established and final designs were completed for most of the systems. Hardware channel assignments were made for all signals going to the computer. The control racks associated with Beam Lines A and X are being wired.

The remainder of the timing distribution and fast-protect chassis for the accelerator were installed and checked. All components for the beam-spill monitor system were received, tested and installed along with the area-monitoring portion of the radiation safety system. Most of the video system beyond the 211-MeV point of the accelerator was installed.

The majority of the equipment for the first two computers in the data-acquisition system was received and put into operation. Some work was done on the software.

The prototype CAMAC branch driver was wired and assembled for checkout. A manual control console for the unit is nearing completion. Performance specifications covering a variety of CAMAC modules were released to industry for quotations. Over \$77,000 worth of equipment was ordered for the electronics pool to support LAMPF users.

Accelerator Operations

A modest number of people now have permanent assignments in the operations group. These people, with substantial assistance from other groups, operate LAMPF eight shifts per week.

The operation of the Electron Prototype Accelerator was terminated the latter part of January.

Experimental Area

The major activities related to experimental area planning have included the gathering and evaluation and incorporation of all user input into the design and function of the many experimental facilities. Both the Isotope Production Facility and the Radiobiology Research Facility have passed through the preliminary design phase. The designs mate with the existing Phase III work which will be completed in April. Planning and construction activities for the switchyard and Area A have covered the process water systems, nuclear chemistry and hot cell services, and surveying and alignment. At present it appears that all schedules will be met provided that the appropriate funding is available.

Minor modifications to the switchyard beam transport have been made to improve its performance. Almost all of the transport magnets are on hand and their stands are being located for final mounting. Plans have been made for all of the switchyard cabling and wiring. The wiring should be started in March when beneficial occupancy is gained in the switchyard equipment aisles.

Considerable progress has been made in the design and fabrication of the hardware for the Nucleon Physics Laboratory (Area B). Magnets, LD_2 targets, instrumentation and the vacuum systems have all received attention. A used crane which can be properly modified will be obtained for installation work in Area B.

A tuning procedure for the High Resolution Proton Spectrometer (Area C) magnet system has been devised. At low intensity and with the judicious use of strippers, a nearly zero emittance beam of high resolution can be obtained for the Line C and spectrometer tune-up. Field studies of the spectrometer prototype magnet have demonstrated the need for field clamp modification but have also demonstrated the satisfactory performance of the HT windings to obtain field homogeneity.

A report is being prepared of the final optical design of the first Energetic Pion Channel Spectrometer (EPICS). A satisfactory procurement schedule is being maintained for both channel and spectrometer components. The efforts to optimize the EPICS detector system have resulted in some success in the development of helical multiwire proportional chambers. Additional improvement in the associated electronics is required. Design work on the EPICS separator is continuing and some components have been procured.

The first and fourth bending magnets for the Low Energy Pion Channel (LEP) had to be rebid, which will perturb the LEP schedules. Otherwise, satisfactory progress is being made on the beam-line magnets and other hardware.

Since the P^3 -High Energy Pion Channel magnets and the related beam-line hardware have reached an advanced state of design and procurement, some attention has been shifted to the tune-up procedures for the channel. A scheme to use Rice University multiwire proportional chambers and a PDP-11 computer to follow particles through the channel at low intensity is being devised. A Monte Carlo code to simulate the tune-up procedure is being debugged at the present time.

Only the four septum magnets remain to be ordered for the Stopped Muon Channel. Other design fabrication and procurement efforts are proceeding smoothly and no difficulties are foreseen.

Magnetic field measurements have been completed on 34 magnets for the injector area and 13 magnets for the switchyard and secondary beam lines. Field measurements are continuing on the switchyard bending magnets. With the appropriate shimming and chamfering, the Line X and Line A-to-beam stop bending magnets and quadrupoles have all demonstrated the required field characteristics. Installation of the magnets must begin by the first of March.

Target testing at the Electron Prototype Accelerator (EPA) has terminated after a successful demonstration of the performance of the wheel-type targets. Plans are under way to initiate a program of target testing using 100-MeV protons at the LAMPF transition region. Target insertion and extraction mechanisms for use in Area A are being designed according to specifications provided by the secondary-beam-line designers.

Four stripper stations have been planned for the proper tailoring of the H^- beam. The actuating mechanisms for the strippers are being designed and the availability of the stripper materials is being investigated.

The design and development of switchyard and experimental area beam-diagnostic instrumentation is nearing completion and many components are being procured. Work is being continued on the problems of data-taking and computer control.

Items of test equipment and fast electronics are being ordered for the equipment pool. Efforts are being made to borrow some of the magnets needed for approved LAMPF experiments.

In the realm of miscellaneous activities, the following work has been performed:

1. Positive results have been obtained in a study to get selected beam micropulses by electrostatic deflection in the C-W injector area.
2. A high-impedance amplifier for wire proportional chambers and an ADC with a logarithmic energy scale have been developed.
3. Production problems for 3/4-in. m.i. cable appear to have been resolved.
4. Efforts to develop formulations of epoxy resin systems for magnet insulation that will withstand $> 10^{10}$ rad have been successfully concluded.
5. Computer codes for experiment simulation and minimization have been developed.

The hot-cell service area and Merrimac system are rapidly nearing completion. Testing and preliminary use of the system can be expected by next quarter. A target-cell door test is being prepared to verify the expected performance of the moving mechanism and to help finalize the plans for shielding stacking.

Extensive use has been made of the ORNL-NMTC code to analyze shielding and background problems for the experimental area and its various beam lines. Results of these calculations are available on request.

LAMPF Facility Construction

As craft installation and building construction progressed to the final stages this period, the previously reported projections were verified. Time lost, as a consequence of the strikes which were not directed at LAMPF but were nevertheless honored by

all crafts, will not be recovered. Site and building construction completion is now projected to occur about two months past the scheduled dates.

Physics Research

Proton Compton-Effect Experiment

The experiment to measure the low-energy proton Compton-effect cross section using the EPA has been completed. The data are being reduced and a paper on the results is being prepared for publication.

Pion-Production Experiment

The analysis of all the cross sections has been completed. A full paper on the results is being written and will be submitted to The Physical Review for publication.

Pion-Absorption Experiment

Analysis of the data on the (π^+, p) and $(\pi^+, 2p)$ experiments continues at LASL and at the Univ. of Virginia. An algorithm to remove the efficiency and acceptance variations from the data has been devised and is being coded. This code will correct the data so that they may be compared directly with various theoretical models.

Scattering of 20-50 MeV Pions by Hydrogen and Deuterium

A proposal to measure π^+ and π^- elastic scattering on hydrogen at a range of energies between 20 and 50 MeV has been approved and 150 hours of beam time have been allotted. This experiment will be performed using the LAMPF low-energy pion channel, a hydrogen-deuterium target, and proportional wire chamber detectors. A large-area dE/dx and E system is being designed to separate pions from muons. A wire-winding machine for fabrication of the chambers is being built. A prototype of the readout electronics unit for a 8000-wire system has been built and evaluated. This evaluation will be used to determine the least expensive way to build 40 units, which will be directly interfaced to the PDP-11 computer and alternatively to the Supernova computer.

Helical Multiwire Proportional Counter Development

Development of helical multiwire proportional chambers for use on EPICS detectors continued with studies of the properties of the helical delay line; an amplifier has been built and is in use for chamber tests; and a design is in process for the readout

electronics for a multichamber system using helical chambers. Studies of special requirements of the EPICS system indicate that the electronics is incompatible with the electronics for a conventional amplifier-per-wire system and that a completely new design is required.

Theoretical Physics

Theoretical physics investigations for the past quarter have included the following:

1. Studies of the possibilities of extracting nuclear structure from pion-scattering and exotic (π^- , K^- , ...) are under way. These studies are based on the optical model in which the particle-nucleus interaction is described by an effective single-particle potential.
2. The determination of neutron distribution parameters for π^+ differential cross sections has been studied.
3. An improved optical model code, which will be useful in analyzing LAMPF pion-scattering experiments, is being prepared.
4. An efficient recursion method has been developed for evaluating multiple-scattering series without making small-angle (Glauber) approximations. It is being applied to recent CERN π -He and π -C data.
5. A study of alternatives to the usual Kisslinger optical model for pions is being made. A tentative conclusion is that the ambiguities in the optical model will not be a serious obstacle to interpretation of pion scattering.
6. The position and width of the resonance in π -nucleus scattering have been studied. Optical models and other methods have been used. This work is being continued.
7. Recent K-mesic atom data have been analyzed. The effective optical potential, V , which was obtained differs greatly from that predicted for free K-nucleon scattering, making the interpretation of nuclear contributions difficult. Also, because the imaginary part of V is very large, there are broad "inner states" trapped in the nucleus. A paper on "inner states" has been accepted for publication.
8. The mathematics of perturbation theory for optical potentials has been studied. A paper giving the general formulation and its application to exotic atoms has just been completed.

Practical Applications of LAMPF

The work presented here is being performed under auspices of the USAEC Division of Research, USAEC Division of Biology and Medicine and the National Cancer Institute.

Biomedical Program

Biomedical Pion Channel Design: Studies have shown that in order to simplify the problems involved in shaping the beam at the end of the channel, the last two bending magnets, that were part of the previously reported configuration, must be replaced by a single magnet which bends the beam to the vertical direction. Work has proceeded to shape the beam assuming this bending-magnet arrangement. Solutions to the beam-shaping problem were found by using five quadrupole magnets similar to the ones used in the pion-decay section of the stopped muon channel. Engineering of the magnets is being done.

Shielding: Detailed studies of the shielding requirements for the Biomedical Facility have been carried out in order to more clearly define the design criteria for the shielding support structure. Although no attempt has been made to obtain an energy distribution for the neutrons emerging from the end of the biomedical channel, estimates of the neutron flux streaming through the channel have so far shown that the anticipated dose to the patient is tolerable.

Depth-Dose-Distribution Calculations: A program is near completion for calculating pion depth-dose distributions. This program uses as input the results of ORNL calculations of dose distributions for monoenergetic pion beams. The program will enable one to weight the number of pions of different ranges and to assign an arbitrary RBE to various parts of the depth-dose distribution for each monoenergetic beam component.

Treatment Planning: A preliminary investigation of the problems associated with treatment planning in the π^- meson beam facility has been undertaken. During this quarter a survey of the approaches to treatment planning used in conventional radiation therapy facilities has been done, and an outline of the input and output information desired from the program has been generated. Treatment planning programs for use on the π^- channel PDP-11 computer are under study.

Biomedical Channel Computer Control: An order has been placed for the control computer for the Biomedical Facility. A preliminary layout of the biomedical control room has been made and the racks and control console will be ordered shortly. In-house construction of some console equipment will be started in the next quarter.

Survey of Other Radiation Sources at LASL: The availability of neutron sources at LASL which could be used for whole-animal radiobiology studies was investigated. No ideal sources are available but work could be done with neutrons from deuterons on beryllium at the P-Division cyclotron or with 14-MeV neutrons from deuterons on a tritiated target at the N-Division Cockcroft-Walton. In the first case the mean energy is low (~ 6 MeV), and in the second case the dose rate is marginal.

Instrumentation for Biomedical Channel: Basic design on the electrometer and charge-accumulation portion of the biomedical channel dosimetry electronics is 50% complete. Work has begun on a prototype NIM chassis to house the linear portion of this subsystem. Preset counters from four different manufacturers are being evaluated for reliability, noise susceptibility, and possible interface difficulties.

A vibrating reed electrometer was ordered to allow the testing of small ionization chambers with isotope sources. Work will be started toward setting up a good ^{60}Co "baseline" reference calibration traceable to the NBS for the ion chambers which will be used for the initial pion beam calibrations.

Procurement of electronics for multiwire proportional counters for channel turn-on and optimization has been started.

Medical Instrumentation in Cooperation with UNM School of Medicine: Efforts to identify areas of possible cooperation between LAMPF and the UNM Medical School are progressing. Information is being sought regarding some of the following specific areas of possible collaboration which have emerged from discussions between LASL and UNM representatives:

1. Design and construction of a pulsed hydraulic pressure chamber intended to reduce the cardiac workload. The pulsing would be synchronized with, and relayed from the ECG potential.

2. Electroanesthesia (EA). This is a technique where electric currents are conducted through the brain by way of electrodes on the skull. The use of EA is considered to be much safer than conventional chemical anesthetics and the recovery from EA is very rapid. LASL may become involved in the design of safe and reliable electroanesthesia generators, and the UNM Medical School and Bernalillo County Medical Center have indicated an interest in the possibility of conducting large-scale clinical tests of EA.

Radioisotope Production: The steering committee for the LASL isotopes program has compiled a list of a few dozen isotopes that can be produced at LAMPF. This compilation was motivated, in part, by a request from AEC Headquarters for a complete cost analysis for a dozen selected isotopes. This cost analysis was made on the assumptions that the total facility would be used for the production of each isotope separately and that only a single product would be extracted from each target. Some of the isotopes included in this analysis are: ^{123}I , ^{32}Si , ^{88}Y , ^{82}Sr , ^{26}Al , ^{68}Ge .

Meson Chemistry: Theoretical studies are under way regarding the muonic cascade process in more complicated molecular systems, as well as of possibly interesting effects to be found using muons in solid-state studies.

In Vivo Tissue Analysis with Muonic X Rays: A proposal to measure the mu-mesic X-ray spectra arising as a result of the capture of stopped negative muons in mammalian tissue has been approved for 100 hours of beam time on LAMPF. Various members of the medical community are being contacted to determine if they are interested in collaborating on this experiment.

Miscellaneous Support Activities: A wire chamber electronics system, in support of the pion-scattering experiment which will be conducted at LAMPF, is being designed and fabricated (see Sec. VIII, Physics Research).

LAMPF Users Group

The Fifth LAMPF Users Meeting was held at Los Alamos on 8-9 November 1971. Some 238 members attended the meeting out of a total Users Group membership of 759. The proceedings of the meeting are in

the final stages of preparation and will be distributed to all members soon.

The Executive Committee is considering the establishment of the Users Group as a non-profit corporation. The matter will be placed before the full membership when the details are worked out and draft papers of incorporation are ready. The Executive Committee also made recommendations to the LAMPF administration concerning the Scheduling Committee, suggesting that the advice of the Program Advisory Committee be sought with respect to the assignment of scientific priority among the approved experiments.

The Technical Advisory Panel took action on a number of topics: (1) to set up a subcommittee on cryogenic targets, (2) to continue committee work on policy recommendations for the equipment pool, (3) to recommend the purchase of two data-acquisition computers this fiscal year, (4) to study further the computer and electronic needs as a whole, (5) to recommend that a crane be installed in Area B, and (6) to recommend that provisions be made for a test channel.

Seven new research proposals have been received since the previous quarterly report, bringing the total to 113.

Publications

"Proceedings of the LAMPF Summer Study Session," Los Alamos Scientific Laboratory report, LA-4824-MS (November 1971).

"LAMPF Neutrino Facility Proposal," Los Alamos Scientific Laboratory report, LA-4842-MS (December 1971).

J. A. Sullivan and C. R. King, "Measurements of Convective Heat Transfer Coefficients for the Subsonic Flow of Hydrogen and Helium on Smooth Tubes at Moderate Surface and Fluid Temperatures," Los Alamos Scientific Laboratory report, LA-4882 (January 1972).

B. Zeidman, "The HRS Spectrometer System 1. Concept and Design," Los Alamos Scientific Laboratory report LA-4773-MS, Part I (October 1971).

H. A. O'Brien, Jr., and M. E. Schillaci, "Isotopic Neutron Sources from the Los Alamos Meson Physics Facility (LAMPF)," Isotop. Radiat. Technol. 9, 105 (1971).

Papers Prepared for Publication; Papers Submitted at Conferences

R. J. Macek, "Recent Experimental Results for (π^+ ,2p) and (π^+ ,p) Reactions on Light Nuclei," (invited paper, San Francisco Meeting of the Amer. Phys. Soc. 31 Jan.-3 Feb. 1972).

M. M. Sternheim, "Test of Quantum Electrodynamics," (submitted to Am. J. Phys. as a Resource Letter) (November 1971).

II. ENGINEERING SUPPORT

LAMPF Accelerator Structures

201-MHz System

The 201-MHz rf systems were operated for 960 h during this report period, primarily in support of beam diagnostic experiments. The prototype oil transformers for the modulators operated satisfactorily and construction of the remaining oil transformers is well under way.

Development work on the RCA-4664 amplifier tube has continued; it was found that a fifth harmonic mode is being excited at a power output of 400 kW. Efforts are under way to modify the final version of the cavity to suppress this higher-order mode.

The 7835 amplifier filament connector for module 3 again developed trouble. This amplifier was assembled using a small spring contact modification, which is now believed to cause the failure by providing insufficient contact. This amplifier was re-assembled using the larger Continental Electronics spring contact and has operated satisfactorily since the change. Module 4 has operated satisfactorily for 450 h of filament time using the larger contact spring without trouble.

Studies are under way in an effort to determine the cause of the apparent low output power of module 3 amplifier and the IPA instabilities. Tuner repositioning and line-length changes on the 7835 were made without conclusive results. This investigation will continue as time permits.

A prototype drive-loop design, utilizing a Rexolite window, was installed in Tank 2 and has been operated for ~ 90 h. One failure occurred which was attributed to excessive vacuum grease on the O-ring seals. Some of the drive-loop and Rexolite-holder components have been received from which permanent drive-loop and window assemblies will be made for Tanks 2, 3 and 4. The ceramic disc for Tank 1 rf window is on order and drawings of ceramic discs for Tanks 2, 3 and 4 have been sent out for quotation. These ceramic discs are intended to replace the Rexolite windows by modifying the holders only. Four titanium-coated drive-loop ceramic domes were received and two were installed in Tanks 3 and 4.

Transition Region (201 and 805)

The Transition Region magnets, beam tubes, bucket rotator and other devices were installed, aligned and evacuated during this reporting period. The magnets were powered to design-current levels and polarities were verified. Table I shows the status of all Transition Region magnets.

Spare magnet and beam-transport devices for this region of the accelerator are either on hand or are being fabricated. Many of these devices require long lead time for procurement and some are available only by means of in-house fabrication.

The twelve power supplies for Transition Region magnets and one spare have been received and all but two are installed.

The bucket-rotator rf system has been operated successfully at full power into a dummy load.

Figure 1 is a photograph of the Transition Region.

805-MHz System

Furnace brazing of 805-MHz structures is nearing completion. Defective copper coupling-cavity clamshells are still being encountered which require additional heats to make repairs. The last 750 clamshells to be processed were forged from LASL-supplied billets, all of which were of excellent quality.

TABLE I
TRANSITION REGION MAGNET STATUS

Magnet	Status
TR-BM-01	In service
TR-BM-02	In service
TR-BM-03	In service
TR-BM-04	In service
TR-BM-05	Completed, tested and in place
TR-BM-06	Completed, tested at low current and in place
TR-BM-07	Completed, tested at low current and in place
TR-BM-08	Ready for final assembly
TR-QD-01	In service
TR-QD-02	In service
TR-QD-03	In service
TR-QD-04	In service
TR-QD-05	Completed, tested and in place
TR-QD-06	Completed, tested and in place

Fig. 1. LAMPF Transition Region

Six hundred and twenty of these forgings were made by cross-grain forging 8-in.-diam billets, which LASL procured some four years ago for stockpiling. The remaining 150 were single-pass forgings made from 5.7-in.-diam billets that were vacuum-melted and vacuum-cast OFHC copper scrap.

Table II shows the complete status of the furnace-brazing operation.

Installation and alignment of LAMPF accelerator structures has continued and is being completed at the rate of approximately one module per week. This activity is now complete through module 40; cooling

TABLE II
Status of the Furnace-Brazing Operation

		<u>Req'd.</u> <u>Completed</u>				<u>Req'd.</u> <u>Completed</u>
Coupling Cavities	4856	4856 (100%)		Bridge Tank Cylinder Head	120	100%
Segment Assemblies	4856	4800 (99%)		Bridge Tank Cylinder to Head	60	100%
Short Stack	144	142 (98%)		Bridge Tank Cylinder to Waveguide Flange and Cooling Tubes	60	100%
				Bridge Tank Segment Head to Cooling Tube	120	100%
Monitor Pad to Short Stack	144	140 (97%)		Bridge Tank Coupler Assembly	60	100%
Tank Section	352	329 (94%)		Pre-Machine Braze of Heads and RF Segments	824	100%

systems are complete through module 36; vacuum manifold welding is complete through module 28; and the quadrupole doublets have been installed and aligned for modules 5-14 and 18-20.

Several of the 805-MHz beam-line quadrupole doublets exhibited overheating tendencies after installation when powered for extended periods of time. The indirect-cooling method used on these magnets, as opposed to the hollow-conductor method, requires considerable time under power to reach thermal equilibrium. The cooling circuits on these marginal magnets were modified and a program has been started to test the remaining quadrupole-doublet magnets for water flow, pressure drop, design current, design voltage, high-pot and pole-tip flux density.

All of the 805-MHz klystron water cabinets have been installed and the control instrumentation has been checked through Sector G. Klystron installation is complete through Sector F and the first unit of Sector G.

Thirty-four Varian klystrons (VA862-A) of the 45 on order have been delivered and 32 have passed acceptance tests. Five of the 25 klystrons ordered from Litton Industries passed acceptance tests at their facility and were shipped to LASL. Three of these were accepted at LASL, one was rejected, and the other is still in transit. The rf window-heating problem, reported previously, has apparently been solved. However, there remains a problem with multipactoring in the output cavity and waveguide. The multipactor causes an abrupt change in output power by as much as 10 kW with a very small change in drive power. This multipactoring in the output cavity is also very sensitive to changes in focus magnet current.

One of the Litton klystrons (SN2012) was installed in module 14 to power the accelerator tanks. With the focus current set at the high end of its range, the multipactoring could be seen on the tank fields when an external demand signal was used. The behavior of this klystron when driving the resonant tanks appeared to be essentially the same as when operated at the 1.5:1 mismatch phase for acceptance tests. The amplitude controller error signal provides a very sensitive means of multipactor detection. The multipactor test equipment in the Equipment Test Laboratory (ETL) is being modified to

produce an error signal to further study this phenomenon. In the meantime, very close engineering liaison is being maintained with Litton Industries.

The 1.25-MW klystrons have been operated for more than 102,000 filament hours and 77,700 plate hours with three failures; the average time-to-failure was 4,518 h. Two Litton klystrons and three Varian klystrons are still in service after more than 6,000-h running time on the filaments. The LPT44 switching tubes have accumulated some 82,000 h of operation time with five failures; the average time-to-failure was 2,200 h.

The klystron rebuilding facility is beginning to take form. A bake-out oven has been received and the heating elements and vacuum systems are being installed. Welding and holding jigs have been designed and are being fabricated.

Three of the titanium-coated G.E. rf windows failed during this reporting period, while none of the Varian coated windows failed. Coating the windows is not the solution to window-failure problems. Plans are to use only coated Varian windows for the accelerator and keep the G.E. windows for emergency back-up.

The basic frequency and phase reference provided by a crystal oscillator multiplier is in final form with metering to show power levels from both sources and for both 805-MHz and 201-MHz systems. The drive-line amplifiers are complete and have been excited continuously for several hundred hours without appreciable trouble. A sufficient quantity of interface amplifiers is on hand to satisfy requirements through Sector F. An improved version of interface amplifiers will soon be ready for the 201-MHz system which has an output of 90W as compared to the 50-W-output version now in use.

Computer checkout of the rf source phase and amplitude control system is ~ 95% complete. The rf reference line installation is complete through Sector F (module 36) and has been checked for air integrity and correct wiring. The temperature-control system for this line is operational and modules 25-36 are currently being tested for thermal stability, the design limit of which is not more than 1°F temperature change per week.

Experimental Area

All switchyard magnet supports have been received and are being prepared for installation in the switchyard beam lines.

Orders have been placed and fabrication started for the Line C twister magnet support and the 1- and 4-deg bending-magnet supports for Lines B and C. Design and drafting are continuing for the balance of Lines B and C magnet supports.

An assembly drawing of the complete Low Energy Pion (LEP) line support system has been started. A prototype LEP magnet support was checked for repositioning accuracy with a 14,000 lb dummy weight. After several cycles of loading and unloading the support with this weight, it was determined that re-alignment could be held within 0.005 to 0.010 in.

A precision survey of the Experimental Area floor is under way which will permit a final layout of the beam lines.

A steel building to house the magnet alignment tooling dock is ready for delivery and the equipment to be used in this building is on order or being fabricated. The tooling dock will be used to make mechanical measurements and set alignment fixtures for the Experimental Area magnets.

Purchase orders for ion pumps, rough vacuum pumps, bellows, beam-line fittings and beam-line tubing have been placed. Quotations for radiation-hard all-metal vacuum valves and vacuum-roughing-line valves have been received and are being evaluated. Engineering information pertaining to commercial-type fast-acting vacuum valves has been received from several manufacturers and is being examined to determine whether or not LAMPF requirements can be met. Drawings of the standard beam-line high-vacuum flanges are complete and will soon be sent out for quotation.

Bursting tests of thin metal windows have been stopped temporarily for test gauge calibration. Preliminary tests indicate that if one window of a widely spaced two-window system should rupture, the resulting shock wave is not of sufficient intensity to cause failure of the second window.

Preliminary vacuum system design calculations have been made for most secondary beam-line apparatus and some systems are approaching the final design stage. An effort is being made to design all Experimental Area vacuum systems using the same

design philosophy wherever possible. This should minimize operational problems at a later date and simplify the stocking of spare components.

The regulators for magnet power supplies have been designed and prototype subcomponents have been tested at low power using an SCR power supply. The responses to open- and closed-voltage and current loops were measured and are in good agreement with the calculated values. Present effort is being directed to the testing of a complete prototype regulator using a final power supply and actual mineral-insulated magnet load. Work is also under way to complete six regulators to be used on Lines A and X magnet power supplies.

Two 60-kW, 300-A bending-magnet power supplies for Lines A and X were received and tested. Several problems were encountered, the most serious of which was a required warm-up time of four hours, rather than the specified one-hour time limit; the vendor has been apprised of this discrepancy and is making the necessary correction. Ten of the 16 H-tangent wound power supplies have been accepted and the other six were returned to the seller for rework. Acceptance testing of six of the 56 brute-type power supplies is under way. Quotations were received for 500-A and 2,000-A mechanical-type reversing switches and are being evaluated.

A preliminary layout of Lines B and C magnet power supply cooling systems has been made and final installation drawings are in the process of being finalized.

Beam-line layouts and first-order magnet designs of several proposed Biomedical beam-line systems were made. Magnet-winding conductor material and some insulators were ordered in an effort to expedite procurement of the magnets once the design is frozen.

III. ACCELERATOR SYSTEMS DEVELOPMENT

805-MHz Accelerator System Installation

Organization and Status

The installation and commissioning procedures for the 805-MHz accelerator systems were reorganized early in the quarter to reflect new techniques for structure tuning and to set up for the final push toward an 800-MeV beam. Parts of the structure manufacturing process were selectively halted while a complete review of tuning procedures was completed. A new set of procedures was devised for cell tuning, and the fabrication of new tooling was initiated. The new techniques were aimed primarily toward tuning in the tunnel, since it was decided that modules 13-26 should be retuned immediately and that modules 5-12 may have to be retuned. Factory operations were thus quickly resumed with little change except to tighten certain tolerances. Manpower was added to the tuning crews and a schedule worked out to achieve the retuning and tuning of new modules. Detailed schedules for all other aspects of remaining accelerator construction and commissioning were then determined. The result showed that with a great deal of work and without more major hitches, the accelerator will be ready on schedule. By the end of December, the new tuning techniques had been demonstrated successfully. At the end of January, the overall installation activity was on schedule, and the structure tuning was ahead of schedule.

805-MHz Accelerator Structure Tuning

As was described in the previous Quarterly Status Report, tuning by septum bending was introducing tilts in the field distributions for some tanks. In addition, certain tanks were uniformly low or high in frequency before tuning. When the septums were bent to tune these tanks, a U-shaped or an inverted U-shaped field distribution resulted. Septum bending affects the field distribution by causing a change in the nearest-neighbor coupling between resonators.

It was decided to limit the allowable peak-to-peak deviation of the field distribution (field scatter) within each tank to 10% or less. In order to do this, it was necessary to develop new methods of adjusting cell frequencies either up or down and also to adjust the nearest-neighbor coupling.

The frequency is raised with a shaped cold chisel applied around the brazed joint of a cell. This technique, called dinging, is quite precise but is limited to ~ 500 kHz. Cells with knife edges cannot be raised in frequency by this method. In this case the tuning error is transferred to adjacent cells with the septum bender and these cells are then dinged if necessary. Another method for raising cell frequency was developed using a cutter inserted along the axis which can machine off the end of the drift-tube nose. This method will be used only if the cell is excessively low in frequency.

Frequency lowering is achieved through the use of a new tool called a "nose-stretcher" which is inserted on the axis and makes a groove in the drift tube a centimeter or so back from the nose. The cutter wheel is shaped so the effect of the groove is to push the nose out slightly, thus shortening the cell gap and lowering the cell frequency. Development of the tool details for proper effect and tracking required considerable effort. The result is very effective, affording corrections of up to 500 kHz per application. The tool strongly perturbs the cell being tuned and thus requires an iterative technique, but tuning can still be accomplished quite rapidly.

Methods for adjusting the nearest-neighbor coupling were investigated; the best seem to be grinding in the slot corners, or using the septum-bending technique. Either method introduces frequency errors which are corrected as outlined above. The septum-bending technique is preferred since tuning progress can be monitored with the septum-bending tools.

The new procedure begins by the derivation of a strategy based on cell-frequency measurements. Cells are raised or lowered in frequency using dinging or nose-stretching respectively. The septum-bending tool is only used to distribute occasional large-frequency errors so the other tools may be used. A bead-pull is then made, and in most cases the field scatter has been within the 10% peak-to-peak tolerance after perhaps one partial iteration. Some tanks have been found to have coupling constant errors which lead to excessive field tilt even when the cell frequencies are right -- in this case, the septums are moved to correct the coupling errors.

Modules 18-26 have been successfully retuned using this combination of techniques.

Some new features have been added to the code for computerized beadpull measurements, which are a part of the final tuning procedure. The code now provides for the calculation of the field scatter (i.e., the maximum deviation, peak-to-peak, normalized to the tank average), the rms deviation of cell fields with respect to the tank average, and the tilt (slope of a linear fit to the normalized cell data) for each tank.

Transition Region

The activities of this quarter were strongly punctuated by a scheduled shutdown of the linac during the month of December for the installation and alignment of the transition region. The work on this complex undertaking proceeded on schedule.

On 19 January 1972, beam was run through the transition region for the first time. Three milliamperes of peak current was transmitted from modules 2-12 with no measurable loss. The uncertainty on that measurement is 5% due to limitation of the current monitor system at the 3-mA level. On the following day, 11 mA was observed at both modules 2 and 12. Figure 2 shows the current at each module as plotted by the program BEAMPLOT. Each trace is taken on a single beam pulse.

Accelerator Systems Performance and Development

Extended Runs

In November, emphasis was placed on running the accelerator as efficiently as possible in order to make progress in the ΔT turn-on process before the December shutdown. This period included the first three in a series of extended 60-h accelerator runs. The purpose of the extended runs was two-fold. First, it was hoped to increase the hours of useful experimental time by reducing the number of turn-on and tune-up activities. Second, the extended run constitutes a better test of the overall reliability of the accelerator. Thus, during these runs, it was attempted to operate all accelerator systems whenever possible on a continual basis.

The results of the 60-h runs were an improvement over previous experience. Beam was available for ΔT work ~ 30% of the time, and more was accomplished in the extended runs than for the same number of total hours of day-to-day operation.

Fig. 2. Beam current profile through module 12 with transition region installed.

RF Field Control

The final design of the phase and amplitude controllers has been completed for the 805-MHz system and fabrication is under way.

A circuit was developed to decouple phase and amplitude in the accelerator tanks. The improvement on the 805-MHz system was negligible, as expected, since time delays dominate the loop performance and the cross-coupling gains are small. However, the improvement in control performance on the 201 system appears significant. Cross-coupling in the 201-MHz system is much more pronounced because of the high Q and therefore narrow bandwidth of this system. The new decoupling system shows promise of reducing this problem to a minor one and allows more optimum gain settings of the phase and amplitude controllers. Further study is planned.

Evaluation of the new optimal turn-on control systems reported in the last quarterly report was made as to long-term drift and temperature stability. The controllers have low temperature sensitivity of an acceptable level. The long-term drift was ~ 1/2% over a 14-h period. Although this is not a large amount, attempts will be made to improve stability.

805-MHz Accelerator Module-to-Module Field Adjustment

The ΔT work of the quarter represents the first opportunity for the development of this complex, but essential, procedure for module-to-module field adjustment. Much of the beam time available was used in debugging the hardware and software involved. The object of the ΔT turn-on procedure is to determine the proper amplitude and phase set points for

the rf in modules 5-12, using measurements of differences in beam time-of-flight as a guide. The results to date are not definitive. The measuring device sensitivities were too high for these preliminary tests, so that much of the data were off-scale, probably as a result of the beam energy being 0.1 MeV or more away from design values. The range of the measuring devices has been quadrupled for future measurements.

Developments in Use of Central Computer Control

Several computer programs have been written for accelerator turn-on and tune-up. A code was written to store linac parameters such as magnet currents and tank phase and amplitude set points on the disk for reference. During turn-on, these parameters may be set up automatically via the computer. At any time parameters may be checked against the reference list, and the operator alerted to discrepancies.

Steering plays an important role in linac tune-up, and it is desirable to have full beam transmission over a reasonably wide range of steering magnet currents. A computer code is now used to check the steering flatness of the steering magnets.

As new sections of the linac are turned on or as better operating points are determined, an admittance measurement constitutes a fundamental check on the transverse properties of the system. A computer code has been written to make this measurement using a pin-hole beam and two steering magnets.

Diagnostic Equipment Development

The design of equipment specifically suited for use in diagnosing problems in systems containing stepping motors was initiated during this period. The design of the device simulation box is complete and a prototype has been built. The design of the current source box (which will be used in the check-out of wire scanners, etc.) is 80% complete. The design of the portable stepping motor driver box is 20% complete.

A sample-and-hold unit was designed for obtaining correlated pulse data from more than one channel at a time in an accelerator module. This unit (four-width NIM) contains provisions for two sample-and-hold channels. The sweep generator board allows adjustment of the "hold" time with respect to t_0 . The sampling gate adapter board provides for control of the sample-and-hold channels by the LAMPF sampling

gate signal. The module contains all required dc power supplies and is very easy to install and use. Two modules have been fabricated and are in use at this time.

Injector Column Exit Measurements

The opportunity was taken during the December shutdown to make a series of measurements on the properties of the beam at the exit of the accelerating column. The results are outlined in detail in the following sections covering the injector programs.

Injector Programs

The High Intensity Injector Program

Accelerating Column Beam Tests

An extensive series of experiments was carried out this quarter to study the properties of the ion beam extracted from the accelerating column.

A pepper-pot emittance measuring device was designed, fabricated and installed at the exit of the accelerating column in order to make emittance measurements on the ion beam extracted from the 750-kV accelerating tube. A photograph of this device is shown in Fig. 3, and a cross section showing the assembled configuration is shown in Fig. 4.

Fig. 3. Pepper-pot emittance measuring device used in the accelerating column beam tests.

Fig. 4. Layout of the components employed in the accelerating column beam tests.

A total of 104 high-quality emittance photographs was taken of the extracted ion beam in an extensive parametric study involving beam current, arc magnet current, chamber pressure, extractor voltage and electron trap configuration. A typical emittance pattern is presented in Fig. 5. (The bright center dot is the result of an extra 0.005-in.-diam hole which was drilled into the plate to mark the center and the orientation of the pepper-pot plate.) Precise data processing¹ of all these photographs has been carried out, and the results are now being analyzed.

A graph showing beam divergence vs beam size for all the beams studied is shown in Fig. 6. At the Pierce design current (45 mA for the 70% proton fraction obtained) and with normal ion source design conditions (point number 26 on Fig. 6), the observed beam size was 1.21 cm radius with a beam envelope divergence of 15.1 mrad. Figure 7 shows the transverse phase space of the core and halo for this beam measured at the pepper pot. The envelope of the beam core is defined by the extremities of the central part of the phase space pattern, while the halo or tails are defined by distinct patterns of a different slope from that of the core. Upon extrapolating this result back 5 in. to the last electrode

Fig. 5. Pepper-pot emittance pattern for a 48-mA beam with 1.5-A arc current. Two sets of beam dots are present; the H^+ dots are to the right of the H_2^+ dots. This displacement was caused by secondary electron suppression magnets which were removed before the main series of photographs was taken.

Fig. 6. Plot of beam divergence vs beam size for all beams studied in the accelerating column beam tests.

¹Robert A. Jameson and Rene S. Mills, "Two-Dimensional Search and Interpolation on a Distorted Rectangular Grid - Program SI4G2D," LAMS Report to be published.

Fig. 7. Transverse phase space of core and halo fo beam obtained at design setting of all parameters at the pepper-pot location.

of the accelerating tube and assuming a space charge loading of 50 mA, a beam size of 1.03-cm radius with 14.6-mrad envelope divergence is found. The intensity profile across the extracted beam was also measured. A pepper pot with a single line of apertures was installed and a TV vidicon intensity scanner was used to measure the intensity profile of the resulting pepper-pot pattern. A typical intensity profile is shown in Fig. 8 for a 40-mA beam.

Still another series of experiments was carried out using a quartz plate viewing screen to observe beam cross sections 16 in. beyond the last electrode of the accelerating tube. At the Pierce design current (45 mA), the observed beam size at the viewing screen was 3.5-cm diam. Using the previously determined value of 1.03-cm radius and 14.6-mrad envelope divergence at the column exit, and again assuming 50-mA space-charge loading, the calculated diameter of the beam at the quartz plate for this beam current is 3.52 cm. Thus, this calculated result agrees with the observed size. This observation provides a direct measurement of the beam size entering the first lens of the transport system if the space-charge neutralization of the beam is the same. If there is appreciable neutralization when the transport system is present, the beam entering the first lens will be smaller.

Fig. 8. Intensity profile for a diametral set of pepper-pot holes for a 40-mA beam with 1.75-A arc magnet current.

Column Operation - Off-Design Currents

Quite often, the current extracted from the accelerating column is different from the design current. It has been the practice to set the extractor voltage at its design value for all extracted currents. Thus, at high currents the plasma surface was convex and the beam was scraped by the electrodes, giving rise to a large radiation. At low currents, the plasma surface was concave and the beam was focused to a waist then expanded and again was scraped by the electrodes. To minimize aberrations, all currents should be extracted from a flat plasma surface as a cylindrical beam. To do this properly for off-design currents, the extractor voltage must be programmed by the current according to the Child-Langmuir Law:

$$V = 6.959 \times 10^4 \left(\frac{I_p}{4\pi R_x^2} \right)^{2/3} z^{4/3}, \text{ volts}$$

where I_p is the equivalent proton current in amperes and is given by

$$I_p = I_\alpha = I \left[\frac{H_1^+}{\sum_{i=1}^n H_i^+} + \frac{H_2^+}{\sum_{i=1}^n H_i^+} \sqrt{2} + \frac{H_3^+}{\sum_{i=1}^n H_i^+} \sqrt{3} \right].$$

I is the actual measured current and the fractions in the brackets are the indicated species ratios.

Figure 9 shows the radiation at the door of the Cockcroft-Walton Faraday cage as a function of the extracted beam current for a programmed extractor voltage. Figure 10 is the same except the extractor voltage is held constant at its design value. Note that by programming the extractor, the radiation level has been almost eliminated at the lower currents and the onset of radiation has been extended to higher currents. In programming the extractor voltage, the ion optic lens is moved from the plasma surface to the extractor region, and in so doing the focal length for a given current is considerably lengthened. Thus, the low radiation window in the curve of Fig. 9 is widened. Operation for off-design currents using a programmed extractor voltage should be more reliable. Fewer arc-downs can be expected due to less column beam loss.

Fig. 9. The measured radiation at the door of the Cockcroft-Walton Faraday cage is plotted as a function of the measured extracted current from the accelerating column. For each extracted current, the extractor voltage is adjusted according to the Child-Langmuir Law. The extractor voltage is also plotted.

In defense of a high extractor voltage at low column current, it should be pointed out that the old procedure of simply reducing the column current gives a small, well-collimated beam at EM3 for diagnostic work. If the extractor voltage is decreased, this feature disappears and a larger beam results.

Another feature to note is the radiation in the region 20 to 50 mA. The measured radiation is linear with current and can be extrapolated back to the origin. The interpretation is that this radiation is caused by backstreaming electrons from the ionization of the residual gases in the column. The radiation, therefore, should be proportional to the total current. A deviation of the radiation from linearity would indicate the beam is being scraped by the electrodes. This has been confirmed by measuring the current to the electrodes. To strengthen

Fig. 10. The measured radiation at the door of the Cockcroft-Walton Faraday cage is plotted as a function of the measured extracted current from the accelerating column. The extractor voltage is held constant at a value determined by the Child-Langmuir Law for the design current of the accelerating column (51.8 mA of proton current or 45.3 mA of total current).

the concept of radiation resulting from the residual gas ionization, the hydrogen gas background was varied. The calculated change in pressure in the accelerating column was from 3.9×10^{-5} mm Hg to 1.5×10^{-5} mm Hg with a corresponding change in the background radiation from 10 to 6 mrad/h. Using the radiation criteria as an indication of beam impingement on the electrodes, it must be concluded that no significant amount of current strikes the electrodes at the design current. The slow rise in radiation for currents greater than design value indicates a low tail on the beam density profile. The sudden rise at 55 mA indicates that the beam blow-up is sufficiently great so that the hard core of the beam is beginning to impinge on the electrodes.

Beam Transport System

Work has continued in studying the transport of beams in the high intensity proton beam line. Beam envelope calculations indicated that a reduction in beam size could be realized in the latter part of this beam line by reversing the polarity of the gradients in the triplet following the prebuncher. Subsequent beam tests with this lens configuration did result in higher transmission at higher currents and in more favorable orientation of the emittance patterns at the final emittance measuring station (EM3). The phase-space distributions obtained for this beam at this emittance station are shown in Figs. 11 and 12.

The Transport Area A (TA) beam line was completely dismantled for the accelerating column beam

tests. Magnetic field measurements were carried out on the initial quadruplet while the beam line was disassembled, and data obtained agreed with previous measurements taken on a similar quadruplet in the injector beam line. These measurements now complete the magnetic field tests on the H^+ injector multi-plets.

Emittance measurements were also made immediately after the column tests, and slight rotations in the horizontal phase space patterns from the original patterns were observed at both EM2 and EM3. Despite all these small differences, it still may be concluded that the performance of the injector had not significantly changed during the accelerating column beam tests.

Ion Source

During this quarter, the duoplasmatron ion source (Mark IIIa/11/CT-2) has been in continuous service on the H^+ injector to provide proton beams for various accelerator tests. This ion source has now been in operation with the same plasma aperture and cathode since its installation over six months ago and has had over 1500 h of service. The source was removed for several hours during accelerating column tests to check the plasma aperture diameter. It was found that the diameter had increased from 0.025 in. to 0.031 in. and that the aperture was now slightly elliptical. The source was replaced with this aperture and is still in operation.

Fig. 11. Horizontal phase-space pattern for a 26-mA proton beam at EM3 when the gradients of the triplet after the prebuncher were reversed.

Fig. 12. Vertical phase space pattern for a 26-mA proton beam at EM3 when the gradients of the triplet after the prebuncher were reversed.

750-kV Accelerating Column

A major cause of column arc-downs under present low-power operating conditions has been traced to malfunction of the modulator controlling the ion source. During the 60-h operation tests, it was noted that most of the column arc-downs were associated with the loss of fast protect pulses from the linac area. When the fast protect system turned off the beam for 8 sec or longer, the column would invariably arc down when the beam was again turned on. Further investigation showed that the problem could be simulated by turning off the beam for 8 sec by any method. The problem was then traced to the failure of the modulator to turn off at the end of the beam gate pulse.

The failure of the turn-off SCR in the modulator was caused by the decay of a delay line voltage which occurs when the input signals to the modulator are turned off. After 6 to 8 sec, the remaining voltage is insufficient to trip the turn-off SCR. In this respect, the modulator was operating as designed since the mode of sudden turn-on was not of its original specifications. This part of the circuit is being redesigned with the addition of a comparator circuit to prevent beam turn-on if the delay line voltage is insufficient. The delay line charging time is ~ 6 msec, so the proper voltage will be attained before the next beam pulse arrives, even at the highest pulse repetition rate of 120 pps.

While the modulator was not designed for sudden turn-on, the crowbar circuits should have protected the system against the long pulse as soon as it exceeded the duration of the beam gate pulse. Circuitry and procedures will be developed to permit a simple, reliable test of the crowbar circuits on the weekly interlock checks or more often if conditions warrant.

The Ultek hydrogen ion pump in the equipment dome shorted out, after $1\frac{1}{2}$ yrs of operation, and was replaced. Large-diameter spalls from the titanium surface created a short between the titanium cathodes and the adjacent anodes. The spalling may be related to a change in crystalline structure due to a high percentage of atomic hydrogen near the surface of the titanium. The life of these specially designed cells greatly exceeded the specification that they operate for 4000 h at a hydrogen pressure of 1×10^{-5} torr. They actually ran for 6600 h at

an average hydrogen pressure around 1.5×10^{-5} torr. Therefore, they pumped $2\frac{1}{2}$ times the quantity of hydrogen specified. After the pump body is cleaned, new hydrogen pumping cells will be installed. The pump will then be returned to service in the dome, giving second pump redundancy before the July beam date. During the pepper-pot tests, frequent opening of the vacuum system caused an appreciable time loss waiting for the hydrogen ion pump to achieve enhanced pumping. To reduce this time loss, argon was introduced into the system at 2×10^{-5} torr with the pump operating. Argon is at least 100 times more efficient than hydrogen in sputtering. A 20-min treatment was sufficient to enhance the pumping speed by a factor of $2\frac{1}{2}$. For the same chamber pressure of 80 millitorr of hydrogen, the pump pressure dropped from 1.3×10^{-5} to 5×10^{-6} torr as a result of the argon sputtering. Higher argon pressures will be tried to reduce the time required to achieve enhanced pumping.

After this enhancement process had been completed on a new pump, it was possible to operate the ion source at a chamber pressure of 220 millitorr with the pump operating at a pressure of 1.5×10^{-5} torr and with a hydrogen gas flow of 3.8 cc/min. In this mode of operation, the current pulse extracted from the ion source exhibited less overshoot, and the overall quality of operation at a duty factor of 1.5% appeared better than with the lower chamber pressure. Work is now in progress to study this effect at full duty factor.

The H⁻ Injector Program

H⁻ Ion Source Development

Because of difficulties encountered in obtaining the design current of 2 mA from the prototype H⁻ ion source system, an intermediate design is now being planned for use with the first H⁻ experiments at LAMPF. A nominal goal of 100-200 μ A peak current is now planned. Detailed schedules are being made for fabrication and checkout. The research program will continue on the development of a high-current H⁻ source which will be installed after the initial low-current experiments have been completed.

The original concepts for the H⁻ injector include the extraction of a beam of protons from the expansion cup of a duoplasmatron ion source, using a spherical electrode configuration. This arrangement

was primarily designed to form a small parallel beam in the charge exchange canal, insuring adequate gas pressure with low gas flow. Experiments to date have not been satisfactory from the point of view of producing H^- currents in the milliampere range, although the ion source is presumed to have the capability of producing the required proton beams. Usable beams, adequate for the initial LAMPF experiments proposed, have been produced in the 100- μA region. The low yield appears to be a problem in the extraction system. A theoretical investigation, to be developed in a separate report, indicates that a positive feedback mechanism may exist which fundamentally destroys the beam uniformity and quality in the present design.

One approach, which would bypass the extraction stability problem, is to use the acceleration-deceleration scheme. Here, the beam is extracted in the cylindrical configuration, which is stable, to ~ 50 kV. This avoids many problems concerned with the plasma surface. The energy of the beam is then lowered to 15 kV, the desired energy for charge exchange. Figure 13 shows the electrode configuration. The 25- and 50-kV electrodes are identical to those designed for the H^+ extractor. The deceleration to 15 kV focuses the beam to a small size, depending on the space charge and beam emittance. This scheme is similar to the lens filter design used many years ago on the electron analog experiment.¹ With proper adjustment, the beam will converge to a waist at the entrance to the charge-exchange canal. A drawback of this system is expected to be the larger gas flow required. The accel-decel system is presently being programmed for computer solution to establish the optimum parametric values. The accel-decel scheme, in a preliminary configuration, is now being tested on the H^- ion source test stand. It is hoped that high-quality currents of 50 mA can be formed for injection into a charge-exchange canal, which should produce H^- beams of the order of 0.5 mA. Later models can increase the H^- beam current should the LAMPF experimental program so require.

Fig. 13. The electrode configuration for the accel-decel scheme for providing a converging high-quality beam of protons for injection into a charge-exchange canal.

The computer code for extraction trajectory calculations (HICIS) has been converted to the LASL CDC 6600 and computations have begun for LAMPF geometrics.

A preliminary study of the column injection optics indicates that beam translation by means of two magnetic bends will provide versatile optics while preventing neutrals or electrons from entering the column. A displacement instead of a simple bend has the advantage of minimizing the effects of energy dispersion. Design of the magnet has begun, and a 30-kV, 50-mA regulated power supply has been ordered for the extractor.

Ion Source - Experiments

The H^- test stand was rebuilt to facilitate source design changes and to decrease subsequent pump-down time.

A set of calorimeters was constructed for measurement of extracted current (H^{+0}), neutral current at ground potential (H^0), and H^- current at the Faraday cup. The latter was used only to verify that the Faraday cup worked properly; and for such calorimetric measurements, the agreement was good ($\sim 20\%$ with 0.1 W into calorimeter).

Although magnetic analysis of the H^- beam has always been used to separate H^0 , e, and H^- , the momentum resolution has not been good enough to positively identify $H_2^+ \rightarrow H^-$ and $H^+ \rightarrow H^-$. For 15-kV accelerating potential, the latter process yields a 30-kV H^- ion and the former yields a 22.5-kV ion. In order to get a good energy spectrum, a Faraday cup capable of holding 30-kV decelerating potential

¹John E. Brolley, Jr., C. Robert Emigh, and Donald W. Mueller, "Electron Analog Tests of Proton Linear Accelerator Structure," IEEE Transactions, NS-12, No. 3, 144 (June 1965).

was built and used. With the analyzing magnet set for 30-kV ions, the H^- current vs decelerating voltage showed the expected sharp cutoff at 30 kV (Fig. 14) in addition to ~ 20% of 22.5-kV ions. The analyzing magnet set for 22.5-kV ions with a similar behavior was observed, and a small amount of 20-kV H^- ions originating from H_3^+ was probably present. The simultaneous momentum and energy analysis confirm previous identification of various H^- currents.

A new extractor system was designed and built to test the gridded source concept (Fig. 15). This system uses tandem grids at the plasma surface with carefully aligned apertures each of which is designed to deliver a parallel beamlet. Experiments were carried out on the single-aperture system with a 3-mm expansion cup, 2-mm extractor, 3-mm bias electrode, and an extractor-cup spacing of 4.5 mm. The calculated space-charge-limited current for 15 kV is ~ 13 mA in comparison with a maximum calorimetrically measured 10 mA. Up to 5.5 mA was measured in the H^0 beam at ground level, and up to 140 μA of H^- was calorimetrically measured; however, this is probably mostly from $H_2^+ + H^-$ since the expansion cup region had high pressure due to the small cup extractor holes. The 55% H^0 transmission is encouraging and the 140 μA represents 1.3% conversion of the H_2^+ beam. A number of questions remain unanswered, the most important concerns pressure in the expansion cup region.

Fig. 14. The H^- current vs decelerating voltage on the Faraday cup, 15 kV extraction voltage.

Fig. 15. A schematic drawing of the experimental single-hole type of expansion cup with the 15-kV charge-exchange canal.

H^- Accelerating Column

The double-cone assembly which supports the accelerating tube is now being fabricated. The remaining parts of the vacuum system in the equipment dome are on order except for the hydrogen ion pumps. Design changes on the outer corona rings have been completed, and these rings will be ordered shortly.

H^- Beam Transport System

The quadrupole multiplets for the H^- beam transport system have all been received. Magnetic field tests have been carried out and all magnets have performed satisfactorily. One coil on one of the triplets was wired incorrectly as received from the vendor, but the quadrupole lens did function properly after the proper connections were made. The mechanical inspection has been done on two of the multiplets and the pole alignment and the alignment dowel pins were within specifications.

Work is now in progress to install interlock relays and times on the ion pump controllers for the ion pumps on this beam line. The final tests have been completed on the ion gauge controllers and partial shipment of these units is expected by the end of the next quarter.

IV. ELECTRONIC INSTRUMENTATION AND COMPUTER SYSTEMS

Injector Control Systems

The injector control systems include controls for the ion source, the Cockcroft-Walton (C-W) accelerator, and the beam transport equipment leading to the first linac tank.

The program of maintenance and improvements on these systems continued this quarter. Several of the steering-magnet power supplies which have proved unreliable and noisy were replaced with units from another manufacturer. The associated current shunts had to be changed and the analog signals were re-calibrated. A new panel showing the current mode of operation of the accelerator was designed and installed in the Injector Control Room (ICR). Both local and computer control of the mode were provided. A new beam-current monitor system is being fabricated. This system will have a wider bandwidth and better calibration characteristics. A portion of the arc modulator is being redesigned to produce a full-intensity pulse on the first pulse. This modification should help prevent arc downs when the arc is first turned on and speed the return to normal operations after any arc down. The analog output resistor in the extractor dc voltage string was changed to a wire-wound type for better stability. A LAMPF-standard analog data system was installed on the NOVA computer used for low-energy beam diagnostics.

Work on the H^- injector continued at a low-priority but steady pace. Sufficient information about the controls was collected so that drawings of the equipment layout could be started. Most of the control equipment and power supplies required for the dome have been ordered and should be delivered by the end of April. Wire scheduling for the interface wiring was completed. An outside vendor is wiring the control bins, fabricating the interface cables and building the beam-pulsar chassis. The optical heads for the light links were completed. New drivers for the light links are being designed to produce a higher gain and less noise. Chassis fabrication for the personnel safety system was started.

201.25-MHz Control System

The 201.25-MHz control system encompasses modules 1-4 and the Transition Region. The major

activity in this area was the installation and wiring of chassis in the Transition Region. The following systems are nearing completion: vacuum, cooling water, temperature control, run-permissive, bending-magnets, and quad-magnets. The hardware channel assignments for computer control of this equipment were made and stored in the channel tables of the computer. The computer interface wiring is being scheduled. As the various systems are checked out, the prints and wiring records are being updated. At the present time the H^+ leg of the Transition Region is essentially complete while the H^- leg is about 50% done.

Associated with the Transition Region is a 100-MeV diagnostics area for target system development. The present design for the local controls in this test area calls for three racks of equipment. The systems involved are vacuum, steering magnets, fast-protect, run-permissive, focus-magnets, cooling water, temperature-monitoring, and associated controls. Designs and equipment from the 805-MHz control system are being used wherever possible to save time.

805-MHz Control Systems

The 805-MHz control system extends from modules 5-48 and includes the instrumentation for Sectors B-H. All of the electrical wiring associated with the control systems in the 805-MHz area was completed. A search was made for missing wires and connectors. Various device simulators were built to aid in the search. The discrepancies were noted in a memo to the contractor. Errors which may still remain will be corrected during device hookup and system checkout.

All of the quad-magnet power supplies have been installed and wired. As soon as the accelerator tanks and magnets are installed a final test of the focus-magnet systems will begin.

The receiving inspection of steering-magnet power supplies was completed. All but seven units passed the inspection. These supplies were returned to the vendor for repairs. The remainder of the units are being installed in the appropriate racks and connected to the preformed power cables.

A circuit problem was discovered in the ion-pump power supplies. The overcurrent trip-out relay becomes unreliable as dust collects on it. The manufacturer agreed to supply the parts to correct the problem.

A rather large effort was put into a continuing program of channel calibration and checkout. This effort has uncovered some minor equipment problems. For example, the gears in the 10-turn digi-dials sometimes slip. This slippage destroys the relation between dial position and the value of the controlled variable. The problem was resolved by placing spacers between the gears.

The installation and checkout of the temperature controllers continued. Controllers have been installed and checked through module 36. High power calibration and dynamic testing have progressed through module 24.

Switchyard and Experimental Area Control Systems

The criteria for the control systems in the switchyard were established and final designs were completed for most of the systems. These designs include system schematics, path number assignments of wires, rack-terminal assignments, and location of the bins in the racks. The racks for the four control centers associated with Beam Lines A and X were sent to a vendor for assembly and wiring. A total of 34 bins of modular controls were specified. Over half were installed. It is expected that the racks will be ready by the time beneficial occupancy of the equipment building is received.

Standard control modules were ordered for the following systems: water, vacuum, quad-triplet magnets, quad-doublet magnets, exhaust, facilities, steering magnets, and bending magnets.

Hardware channel assignments were made for the signals associated with all of the systems. The information was prepared for storage in the channel tables of the control computer. An effort is being made to have computer and local controls ready at the same time.

A work order for 40 interphone stations for use in the experimental areas was placed with an outside vendor. Installation of the Beam Switchyard and Area A systems will begin next quarter.

A final design was completed for the transistorized shunts which will allow several magnets connected to the same power supply to be controlled independently. A decision to change the current transducer from a four-core transducer to a shunt caused some delay, but the system is ready for fabrication. Procurement of the hardware was started. The eleven

current shunts required for the switchyard should be operational prior to the 800-MeV beam date.

Three design tasks were undertaken in support of the High Resolution Spectrometer (HRS). A preliminary design was completed for a device to indicate the position of the HRS. One display of the position is needed in the counting trailer and one at the HRS control panel. A drive system for the HRS was developed and a drive motor controller was ordered. Work was started on a position indicator for the Nuclear Magnetic Resonance (NMR) probe. Several schemes are being evaluated.

LAMPF Data Terminals

Each module of the accelerator is connected to the control computer by a data-acquisition and control terminal (DACT) which includes remote information and control equipment (RICE), an input/output unit (RICE I/O), an analog data system (ADS), and a power supply.

All modules on the accelerator are equipped with an operational DACT and on-line testing is being continued. The process of training additional people to repair and maintain the DACTs was begun; a manual to facilitate this work is planned.

The prototype power supply for the ten DACTs in the Experimental Area was received. After the acceptance tests, it was returned for corrections and changes. The production units began to arrive at the end of the quarter and are meeting the performance specifications. The ten RICE I/O units are scheduled for delivery early in February. The checkout of the complete DACTs will be conducted by the maintenance class as a training exercise.

The DACT for the Transition Region was modified to handle 128 channels of analog data as opposed to the standard 64. Other simple extensions of the I/O are being considered. These extensions are feasible because of the expansion capabilities built into the DACTs at the time of their fabrication.

The DACTs are connected to the control computer through the RICE Interface Unit (RIU). The two RIU backup chassis were installed in the racks above the ones currently in use and were tested on-line. These units can be substituted quickly if either of the on-line units is suspected of faults.

Central Control Room (CCR) Systems

Work on the operator's consoles in CCR was curtailed due to necessity to assign manpower to more urgent activities. Emphasis was placed on getting the second Console Interface Unit (CIU No. 2) built and tested. Installation and termination of the cabling that will connect CIU-2 to the second console was completed. Over 2400 terminations were involved. Two chassis to increase the capacity of CIU-2 were sent out for fabrication. Work on the skew knob and alphanumeric readout chassis, the function-button panels, and the status-indicator panels proceeded on a time-available basis. However, the priority on all this work was raised recently so that the second console should be in its final form by the end of March. Then the original console will be retrofitted to make it identical to the new one.

The Tektronix-611 Hard Copy Unit was put back in service after modifications were installed under warranty. Unfortunately, the improvements caused the paper to wrinkle and jam. The copier was returned for further repairs. A Tektronix Video Hard Copy unit was demonstrated in CCR, but a decision was made not to purchase the device. The problem of images being "burned" into the Tektronix storage scopes was traced to excessive noise on the input lines to the scope. The electronics interface was modified to eliminate the noise.

The counterpoise grounding system and the ac power distribution system for CCR were completed, including ac power for the PDP-11 and SEL-810A computer systems recently installed in CCR.

The engineering to solve the CCR lighting problem was completed, but the work was postponed because of lack of funds.

LAMPF Control Computer

The LAMPF control system is organized about an on-line digital computer. The computer, a SYSTEMS SEL-840MP, became available for accelerator operations 24 h/day in January. The computer equipment and programs are not free from faults; however, the hardware and software are sufficiently reliable to support operations on a continuing basis. Improvements to the system will be scheduled at times which do not conflict with operations.

The first step toward a backup system for the control computer was taken when the SEL-810A was

removed from the Electron Prototype Accelerator (EPA) and relocated in CCR. A series of control panels will be designed and interfaced to the backup computer. The backup RIU interface to the SEL-840MP will be modified for 16-bit operation. These actions should produce a backup system through which the accelerator could be kept in operation while repairs are made to the control computer. Fortunately, the SEL-840MP has caused little if any time to be lost from operations. Consequently, work on the backup system was given a low priority with a scheduled completion date of January 1973.

Two failures were logged against the magnetic tape drives. One unit was down for half a day while worn brushes were replaced in the vacuum motor. The other unit was lost for 1.5 days when one of the windings on a transformer burned out. The card reader and logging printer were each down for several hours for minor repairs. A transient failure of the disk took it out of service. The disk from the SEL-810A was substituted while the fault was being diagnosed with the aid of the backup computer.

A modification to the SEL-840MP was designed to provide a quick re-start capability when the system crashes. Pressing a button on the operator's console will reactivate the computer and save a record of the previous crash for subsequent analysis. A second modification was designed as an aid in trapping programming errors. This circuit causes the computer to branch to a special section of code whenever it tries to store a word into a cell whose address matches the address set into the sense switches on the programmer's console. Both of these modifications will be completed by next quarter.

Programming

One prerequisite for full-time operation of the control computer is the capability for on-line testing of new programs. This requirement was satisfied by a Debug program. Debug interprets each instruction of the program under test and determines if the consequences of executing that instruction will break any rules, e.g., branch outside the memory bounds of the program. If it does, Debug aborts execution and gives the programmer a chance to correct the error. A display on the character scope provides a means for observing and changing the registers and cells in memory. Options to single step,

trace one or more parameters, and breakpoint are available. Data and control instructions to the accelerator can be simulated or executed. Operating experience may suggest other features.

Work continued on the problem of system crashes. As the load on the control computer becomes heavier and the system is driven harder, hidden errors manifest themselves in the form of system crashes which require a re-start sequence. Each crash has to be analyzed to locate the source of the problem and then corrective action has to be taken. The general approach is to devise a test that will trap potential errors before they occur and dispose of the offending program with a message to the operator. This checkout process is slow and time consuming, but steady progress is made each quarter.

Several programs were written to help monitor the status of the accelerator for the Operations crew and to diagnose the reason for loss of beam. The most important of these programs analyzes the faults from the fast-protect system and displays a message to the operator. Another program checks the run-permissive system and keeps a bank of lights glowing if all conditions are satisfied. The lights on another bank are turned on if all of the operating conditions in each sector are satisfied. While these programs are of immediate utility, they are viewed as interim solutions to the more general problem of monitoring.

The long-range solution to monitoring will be provided by Data Scan, a group of programs to perform the scanning and recording functions on the accelerator. Work on this project was reactivated last quarter. In its present state Data Scan will accept a list of channels to be monitored and the frequency of scanning (1/sec, 1/min, 1/h, etc.). If any of the channels changes state or drifts out of tolerance, this fact is logged for the operator. Programs for the long-term recording of channels and the display of these data will be debugged next quarter.

Work continued on the program to automate the testing of any channel on the accelerator. The experience gained from using the first version suggested that a different organization of the program could more nearly provide the flexibility for devising tests and printing out the results. Hence, the program was rewritten, debugged, and put back in

operation for the development of further tests. One test has proved particularly useful. It measures the gain and noise associated with each 16-channel multiplexer in every analog data system on the accelerator. This test uncovered the fact that the calibration voltages were not correct. All of the standard voltages were rechecked and the new data were stored in the computer. In the future this program and others like it will be used to search for any degradation in the performance of systems along the accelerator.

Programming was essentially completed for the magnet-mapping system built around a small digital computer.

Distributed Operational Systems

The systems described below extend over the length of the facility and are essential to the operation of the accelerator.

Timing System

The timing system serves to synchronize the rf and beam turn-on throughout the accelerator. Time intervals are under control of the computer.

Several minor modifications were installed on the master timing unit to aid accelerator operations. For example, it was necessary to provide separate timing controls for the 201- and 805-MHz rf systems, while still maintaining synchronism between the two. This was accomplished by re-utilizing the prototype master timer. This unit was removed from EPA and installed in CCR where it was altered to the LAMPF master timing unit to drive the rf equipment in the 805-MHz area.

The remainder of the timing distribution chassis for the accelerator were installed and checked. They are ready for use except for a small modification in the delayed rf gate latch-back circuit for each module to make them conform to the LAMPF binary command standard.

An oscilloscope to display the relations among the various accelerator timing signals was installed in CCR. This unit will be available as an aid to operators when the necessary interconnections are completed.

Fast-Protect (FP) System

The FP system is hardware which can quench the proton beam rapidly in the event of a beam spill, or a fault which might result in a beam spill.

The remainder of the FP chassis along the accelerator were installed and checked. Retrofitting of the FP chassis in Sectors A, B, and C and Injector A was completed. The original chassis from these areas were updated and are available as spares. A proposal was approved for the FP system in the Switchyard and Experimental Area and the procurement was completed of all chassis except the one for CCR. That chassis will be fabricated locally.

Two of the FP chassis were modified to solve special problems. A circuit was installed in the Injector A chassis to inhibit the beam whenever a 5-sec interval elapses with no beam gate pulses. This feature prevents arc downs associated with very low repetition rates. The Sector A chassis was modified to make it immune to rf noise from module 3.

The major problem remaining with the FP system is that it is too efficient, thereby frustrating efforts to obtain a beam. The difficulty lies in diagnosing the nature of the fault which is inhibiting the beam. After each fault the computer responds to the FP interrupt and acquires data which should define the offending device. However, these data can be ambiguous or even misleading because of certain design features related to timing or the fail-safe nature of the system. As these problems are corrected, the control computer should be able to provide an accurate diagnosis of the fault.

Run-Permissive (RP) System

The RP system is hardware which can inhibit the beam upon detection of any abnormality in the personnel safety system or machine interlocks. The installation of the RP system for the accelerator is complete and system checkout has progressed through Sector D.

Personnel Safety System

The LAMPF personnel safety system includes key banks, door interlocks, warning systems, and the interconnections of these systems to the FP and the RP systems.

Modifications were installed on the 201.25-MHz rf stands so they could be run during 5-MeV operations without the beam channel safety system being secured. Barriers are required to keep personnel out of the radiation area. The state of the truck access door (closed - not closed) was included in the Sector B interlock chain so that if the door is

opened at any time the personnel safety signal is lost, requiring a sweep of the Sector B beam channel and maze area. The gate between the Transition Region and module 5 was added to the Sector B interlock chain in a way that requires Health Physics personnel to reset the stations in the beam channel if the gate is opened. A new sweep procedure was developed for use prior to 211-MeV operation.

The installation of the personnel safety system for the remainder of the accelerator was completed. Checkout of the system progressed to Sector D.

Radiation Safety System

The radiation safety system has two purposes: personnel and machine protection. Personnel protection is provided by area monitors, air-activity monitors, and fast-acting neutron monitors; machine protection is provided by fast-acting beam-spill radiation monitors.

Installation and checkout of the area monitoring system for the remainder of the accelerator beyond Sector C was completed. However, satisfactory operation of the system depends on resolving problems with the detector and with the electrometer.

As reported last quarter, some of the detectors (ionization chambers) were found to have leaks. A total of four chambers were returned to the manufacturer for repair. A second problem related to the detectors was noise in the associated electronics in the range of 10 mR/h. To alleviate this problem it was decided to raise the chamber pressure to one atmosphere thereby increasing the chamber output signal by 10 times. The increased recombination losses (lack of saturation) at 100 R/h would be reduced by substituting dry nitrogen or one of the noble gases for air. Several detectors with various gas mixtures were tested with inconsistent results before it was discovered that a faulty pinch-off technique had caused indeterminate fill pressures. This work will continue as soon as some new equipment arrives.

The electrometer problem was solved by a new circuit design utilizing all solid-state devices to replace unstable vacuum tube circuits. A prototype circuit board was assembled and tested. The observed drifts were well within established tolerances. Fifteen of the new electrometer circuits were built on printed circuit (PC) boards. Ten of these boards were installed in Sectors A through H.

All components for the beam-spill monitor system for the remainder of the accelerator were received. As the station units were bench-tested, they were retrofitted with a circuit to make them immune to electrical noise; a requirement which was not discovered until after the fabrication contract had been let. The equipment was installed along the accelerator following completion of work by the wiring contractor. The three signals from each monitor--instantaneous beam-spill, peak beam-spill, and beam-spill fault--were checked and calibrated through module 13. The peak and fault signals were verified through Sector G. System checkout and calibration will continue next quarter.

A system to monitor radiation emitted from the exhaust stack in the Experimental Area received further attention. A revision in the AEC regulations governing such radiation forced a different approach to the monitoring of exhaust velocities. Fortunately, a newly developed velocity meter appears to satisfy the criteria. This instrument can also measure mass flow. An order was placed with the proviso that the meter can be returned if its calibration is affected by radiation.

Auxiliary Systems

Communications System

The LAMPF communications system includes interphone, paging, telephone, and FM radio services. An effort was made to correct as many as possible of the faults still lingering in the interphone system. A tester was designed and built to diagnose wiring errors in the cables. All known errors have been corrected.

A microphone to monitor for arc downs in the C-W accelerator was installed. Audio speakers were connected in the ICR and the CCR. These monitors have a built-in squelch or threshold level so that no background noise is heard between arc downs.

The Laboratory-Office Building (LOB) guard line and LOB paging console were put into operation. This makes it possible for people to call the LOB receptionist for paging or radio assistance simply by selecting the LOB guard line at their interphone station.

Because of increasing concern about security of buildings at the LAMPF site, all major buildings are being provided with PA systems. The system for the

LOB is scheduled for installation next quarter. Designs are being developed for the systems in the Operations Building, Equipment Test Laboratory, and Nuclear Chemistry Wing of the LOB.

TV System

The LAMPF TV system facilitates the monitoring of accelerator operations and provides access surveillance.

A camera in the Operations TV system was used to record real-time emittance and beam-profile data from a pepper-pot viewing screen located at the exit of the Pierce column in Injector A. This test showed that the TV system had five times the dynamic range required. It also disclosed a nonlinearity in the quartz viewing screen. The experiments in measuring the time dependence of beam emittance will continue.

The access surveillance TV system was extended so that all access points to the accelerator from Butt-Line Zero through Sector C can be monitored in CCR. The cameras for Sectors D through H are in temporary use in the beam channel. They will not be needed until the temporary shield wall is removed.

Video System

The function of the video system is to provide a means for automatic and manual switching of signals from the accelerator to CCR for display on one or more oscilloscopes. Substantial progress was made on the video system beyond the 211-MeV point on the accelerator. All of the NIM bins, power supplies, patch panels, channel decoders, and line drivers were installed. Only 60 signal conditioners and 14 ADS buffer amplifiers remain to be installed. The final tasks will be the calibration of the line drivers and buffer amplifiers plus a final system checkout through the control computer.

Work was started on a manual describing the operation of and maintenance procedures for the video system. The document is 50% complete.

Experimental Area Computers

Portions of the first two PDP-11's for the LAMPF data-acquisition system began arriving last November. However, several items remain to be shipped, namely, the line printer, DEC tape, and fast paper-tape unit for the Terminal computer. Moreover, the lack of a cable renders the card reader inoperable. The data-acquisition computer is essentially complete, but cannot be utilized effectively until the

Terminal computer is fully operational. Pressure is being applied on the manufacturer to correct these deficiencies.

In the meantime an effort was made to get the software running. It proved very tedious to get the disk-operating system (DOS) loaded without a DEC tape unit or a fast paper-tape reader. However, DOS is now in operation on both computers. As soon as more familiarity is gained with the system, a series of modifications will be developed to make DOS more suitable for the tasks of data acquisition.

A specification was written for the graphics software which will be developed for the PDP-11. The package is a set of FORTRAN-callable subroutines intended to facilitate the display of data on a storage scope.

Bids were solicited for a controller to interface a PDP-11 to an IBM-729-IV tape drive. Several of these controllers are needed so that the 14 tape drives obtained from surplus can be used on the data-acquisition computers. Four responses were received, but all quotations were unacceptably high. Consequently, this development will be undertaken at LASL.

The Sigma-2 data-acquisition computer was traded to another group at LASL for the equivalent computing power in a PDP-11. The replacement computer, a LAMPF standard model, will be ordered next quarter.

CAMAC Hardware

The prototype CAMAC branch driver was wired and assembled for checkout. Better known as the MIOP (for Microprogrammed Input/Output Processor), this device will be the LAMPF standard for connecting CAMAC crates to PDP-11's. The unit is comprised of two planes of PC cards with extra space for expansion or modifications. Each plane was wired by a wire-wrap machine from a deck of cards. These cards were generated by a program that accepts a wiring list punched on cards. The program searches for both keypunching errors and design mistakes. Once the prototype is checked out, it will be simple to make several units for the Electronics Pool.

A manual control console for the MIOP is being built. The unit will simulate the PDP-11 computer and will be used for checkout and manual operation of the MIOP.

A performance specification covering CAMAC modules to interface a storage scope to a PDP-11 was

released for quotations. The three module types will provide for point plotting, character generation, and vector generation. The control signals and digital-to-analog converters are to reside in the display driver/controller module while the character and vector generator modules are to modify the x-y signals in this module. The bids are due to be received in February.

Two other packages were sent out for quotations. The first covered CAMAC modules to implement control or beam-line equipment. The specific functions requested were binary output, binary input, analog output, pulse output, and analog input from a digital voltmeter or analog-to-digital converter. The second specification dealt with the readout electronics to decode signals from a multiwire proportional counter. The design called for an input capacity of 256 wires and a decoded output of up to eight pairs of x-y coordinates, with eight address bits for each coordinate.

The conceptual design of a CAMAC module for the data-link system was completed. This system will link each data-acquisition computer having a CAMAC crate to the Terminal computer which, in turn, is linked to the large computers at the LASL CCF. The design of the module will also allow a stand-alone data-logging system (no computer in the system) to be linked to the Terminal computer.

LAMPF Electronics Pool

A pool of electronics equipment of general utility is being created to support LAMPF users. Over \$77,000 worth of equipment was ordered for the Electronics Pool. One order covered instrumentation--scopes, pulsers, digital voltmeters, power supplies, 512-channel pulse height analyzers, NIXIE scalars, etc. Another order dealt with fast electronics--discriminators, coincidence circuits, logic fans, etc. All of these purchases were made at the specific recommendation of the LAMPF Electronics Pool Committee.

Wiring and Termination Records

Work continued on the task of merging and updating all the wiring and termination records for each system in the 805-MHz area. Wire-list books representing the following systems were completed: beam-spill monitors, klystron wiring, fast-protect, sector controls, monitor loops, cooling tower, wire scanners, and startup rack. A complete set of books will be located in each sector to aid in maintenance.

V. ACCELERATOR OPERATIONS

LAMPF Operations

One of the purposes of the division-wide reorganization was to form a permanent operations group. This group will eventually have a large enough staff to operate the accelerator; the present staff (four part-time staff members and three full-time technicians) is adequate only for a very restricted number of shifts per week even with the aid of many other members of the division. During the next quarter, additional personnel will be assigned to this group and its effectiveness should increase.

During January, a LAMPF schedule of eight 8-hr shifts per week was attempted. A very modest amount of progress was made on accelerator physics problems (i.e., first beam through the Transition Region), but most of the effort was expended on correction of routine problems.

Electron Prototype Accelerator (EPA) Operations

During the quarter, the EPA beam was on for a total of 313 h. Early in the quarter, the GMX-1 Fuel Activation Analysis program was completed with 18 h of beam time. The extended and analyzed beam lines were then removed to allow installation of the D₂ target by P Division. This installation and experimental time covered four weeks, with beam delivered for 45 h.

The head unit was then changed out and the Arco Model 5.5 gun was installed for the W-8 experiment. This experiment consumed 220 h of beam time. The GMX-11 gun then was reinstalled to complete the LAMPF target tests. These tests were concluded with a run of 30 h on 27 January, 1972.

VI. EXPERIMENTAL AREA

Facility Planning

The conceptual design report (CDR) for the Isotope Production Facility to be added to the Beam Stop A complex has been completed and sent to the AEC. Final design of this facility has been started by the LASL Engineering Department and will be coordinated with the existing Phase III effort. Construction and installation of equipment is scheduled for completion by January 1973.

The CDR for the proposed Radiobiology and Therapy Research Facility is presently being prepared by the Engineering Department. Funds for design of this facility have been received and design will begin upon completion of the CDR and selection of an architect-engineering firm. Design work has been in progress on the pion beam-line hardware and shielding for the facility. Funds for the beam line have been received and design, fabrication and installation can proceed without delay.

The Phase III construction contract, Beam Area A-East and Beam Stop A, is now scheduled for completion in early April. Phase III work during the past quarter has included the fabrication and placement of the permanent steel and iron shielding along the Area A-East beam tunnel and around Beam Stop A.

Weekly meetings to coordinate design efforts for beam lines, services and shielding for Area A, have continued through the report period. Design of the main process-cooling-water lines serving Line A, Targets A-1 and A-2 and the secondary lines has been completed. The design has been incorporated into a bid package with other utility jobs and submitted for construction bids. The hardware for this bid package has been LASL-ordered in an attempt to save four weeks of construction time.

Preliminary design has been completed for installation of services for the radiochemistry labs and hot cells in the Merrimac area. Meetings have been held to review this design, particularly as these services affect health and safety. Present designs remain compatible with new environmental control limits.

Surveys have been completed for the switchyard and are being extended to cover Areas A, B, C and A-East. A grid system of floor markers has been established in Area A consisting of 1-in., round brass plugs set in the floor at 30-ft intervals based on the projected proton beam line. A series of elevation markers have also been established around the area to be used to maintain a check of floor elevations as the massive shielding is installed around the target stations.

Major design and drafting effort during the report period continued on switchyard systems. Extensive design effort was also applied on Merrimac and related hot-cell equipment, on secondary beam-line equipment and shielding, on diagnostic equipment,

process water lines and on target development and handling.

As slight changes in target position have been prescribed in Areas A and A-East, it has been shown that the primary beam transport solutions may still be attained. Calculations to verify that the quadrupole triplets may be used to steer the beam onto the various targets have been carried out and a series of calculations concerning the effect of magnet displacements and imperfections has been initiated.

The assembly of the first 3-MW pump-heat-exchanger package for the radioactive water system is in progress at this time. The installation of the filter boxes and their associated shield wall has been completed in the basement of the Merrimac area. Parts for the ion exchanger and filter systems are completed and are awaiting installation by a contractor. A contract has been awarded for the installation of the interface piping between the process water transmission lines and the Lines A and X magnets. The contractor will proceed with this work as soon as the switchyard magnets are in place. The design and layouts of the Area A valve caves are nearing completion. Some preliminary layouts of a target-cell cooling system have been made.

Switchyard

In efforts to improve the switchyard beam transport, a study was made of the effects of moving the second Line A bending magnet upstream by one meter to eliminate excessive scraping of a possible low-momentum component of the primary beam on this dipole. In effect, more space is left between this magnet and the collimator which eliminates the low-momentum component. No adverse effects are seen, and considerable advantages are gained in that: 1) the magnet will be less irradiated by low-momentum protons and H^- , 2) the Line X and Line D trajectories will pass through better-quality dipole fields of this magnet.

New setups of the primary dynamics run decks specifying the position of all instruments and other items in Lines A and X have been assembled. Beam-dynamics calculations have required less effort than in previous periods. The interpretation of data from magnet-quality measurements, as these are now becoming available, has and apparently will continue to take considerable time.

Fifteen switchyard magnet stands have been received and are being prepared for installation. Two of the 6-in. quadrupoles are being fitted to their support plates.

Initial surveys have been made which extend the beam line from the end of the 805 accelerator to Area A and establish Line X. Two of the permanent alignment stations in Line A have been installed. A survey of the switchyard beam channels has been completed and no large variations in the dimensions were noted.

Many changes have been made in the arrangement and location of instrumentation in Lines A and X. A complete revision of the switchyard installation drawings is in process to incorporate these changes, and to establish final dimensions for beam-tube fabrication and magnet installation. Magnet locations have been revised to agree with the latest transport dimensions.

Drawings of the mineral-insulated cable installation have been completed, and the package should be out for bids in early February. Orders have been placed for seventeen 6-in. linear actuators and fourteen beam boxes for the switchyard diagnostic instruments. Design of the main collimator is ~ 80% complete. Detail drawings of the vacuum enclosure and the graphite assembly are in preparation.

Beam Area B - Nucleon Physics Laboratory (NPL)

Most of the activity during this period dealt with the detailed design required to produce actual hardware. All of the simpler magnet stands have been designed. The quadrupole magnets are being fitted with water manifolds, thermal switches and alignment fixtures. Thermal switches and water system insulators have been ordered for other magnets. Vacuum pumps, instrumentation, bellows, flanges and valves have been ordered for the beam-pipe vacuum system. Further definition of the diagnostic instrumentation requirements has been done, and the development of specific instruments has been started. The mechanism for manipulating stripper foils in Lines A, X, B and C is in the final design stage.

Discussions were held to formulate a basic philosophy for remote handling of equipment in the LD_2 target cave. Magnet stands are being designed accordingly, and the electrical, water, and vacuum connections required in the cave are being developed.

The LD₂ target prototype was tested at the Electron Prototype Accelerator and data were gathered on rates of heat deposition, behavior of the heat exchangers and pumps and, to a limited extent, on lifetime of the windows. Design work is under way to incorporate these findings and other criteria into a final design for the LD₂ target to be used in the NPL.

A used bridge crane which may be modified to fit the NPL building has been located, and a price quotation has been obtained. The crane may be installed in time to be used for installation of all beam-line components in the NPL building.

Beam Area C - High Resolution Proton Spectrometer (HRS)

A procedure for tune-up of Beam Line C has been defined in which small increments of the overall phase space of the incident beam can be sampled. By measuring the response of the system at successive places along the beam path the first-order tune-up can be optimized. A means had been found by which a nearly zero emittance beam with a resolution $< 10^{-5}$ can be obtained from the switchyard. It requires no new equipment along the beam line except for additional strippers. By the use of this procedure, it is expected that this complicated beam line can be rapidly and accurately tuned.

Because of the large dispersion of the beam after the target, a secondary emission-type current integrator (SEM) may be used for Beam Line C. In order to test this device as well as the stripper foils, etc., at realistic currents and energy, a small scattering chamber has been designed which will go into the accelerator line at the transition region. The SEM should give accuracy (0.1%), which is comparable to the previously proposed Faraday cup.

At the time of the last quarterly report the last four (4) magnets, LC-BM-04, LC-BM-05, LC-QM-12 and HS-QM-01 were on bid. Two of these four (LC-QM-12 and HS-QM-01) were placed on order in the last quarter. Because of the complexities of fabrication and the close tolerance required for the two 57° bending magnets, an extensive review of the design is required on the bidder's part, and is the cause of delay in placement of an order for these magnets.

None of the Beam Line C magnets has been received yet. Delay of LC-BM-01, -02, -03 has been caused by the inexperience of the fabricator with

the new kinds of epoxy used for the potting of coils. However, the difficulties have been overcome and no serious consequences are anticipated. The status of 6Q29R/7 twister quadrupole magnets is as follows: 1) all the steel pieces required for these magnets have been machined; 2) delay in the coil winding caused partly by late delivery of copper conductor, resulted in the slight delay in delivery of the first quadrupole magnet.

Fabrication of the two bending magnets for the spectrometer is proceeding without major difficulty. The last and most critical pieces of the magnets, namely the poles, are being machined. The first coil for these magnets has just been wound. Since the winding form and potting form for the coil are the same, winding and potting processes cannot be done simultaneously. To alleviate this problem and improve the delivery schedule by at least two months, an additional potting form will be made. Fabrication of the spectrometer support structure has started and is expected to be finished sometime in March.

Extensive studies of the effective field boundary movement as a function of field clamp positions have been conducted using the prototype magnet. During this study saturation in certain parts of the field clamp was found which may require changes in the field clamps for the HRS and EPICS. Continued study of the effect of the HT-windings indicates that the field homogeneity of 1 part in 10^4 can be achieved at high field (~ 17 kG) with the maximum current on the HT-winding of 625 amp-turn; 1 part in 10^4 can be achieved at low field (~ 3.5 kG) with the maximum current on the HT-winding of 12.5 amp-turn; and 1 part in 10^5 can be achieved at ~ 14 kG with the maximum current on the HT-winding of 300 amp-turn.

Energetic-Pion Channel and Spectrometers (EPICS)

A final optical design for the first EPICS spectrometer has been completed. The design parameters of this spectrometer are tabulated below:

Maximum Momentum	700 MeV/c at 18 kG
Solid Angle	10 msr
Momentum Acceptance	10% at full solid angle
Momentum Resolution	$2-3 \times 10^{-4}$ fwhm, depending on central momentum.

A line drawing of this design is presented in Fig. 16.

Fig. 16. Schematic of EPICS Spectrometer

The momentum resolution function for 100-MeV pions, which is the worst-case condition, is presented in Fig. 17. The momentum resolution is a function of the particle momentum since multiple scattering in the detectors is a problem. For 700-MeV/c protons, the resolution improves to $\sim 2 \times 10^{-4}$ fwhm. The spectrometer has a useful momentum acceptance of 20%. The solid angle as a function of momentum is given in Fig. 18. For the central 10% the solid angle is reasonably independent of momentum, and only this portion of the focal plane will be instrumented for the first experiments. Complete documentation of the final design for the EPICS channel and spectrometer is in preparation.

The design and procurement of the EPICS magnets have proceeded smoothly. The present status of the magnets is tabulated below:

Channel	Steel	On order
	Rad-hardened conductor	On order
	Coil fabrication	On order
	Steel fabrication	On bid
Spectrometer	Quadrupoles	On order
	Bend steel	On bid
	Bend coils	On bid
	Bend steel fabrication	In design

It is expected that all magnets will be on order by mid-March. Magnets will be ordered this fiscal year and procurement of spectrometer power supplies will be postponed until FY-73.

Work was continued on the development of helical multiwire proportional chambers for use as EPICS detectors with studies of the properties of the helical delay line. Several configurations of delay lines were tried, and a bifilar winding appears to be the most promising.

SPECTROMETER MOMENTUM RESOLUTION

(3 MR. MULT. SCAT. IN DETECTORS
CORRESPONDS TO 100 MeV PIONS)

Fig. 17. Spectrometer Momentum Resolution for 100-MeV Pions

SOLID ANGLE SUBTENDED FOR 1.0% MOMENTUM SPREADS VS THE DEVIATION OF THE SPREAD CENTER FROM THE CENTRAL MOMENTUM OF SPECTROMETER

MOM.	0.0	2.5	5.0	7.5	10.0
Ω	10.99	10.4	8.20	5.17	2.43
	± 7.8	± 7.2	± 6.2	± 5.2	± 3.4

Fig. 18. Spectrometer Solid Angle vs Momentum

A first design for an amplifier for the low-level positive pulses has been obtained, and this amplifier is in use for chamber tests that are presently being undertaken. A design for the readout electronics for a multichamber system using helical chambers is in progress. In all work on detectors and electronics, the following special requirements of the EPICS system have been considered: 1) the need for good timing measurements (1-2 nsec) on low-level positive pulses; 2) the dead time introduced by the delay line; and 3) the long cable runs (300 ft) between the detectors and the computer. This study indicates that the electronics is incompatible with the electronics for a more conventional amplifier per wire system, and that a completely new design is required.

Low-Energy Pion Channel (LEP)

All four quadrupoles for the LEP have been delivered. A contract for fabrication of the second and third bending magnets was signed. It was necessary to terminate the original fabrication contract for the first and fourth dipoles and quotations have been received. The new contract should be signed early in February. Difficulties have also been encountered in the fabrication of the mineral-insulated conductor for these magnets; delivery of the conductor is not expected until the first of March.

A mock-up of the support for the first bending magnet was fabricated and tested. It was demonstrated that a magnet could be removed from the support and then replaced within the position tolerances.

Additional engineering effort during the past quarter was directed toward firming up designs for the support stands, vacuum system hardware, collimators, and special shielding to be placed around the magnets.

P³ High-Energy Pion Channel

The design of a tune-up procedure for the P³ channel utilizing Rice University multiwire proportional chambers and PDP-11 computer has been started. The idea behind the procedure is to tune the channel at low intensity by following individual particles through the channel. Measurements of a particle's position are to be made at several locations in the channel. The measurements from a good statistical sample over the phase space of the beam will be used

to construct a figure of merit which can then be optimized by varying quad currents. The figure of merit will be a sum of squares of quantities representing the departure of the beam from its desired characteristics.

Several figures of merit have been formulated, and a Monte Carlo program to simulate the tune-up procedure is being debugged at the present time. The program will be used to test the convergence and effectiveness of the optimization and of the various formulations for a figure of merit.

In work on the hardware of the beam line during the past quarter, the location of some of the ancillary equipment such as beam jaws, beam plugs, and degraders was established and the preliminary design of this equipment has been started. The vacuum requirements were established and an order has been placed for part of the required hardware. The PERT program for the channel is now completed and will undergo its first update on 14 February.

The renovation of P3-BM-02, which is the second bending magnet in the channel, is 90% complete. The only thing this magnet lacks is the installation of the thermoswitch protect system. The vacuum envelope, which came with the magnet from the Princeton Pennsylvania Accelerator (PPA), was leak-checked and found to be vacuum-tight. Of the seven PPA quads that have been closely inspected, five were found to have very significant cracks in the epoxy insulation of the coils. An attempt to repair these cracks is now under way at LASL's Group CHB-6.

The alignment stands for the first five magnets in the channel have been designed and fabrication drawings are now being made. These stands are designed so that, after initial installation and alignment, a component may be removed and reinstalled by remote control. It should self-align when it is reinstalled. A prototype has been made of the self-aligning portion of the stands, which will be tested for reliability before the stands are fabricated.

Stopped Muon Channel (SMC)

The first two quadrupole magnets (14QE22) and the first bending magnet (32XI18) of the Stopped Muon Channel will have coils encapsulated in cement. Orders have been placed for the iron cores for these magnets with delivery expected in May and June. The coils will be wound and taped with fiberglass by a

magnet vendor, but will be potted in cement at LASL. Four of the eight quadrupole coils have been received ready for potting, and the C32XI18 coils have been ordered.

The epoxy coils in the quadrupole magnet after the first bend will be replaced with cement coils. The four wound and taped coils have been received, and one has now been encapsulated in cement.

The bending magnets for the second, third, and fourth bend (C32XI30 magnets) have been received and tested. All nine of the 12QE20 quadrupoles have been received and testing has started. The vendor has completed four of the twelve cores for the 12Q15 quadrupoles and has started winding the coils. The only remaining magnets for the Stopped Muon Channel to be ordered are the four septum magnets. The design of these magnets is near completion.

The design of the supports for the 12QE20 magnets is near completion and design work on the other magnet supports has started. Design and drafting has started on the beam tubes and collimator.

Field measurements have been made on the three C Magnets, C32XI30. The vertical component of the central magnetic field in, above and below the mid-plane was scanned and the line integral of the vertical field component was obtained. The magnetic field over 20 in. of the midplane normal to the beam is fitted with an rms error of $< 0.5\%$ by a field with field index $n = 0.256$ and second order $\beta = -0.399$. Second-order beam-transport calculations show that n and β do not affect the channel performance in any way.

Primary and Secondary Beam Transport

All the 6-in. quadrupoles and bending magnets required for the switchyard "beam-day" operation are now on hand. Also required will be a 2-in. quadrupole doublet, and the status of the 2-in. quadrupole is: 1) all mineral-insulated coils have been tested, and are on hand; 2) all miscellaneous assembly parts are machined and on hand; 3) all yokes and poles are machined and assembly is in progress at the vendor's plant. The machining of these parts was delayed by breakdown of a planer mill.

Final machining on four 2-deg bending magnets has been completed and $B \cdot d$ measurements are in progress to determine the pole end shimming necessary for the main beam's field requirements.

Measurements of the 8-deg bending magnet central and integral fields have been completed. End and side magnet-pole shimming has achieved field flatness within 3 parts in 10^5 over the required field interval. The 12-deg bending magnets have been measured and have shown excessive side shimming. Modifications are being made to reduce the shim height to obtain the required central field flatness.

Typical integral field harmonic content of the 6-in. m.i. quadrupoles is (% of $n = 2$ at bore radius):

<u>Integral Field Harmonic Content</u>					
<u>Current</u>	<u>$n = 3$</u>	<u>$n = 5$</u>	<u>$n = 6$</u>	<u>$n = 10$</u>	<u>$n = 14$</u>
100 A	0.015	0.015	0.161	0.06	0.05
180 A	0.056	0.023	0.133	0.07	0.05

The five mineral-insulated "C" magnets for Beam Line B are now on order. These C7III32M/16 magnets have pole-face shaping generated by the MIKT optimization program; the resulting field, at 16 kG, is calculated to be flat to better than 0.5 G over 2.35 in.

The first target cell triplet for Area A is being assembled at the vendor's plant. All three components, 8QN16M/7, 11QN32M/9 and 11QN15M/9, have been individually dovetailed to specification. Alignment of the three components, painting with an inorganic zinc coating and coil installation remain to be done. The mineral-insulated coil winding is proceeding well.

Seven completely inorganic quadrupoles for secondary beam lines (LEP and P^3) are now on hand. Ceramic seals, water insulators and temperature interlocks will be installed in-house. Final harmonic content measurements on the first 8QN16M/7 and 11QN22M/9 quadrupoles, with pole ends chamfered, are (% of $n = 2$ at bore radius):

		<u>Central Field Harmonic Content</u>				<u>Integrated Field</u>
		<u>$n=3$</u>	<u>$n=6$</u>	<u>$n=10$</u>	<u>$n=14$</u>	<u>$n=6$</u>
8QN16M/7	500 A	0.02	0.05	0.08	0.16	0.251
11QN22M/9	490 A	0.02	0.135	0.01	0.05	0.065

These figures are representative of what is expected on the secondary beam line and target cell triplet quadrupole, except that a small change has been made to the 8-in. quad chamfer to reduce the integrated $n = 6$.

Experimental Area Equipment and Experimental Area Support

The operation of the Electron Prototype Accelerator (EPA) for target testing has terminated. Before its demise a new wheel target drive mechanism was designed and tested. The apparatus is shown schematically in Fig. 19. The principal change in the drive mechanism is the use of a pair of bevel gears, one made of Ampco 18, an aluminum bronze alloy, and the other of cast iron. For lubrication, a mixture of MoS_2 , Sb_2O_3 and a polyimide binder is used. The yoke was redesigned to support the bevel gears and to provide better cooling. The target wheels were made to be remotely removable for future testing with 100-MeV protons. The target and drive mechanism was successfully run at EPA in 5×10^{-5} mm Hg vacuum without a beam for 500 h. The graphite wheel was then tested under irradiation by the electron beam at 1450° to 1600°K for 30 h. The temperature anticipated for a graphite target in the LAMPF beam is 1450°K . Test results showed no deterioration of the graphite wheel. The drive mechanism performed satisfactorily although there was a slight loss of the dry lubricant.

Design work was completed on the 100-MeV beam target test area. Support rails, quadrupoles and water lines have been installed. The main beam stop is 50% fabricated. The collimated beam stop and spreader have been fabricated, but flow tests showed that proper water flow was not reaching the spreader. The spreader is being reworked.

Fig. 19. Schematic of target wheel assembly.

In a continuing program of target development, calculations have started on wheel targets of different shapes and materials. An MgO , or composite thereof, looks promising as an intermediate density target between graphite and molybdenum. Such a target is predicted to be optimum for use at the Bio-medical Target Station.

In the manipulation of the H^- beam, the basic requirements for the beam strippers have been reduced to the following, which satisfy all foreseeable needs:

1. Graphite foils, 1.25-in. diam, 1 ± 0.1 mg/cm² thick, smooth-surfaced, with a single hole in the center. This hole will vary in size, depending on the application, from 0.001-in. diam to 2-cm diam. A number of foils will be mounted in a rotary actuator which will insert them into the beam line and these foils will cover a range of specific hole diameters between 0.001 in. and 2 cm.

2. The same graphite foil size and thickness as above, but with a slit rather than a hole. The slit is 1-cm long and its width varies from 0.0005 in. to 2 cm. The slit is centered in the foil. Slit length tolerance is $\pm 10\%$.

3. Graphite or carbon fibers, spanning 1 in., with diameters of 2, 5 and 10 μ .

4. Very thin foils, 10 - 100 $\mu\text{g}/\text{cm}^2$ thick. Preliminary inquiries have revealed that No. 1 above may be commercially available. A formal inquiry has been written to determine the availability of Nos. 1 and 2. For No. 3 the fibers are readily available in 5- and 10- μ diameters and the availability of 2- μ diam fibers is being investigated. The 10 - 100 $\mu\text{g}/\text{cm}^2$ foils are also commercially available. The rotary actuator for supporting a variety of 18 strippers and inserting and positioning them in the beam line is being designed.

The delta-ray energy monitor was installed in the transition region at the end of October. The first run on LAMPF occurred on 19 November, with a beam that was accelerated through Tanks 1, 2 and 3, but was drifted through Tank 4. After 2 - 3 h of adjustments the delta-ray monitor produced its first measurement of the proton energy, 72.7 MeV. Design value for these conditions is 72.7198 MeV. The apparent energy width of the proton beam was smaller than could be resolved with the instrument with its present detector. Improvements in the electronics

and shielding were then made to reduce pile-up and to eliminate pickup. Pulse-height spectra like that shown in Fig. 20 were obtained at 100 MeV. The width seen there is mainly due to detector noise. The experiments also showed that the magnetic transport that brings electrons from target to detector was selecting a narrow bite ($\Delta p/p = 1 - 2\%$) out of a rather wide ($\sim 8\%$) momentum spectrum emerging from the target. This means that unless care is taken to find the centroid of this distribution as a function of magnetic field an incorrect value of proton energy can be deduced from measurement of the electron energy. The $1 - 2\%$ momentum bite is exasperatingly close in energy to the detector noise line width, so the width of the momentum spectrum emanating from the target was not immediately evident in the pulse-height analyzer energy spectrum. A simple estimate of the spread in scattered electron momenta induced by the motion of the bound atomic electrons yields an 8% width for electrons ejected from aluminum atoms indicating a need for a lower Z target. The slits and baffles with which the transport is presently equipped can be modified to accept a larger momentum bite, so that the setting of the magnetic field becomes unimportant, as it should be. Further tests are planned.

In other equipment development the high-voltage ceramic standoffs were ordered for the EPICS particle separator and have been received from Coors. The corona shield spinings are being fabricated. Tests on the revised model magnet show that excessive flux leakage to the flux box is caused from the

simple wrap-around coil used on two legs of the window frame and results in saturation of the yoke. It is therefore necessary to use a saddle coil on this magnet. A 10-ft -long particle separator and associated equipment has been received as excess property from the Argonne National Laboratory and is presently being stored for possible use at LAMPF.

The possibility of accelerating selected micropulses is being studied. It seems feasible to use an electrostatic deflector of 50-cm length with a 2-cm aperture 20 cm downstream from the deflector. The deflector would be located in the 3-ft open section of the injector beam line between the viewing screen TDVS01 and the emittance scanner EM02. The deflected beam will spill at one of the three apertures, i.e., the deflector, the buncher, or the emittance scanner EM3 aperture. The required deflector voltage would be 5.6 kV. The calculations have been done for 20-mA beam current for which good agreement with measurements was obtained. The possibility of using an electromagnetic shock wave technique for the power supply in order to extract the single micropulses is presently being studied.

In the realm of switchyard beam diagnostic and control instrumentation, the design of centroid monitors in three sizes including accelerating structure and beam boxes has been completed. Prototypes of a secondary emission monitor (SEM) and a strip ion chamber (ISIC) are ready for test. The large toroids for the 6-in. current monitors are scheduled to arrive any day. Tests of very sensitive current monitors using a digital signal averaging technique are being performed. The monitors have a low input impedance preamp next to the toroid which has only a few turns. The combination shows promise of solving the current measuring requirements in Area A. Except for selection of plugs for multiwire instruments, such as the SEMs and ISICs, the connector and wire requirements for all switchyard beam monitors have been established. A report outlining the data-gathering problem these instruments present is available as an internal memorandum.¹ The interfacing and application of all instrumentation including that

Fig. 20. Delta-ray energy monitor pulse-height spectrum.

¹Internal memo MP-6/PAMG-3, P.A.M. Gram, "Information Retrieval from the Switchyard Beam Monitors", dated February 22, 1972.

devoted to radiation surveillance is being developed in cooperation with MP-Division's systems engineers.

Other electronic developments have produced a high input impedance, fast FET amplifier for wire proportional chambers and a very simple ADC with a logarithmic energy scale. The latter circuit performs both the stretching and digital conversion of a phototube pulse within a single stage by allowing the pulse to shock-excite a high-Q-resonant circuit. The number of oscillations that exceed a preset threshold is proportional to the log of the pulse height. At present a dynamic range of 50:1 has been achieved, with acceptable temperature stability. This circuit is intended to be an economic solution to the problem of providing an experiment with a large number of ADCs.

Production of the 3/4-in.-sq hollow mineral-insulated cable for secondary beam line bending magnets (it is rated at 1800A in 220-ft lengths, and is used at 2000 A in 100-ft lengths) has been delayed by manufacturing difficulties. The vendor, Pyrotech of Canada Ltd., is now using two different approaches to meet the rather stringent fabrication criteria. Eight 220-ft lengths have been produced for the P^3 bending magnet, C12VI34M/15, and tests at the vendor's plant indicate that a water flow of 1.75 GPM has been achieved at a pressure drop of 100 psi/223 ft (2.5 GPM is specified at 200 psi/180 ft). Thus, it appears that the water flow is close to specification. All other cable parameters are satisfactory.

Efforts have been made to find epoxy insulation formulations which provide radiation resistance intermediate between that of m.i. cable and conventional insulation for magnet cabling. Epoxy novolac-methyl nadic anhydride samples have been irradiated in the Omega West Reactor. The most successful formulation has been irradiated to an estimated dose of 9×10^{10} rads of reactor fission flux spectrum. The net density change has decreased ~ 8% during the total irradiation history. Small surface cracks are becoming increasingly apparent and the deterioration rate appears to be increasing; however, this is the most radiation-resistant system tested here to date. One formulation of bisphenyl-A (Dow 332)-methyl nadic anhydride has shown better radiation resistance than other bisphenyl-A systems. Its radiation tolerance appears to be in the order of 5×10^{10} rads. Four

formulations of a vendor's proprietary resin system (containing alumina) have been irradiated to ~ 6×10^9 rads. Considerable outflow of a gum-like fluid was observed on the sample surfaces. Some cracking was also observed. This resin system appears to be inferior in radiation resistance to the above systems which have been formulated by LASL.

A Monte Carlo code, LLORCA, designed to simulate experiments involving target, counter and wire chamber systems, has been written and tested through a first phase. Its display portion relies on the code KIOWA, developed earlier from a converted Lawrence Berkeley Laboratory (LBL) code. Many refinements need to be added, but it is presently sufficient to aid in the design of experiments. The added features will be especially useful in the analysis of experiments. The multidimensional, multi-mode minimization code, MINUIT, has been studied further to gain a better understanding of the three varieties of search methods in it. This will eventually evolve into a search routine necessary to the optimization code for beam control.

Remote Handling

All assembly work on the Merrimac gantry is complete except for the installation of the hydraulic system. The hydraulic package is due from the vendor within one month. Equipment installation is beginning in the Merrimac box. The box roof structure has had a trial assembly for fit and drilling. Bids have been received for the cleaning and rebuilding of the old "Beetle" windows for use in the roof of the Merrimac box.

Some of the ways for the hot cell window boxes have been installed. The couches that carry the cell covers over the window boxes have been fabricated and installed. Fabrication of the cell covers has begun. The drive system to open the covers has been designed and all components are on order.

A test is being assembled to check out the stacking and opening of the target cell doors. All opening hardware has been received. A satisfactory target-removal concept may have been achieved in which target wheels can be changed automatically with the proton beam being shut off only a few seconds, if at all. The scheme does not require vacuum valves close to the target nor are rad-hard vacuum valves required. Target wheels can be added or removed from

the changer without letting the system up to air. All the changing and drive hardware is mounted on the end of a horizontal shield plug. Design details are now being established.

Shielding

During the past three months ~ 3600 tons of the in-place steel shielding around Beam Stop A and along the beam channel from Area A to the beam stop were installed by the Phase III construction contractor. The backfill of tuff shielding has been started in this area. Additional steel shielding material in the form of salvage steel plate from the breakup of navy vessels has been delivered to LASL. Most of this is in disappointingly poor condition--rough cut, dirty and containing numerous holes and irregular projections. About 600 tons of this material has been delivered, most of this from the cruiser Astoria. Another 500 tons from the carrier Valley Forge is due to arrive next month. This material is best utilized buried in its received form.

Design of mass shielding stacking in Area A is continuing with layouts completed for the bottom layers of steel. Design work is under way for the stacked shielding for the temporary beam stops in the switchyard and for the plug for the switchyard service entrance. This shielding needs to be in place for the 800-MeV beam tests.

To help in the shielding design for experiments, the Oak Ridge National Laboratory (ORNL) Monte Carlo code, NMTC, simulating intranuclear cascade processes was used to generate particle-production spectra for π^+ incident on ^{64}Cu at energies of 50, 100, 300 and 500 MeV. History tapes have been compiled for the above cases and have been analyzed to produce spectral information as represented in Fig. 21 and 22. The particle-production summary for the 300-MeV π^+ incident on ^{64}Cu is given in Table I.

Fig. 21. Cross section for neutron production per unit energy vs energy for 300-MeV π^+ on copper.

Fig. 22. Number of neutrons per unit solid angle vs angle for indicated conditions.

TABLE I

PARTICLE PRODUCTION FOR THE
300-MeV π^+ INCIDENT ON ^{64}Cu

SUMMARY OF EVENTS FOR TAPE

INCIDENT ENERGY (MEV): 300 INCIDENT PARTICLE TYPE: 2
TARGET NUCLEUS: $Z = 29.00$, $A = 64.00$

TRANSPARENCIES -	6310	EVAPORATED PARTICLES	
INTERACTIONS -	10000	NEUTRONS -	32755
		PROTONS -	16406
CASCADE PARTICLES		DEUTERONS -	2386
PROTONS -	16463	TRITONS -	443
NEUTRONS -	11677	HELIUM-3 -	240
PIPLUS -	3943	HELIUM-4 -	1829
PIZERO -	1790	LEGEND FOR PARTICLE TYPE	
PIMINUS -	398	TIP=0. PROTON	
		TIP=1. NEUTRON	
		TIP=2. PI PLUS	
		TIP=3. PI ZERO	
		TIP=4. PI MINUS	
		TIP=5. MU PLUS	
		TIP=6. MU MINUS	

Similar information is available for all of the cases indicated at the above energies.

Fig. 23. Energy spectrum of neutron flux from iron beam stop at indicated shielding depth.

Additional calculations for the Area A-East beam stop have been made. If it is assumed that the neutron spectra from the beam stop are not highly sensitive to the exact design details and dimensions of the stop, Figs. 23 and 24 represent the current best estimate of the character of the neutron flux, $E_n > 15$ MeV, penetrating the shielding at 90 deg to the incident beam direction. Figure 23 also shows the energy spectrum of the flux crossing a tally boundary 30 cm into the iron. Figure 24 is a semi-log plot of $r^2\phi$ vs r where r is the distance from the center of the beam stop and ϕ is the neutron flux (number of neutrons/incident proton/m²). Assuming the flux is approximated by $\phi(r) \sim e^{-\lambda r}/r^2$, a least squares fit of the five data points yields a $\lambda = 4.65 \text{ m}^{-1}$ which gives a mean attenuation length for the integral spectrum of neutrons of 21.5 cm.

Fig. 24. Neutron attenuation of beam-stop neutrons at 90° vs shielding depth.

VII. LAMPF FACILITY CONSTRUCTION

Craft Equipment-Installation Activities

The ZIA/LACI crafts continued to provide about 1200 manhours per month of installation assistance; completed in this period were miscellaneous wiring terminations in the Injector Building, communication and paging installation in the Laboratory-Office Building, personnel safety additions and cooling-water connections in the waveguide accelerator portion and setting of magnet stands in the beam switchyard.

The L. E. Meyer Co. completed installation of the A01b and A05 cooling-water systems in the drift-tube sector of the accelerator. They are now 85% complete in comparison with a scheduled 89% on the hookup of cooling to the waveguide accelerator; all rf water cabinets are now installed and the remaining work is in beam channel systems. This same company has now completed 35% versus a scheduled 24% of the vacuum manifold connections for modules 24 - 48 and was the successful low bidder at \$38,000 for the extension of cooling water systems X01 through X08 on into the main beam line of Experimental Area A. The latter work is now about 10% complete.

The Beaty Electric Co. essentially completed the accelerator electrical installation contract during this period; only a few punch list items remain. This company has now completed 60%, compared with 53% scheduled, of their rf reference line installation work.

The Merrimac Service Cell beam and cover installation by the Richard Park Co. is now 95% complete compared with 100% scheduled. On February 18 bids will be opened for installation of an additional cooling water system in Experimental Area A.

Lot I of the High Resolution Spectrometer (HRS) installation contract consists of fabrication and installation of the support frame. The fabrication portion was initiated in this period and is now 15% complete; installation is not scheduled until June of 1972. Lot II of this contract covers magnet moving and installation onto the support frame. The original contractor declared during this period that he elected not to do the work and wished to default. The performance bonding company therefore negotiated with the next low bidder on this package, Southwestern Industrial Contractors and Riggers, Inc.; an agreement was reached such that LAAO is currently

issuing a new contract to that firm. Actual work on this phase is not scheduled to start until Aug. 1972.

Building Construction

Occupancy of the Nuclear Chemistry wing of the Laboratory-Office Building was taken on 16 December; only a few punch list items remain to be corrected. Final acceptance of the Experimental Facility Phase I package was taken during this period.

The Experimental Area Phase II contract is now 88% completed compared with a scheduled 84% which includes an extension of time for strike and weather days. Beneficial occupancy of service aisle A is expected about 21 February. During this period, all siding and roofs were completed, the top of the C-Area dome was poured and the forms were stripped and transformers were installed in the mechanical equipment building.

The Experimental Area Phase III (Area A-East) contract has progressed to 59% completion. Current work on this package includes rubbing of concrete work, forming of the biomed service shaft and prefabrication of cooling water lines. This contractor, Beckman Construction Co., is not expected to make up any appreciable amount of time toward the original schedule which projected the current status to be 94%. Architect-engineering was initiated on Site-work and Utilities Phase III. This package will include completion of site erosion control, extension of roads around the experimental area and miscellaneous paving.

Figure 25 is an aerial view of LAMPF which shows the construction activities (as of Fall 1971). In the foreground is the Experimental Area.

Fig. 25. Aerial view of LAMPF.

VIII. NUCLEAR AND PARTICLE PHYSICS RESEARCH

Proton Compton-Effect Experiment

The data, obtained from the experiment to measure the low-energy proton Compton-effect cross section using the LAMPF prototype accelerator, are being reduced and a paper is being prepared for publication.

Pion Production Experiment

The analysis of all the cross sections has been completed. An extensive paper entitled "Production of Charged Pions by 730-MeV Protons from Hydrogen and Selected Nuclei" is being prepared and will be submitted to The Physical Review for publication.

Pion Absorption Experiment

Analysis of the data on the (π^+, p) and $(\pi^+, 2p)$ experiments continues both at LASL and at the Univ. of Virginia. The ${}^6\text{Li}$ data have been the most thoroughly analyzed. The events leading to the ${}^4\text{He}$ ground state, ${}^6\text{Li}(\pi^+, 2p){}^4\text{He}(\text{g.s.})$, are fitted very well by a deuteron pole diagram in the impulse approximation.

An algorithm to remove the efficiency and acceptance variations from the data has been devised and is being coded. This code will correct the data so that they may be compared directly with theory. This method is an alternative to making an integration of each theoretical model over the acceptance of the apparatus. In addition, a Monte Carlo code has been written which is used to calculate the acceptance of the apparatus as well as to integrate either phase-space or pole-diagram cross sections over the acceptance of the apparatus.

An invited talk on this experiment will be presented at the American Physical Society Meetings in San Francisco.¹

Scattering of 20-50 MeV $\pi^\pm$ by Hydrogen and Deuterium

A proposal to measure π^+ and π^- elastic scattering at a range of energies between 20 and 50 MeV has been approved and allotted 150 h of beam time. This experiment will be performed using the LAMPF low-energy pion channel, a hydrogen-deuterium target, and proportional wire chamber detectors.

A new type of high-pressure gaseous hydrogen target is being tried. An order for three thin-walled filament-wound flasks made with a new organic fiber has been placed.

Monte Carlo studies of the pion scattering and decay kinematics indicate that considerable effort will be required to separate pions from muons. Work is proceeding on the design of a large-area dE/dx and E system to accomplish this task.

The wire-winding machine for fabrication of the chambers is nearly complete. The winder frame is finished as well as most of the carriage components. The control electronics are being fabricated; the winder is being assembled. Extrusion and casting for possible inexpensive wire chamber frames has been investigated, and the possibility of simple gluing of strips for the frames is being studied. These methods would eliminate costly machining operations, making it possible to mass-produce frames at a reasonable cost.

Substantial progress has been made in the development of the wire chamber electronics system which should be useful in a variety of experiments. With a slight modification, the original amplifier can be used for on-chamber and off-chamber amplifiers. It is likely that a single electronic system can be built which can be used in either application which would result in a monetary saving. Construction of readout electronics for an 8000-wire system, based on the original design using Wylie hardware for packaging, is proceeding. The CAMAC packaging appears too expensive at this time. A prototype readout unit has been evaluated. This evaluation will be used to determine the least expensive way to build 40 units. These units will be directly interfaced to the PDP-11 computer, bypassing CAMAC and hopefully eliminating a great deal of system complexity, cost, and software overhead servicing time. These units will also be interfaced to the Supernova computer; the box to accomplish this has been designed and is now under construction.

Helical Multiwire Proportional Counter (MWPC) Development

Work on the development of helical multiwire proportional chambers for use as EPICS detectors continued with studies of the properties of the helical delay line. Several configurations of delay lines were tried, and a bifilar winding appears to

¹R. J. Macek, "Recent Experimental Results for $(\pi^+, 2p)$ and (π^+, p) Reactions on Light Nuclei."

be the most promising. A first design for an amplifier is in use for chamber tests. A design is in process for the readout electronics for a multi-chamber system using helical chambers. In this work on detectors and electronics, the following special requirements of the EPICS system have been considered: 1) the need for good timing measurements (1-2 nsec) on low-level positive pulses; 2) the deadtime introduced by the delay line; and 3) the long cable runs (300 ft) between the detectors and the computer. Studies of these requirements indicate that the electronics is incompatible with the electronics for a more conventional amplifier per wire system, and that a completely new design is required.

Theoretical Physics

Investigations of the possibilities of extracting nuclear structure information from pion scattering and exotic ($^{-}\pi, K, \dots$) atoms are under way. They are based on the optical model in which the particle-nucleus interaction is described by an effective single-particle potential, which is non-Hermitian, i.e., it has an imaginary part arising from inelastic processes.

The determination of neutron distribution parameters from π^2 differential cross sections has been studied. These may be measured to 0.1 or 0.2 F using EPICS. This work is now complete and a paper is being written.

An improved optical model code, which will be useful in analyzing LAMPF pion-scattering experiments, is being prepared.

An efficient recursion method has been developed for evaluating multiple-scattering series without making small-angle (Glauber) approximations. It is being applied to recent CERN π -He and π -C data.

A study of alternatives to the usual Kisslinger optical model for pions is being made. A tentative conclusion is that the ambiguities in the optical model will not be a serious obstacle to interpretation of pion scattering.

The position and width of the resonance in π -nucleus scattering have been studied. Optical models and other methods have been used. This work is being continued.

Exotic atoms have a negatively charged hadron in an orbit about a nucleus. In some states there is overlap of the wave function with the nuclear

surface, causing atomic levels to shift and broaden. Recent K-mesic atom data have been analyzed. The effective optical potential, V , which was obtained differs greatly from that predicted for free K-nucleon scattering, making the interpretation of nuclear contributions difficult. Also, because the imaginary part of V is very large, there are broad "inner states" trapped in the nucleus. A paper on "inner states" has been accepted for publication,¹ and another paper on K-mesic atoms is being written. Work on π -mesic atoms is under way.

The mathematics of perturbation theory for optical potentials has been studied. A paper giving the general formulation and its application to exotic atoms has just been completed.²

¹Justus H. Koch, Morton M. Sternheim and James F. Walker, "Complex Eigenvalues of a Coupled Channels Model," (to be published in Phys. Rev.).

²Morton M. Sternheim and James F. Walker, "Optical Models, Decaying States, and Perturbation Theory," (to be published in Phys. Rev.).

IX. PRACTICAL APPLICATIONS OF LAMPF

[Summarizes work being performed under auspices of USAEC Division of Research, USAEC Division of Biology & Medicine and National Cancer Institute.]

Biomedical Program (Application of Negative Pi-Mesons for Cancer Therapy)

Biomedical Pion Channel Design

Continued study has shown that in order to simplify the problems involved in shaping the beam at the end of the channel, the last two bending magnets, that were part of the previously reported configuration, must be replaced by a single magnet which bends the beam to the vertical direction.

Work has proceeded to shape the beam assuming this bending magnet arrangement.

Solutions to the beam-shaping problem were found using five quadrupole magnets similar to the ones used in the pion-decay section of the stopped muon channel.

Engineering of the magnets is being done.

Shielding

Detailed studies of the shielding requirements for the Biomedical Facility have been carried out in order to more clearly define the design criteria for the shielding support structure.

Using the Oak Ridge Nuclear Monte-Carlo Transport Code (NMTC) together with analytical methods, estimates were made of the neutron flux streaming through the biomedical channel assuming both 65- and 45-degree-bend designs. The NMTC was used to check the analytical techniques for the first two straight sections, including the first bend. The corrections obtained here were then extrapolated over the entire channel. The resulting neutron fluxes at the end of the channel were found to be $1.5 \times 10^{-2} \text{ nsec}^{-1}/\text{cm}^2$ for the 65-deg-bend design and $2.7 \text{ nsec}^{-1}/\text{cm}^2$ for the 45-deg-bend design. Only neutrons with $E > 15 \text{ MeV}$ are treated by NMTC, however. The lower-energy neutron flux was estimated assuming an E^{-1} distribution, thereby boosting the above numbers by a factor of about 2 to 5. The neutron flux due to π^- beam stripping was estimated to be just about comparable to the fluxes stated above, while that caused by the protons entering the channel was found to be negligible. Finally, the neutron flux at the same location, due to direct

penetration of 10-in. steel shielding, was estimated to be $\sim 2.4 \text{ nsec}^{-1}/\text{cm}^2$. Although no attempt has been made to obtain an energy distribution for the neutrons emerging from the end of the channel, it is nevertheless clear that the anticipated dose to the patient from such neutrons is well below the maximum tolerable.

Dose-Distribution Calculations

A program is near completion for calculating pion depth-dose distributions. This program uses as input the results of ORNL calculations of dose distributions for monoenergetic pion beams. The program will enable one to weight the number of pions of different ranges and to assign an arbitrary RBE to various parts of the depth-dose distribution for each monoenergetic beam component.

Treatment Planning

A preliminary investigation of the problems associated with treatment planning in the π^- meson beam facility has been undertaken. During this quarter a survey of the approaches to treatment planning used in conventional radiation therapy facilities has been done, and an outline of the input and output information desired from the program has been generated. Treatment planning programs for use on the π^- channel PDP-11 computer are under study.

Biomedical Channel Computer Control

The control computer for the Biomedical Facility was ordered this quarter. It is planned that a significant amount of both patient record-keeping and treatment-planning will be done on this system in addition to control of the beam line. The system is based on a DEC PDP-11/45 CPU with 8k of MOS memory (450 nsec cycle time) and 16k of core memory, floating point hardware, memory segmentation, 256k disc, and two IBM tape drives.

A preliminary layout of the biomedical control room has been made and the racks and control console will be ordered shortly. In-house construction of some console equipment will be started in the next quarter.

Survey of Other Radiation Sources at LASL

The availability of neutron sources at LASL which could be used for whole-animal radiobiology studies was investigated. No ideal sources are available but work could be done with neutrons from

deuterons on beryllium at the P-Division cyclotron or with 14-MeV neutrons from deuterons on a tritiated target at the N-Division Cockcroft-Walton. In the first case the mean energy is low (~ 6 MeV), and in the second case the dose rate is marginal.

Biomedical Channel Instrumentation

Basic design on the electrometer and charge-accumulation portion of the biomedical channel dosimetry electronics is 50% complete. Work has begun on a prototype NIM chassis to house the linear portion of this subsystem. Preset counters from four different manufacturers are being evaluated for reliability, noise susceptibility, and possible interface difficulties.

A vibrating reed electrometer was ordered to allow the testing of small ionization chambers with isotope sources. Work will be started toward setting up a good ^{60}Co "baseline" reference calibration traceable to the NBS for the ion chambers which will be used for the initial pion beam calibrations.

Procurement of electronics for multiwire proportional counters for channel turn-on and optimization has been started.

Medical Instrumentation in Cooperation with UNM School of Medicine

Efforts to identify areas of possible cooperation between LAMPF and the UNM Medical School are progressing. Information is being sought regarding some of the specific areas of collaboration. One possibility involves a pulsed hydraulic pressure chamber intended to reduce the cardiac work-load. The pulsing would be synchronized with (and relayed from) the ECG potential. Another area that is under discussion is electroanesthesia (EA). This is a technique where electric currents are conducted through the brain via electrodes on the front and rear (or each side) of the skull. Electroanesthesia is considered to be much safer than conventional chemical anesthetics, and the recovery from EA is very rapid. LASL may wish to become involved in the design of safe and reliable EA generators. The UNM Medical School and Bernalillo County Medical Center have indicated a definite interest in the possibility of conducting large-scale clinical tests of electroanesthesia.

Radioisotope Production

The steering committee for the LASL isotopes program has compiled a list of a few dozen isotopes that can be produced at LAMPF. This compilation was motivated, in part, by a request from AEC Headquarters for a complete cost analysis for a dozen selected isotopes. This cost analysis was made on the assumptions that the total facility would be used for the production of each isotope separately and that only a single product would be extracted from each target. Some of the isotopes included in this analysis are: ^{123}I , ^{32}Si , ^{88}Y , ^{82}Sr , ^{26}Al , ^{68}Ga .

Meson Chemistry

Theoretical studies regarding the muonic cascade process in more complicated molecular systems is continuing in addition to possibly interesting effects to be found using muons in solid-state studies. Equipment is being ordered (ADC's, telescope, detectors, etc.), target holders are being designed, and targets are being selected for use in these studies.

In Vivo Tissue Analysis with Muonic X Rays

A proposal to measure mu-mesic X-ray spectra arising as a result of the capture of stopped negative muons in mammalian tissue has been approved for 100 hours of beam time on LAMPF.

In this experiment, beef bone and selected soft-tissue organs will be used. Comparison will be made between the yield of X rays from various elements in the tissue and the amount of those elements as determined by chemical analysis of the tissue. This comparison will indicate the precision and accuracy with which the concentration of selected elements can be determined by use of mu-mesic X rays. The results will provide information on which medical researchers can base subsequent studies of the potentialities of mu-mesic X rays in their specialties, and will lay the groundwork for a more extensive program of study.

Various members of the medical community are being contacted to determine if they are interested in collaborating on this experiment.

Miscellaneous Support Activities

A wire chamber electronics system, in support of the pion-scattering experiment which will be conducted at LAMPF, is being designed and fabricated (see Sec. VII, Physics Research).

X. LAMPF USERS GROUP

Annual Users Meeting

The Fifth LAMPF Users Meeting was held at Los Alamos on 8-9 November 1971. The meeting was attended by 137 members from outside institutions and approximately 101 LASL members for a total attendance of about 238.

The meeting was opened with an address by LASL Director Harold M. Agnew, followed by a short business session. The results of the election of officers for 1972 were given:

Chairman:	Kenneth M. Crowe (LBL), succession from 1971 post of Chairman man Elect
Chairman-Elect:	Mark J. Jakobson (Univ. of Montana)
Executive Committee:	George J. Igo (Univ. of California, Los Angeles)
	Lee C. Northcliffe (Texas A&M Univ.)
	Chaim Richman (LASL)
Liaison Officer:	Lewis E. Agnew (LASL), serving on appointment by LASL

In his annual report to the members, outgoing Chairman Gerald C. Phillips remarked on the growth of the Users Group to 759 members, and gave a brief summary of its history. He also reviewed the activities of the Users Group and its working group subcommittees during the past year. The concerns of the Technical Advisory Panel (TAP) and the Executive Committee during the past year were data-acquisition systems, equipment-pool policy, channel tune-up plans, and housing for LAMPF users. Chairman Phillips briefly reviewed the funding situation for LAMPF users and the possibility of incorporating the Users Group.

The schedule of invited talks included "LAMPF Status Report" by Louis Rosen, Director of LAMPF; "Will Medium Energy Research Fly or Die?" by George A. Kolstad, Division of Research; "An Overview of the LAMPF Research Program" by Herman Feshbach, Massachusetts Institute of Technology; and "Status Report on LAMPF Research Proposals" by Louis Rosen. The banquet speaker was Paul W. McDaniel, Director, Division of Research, who spoke on "Promotion of the Academic Uses of LAMPF."

The program of the meeting also included brief technical reports on the experimental facilities, meetings of the various working groups, and a summary round-table discussion. The new Assistant Liaison Officer, Hillard H. Howard, was introduced to the members.

The proceedings of the meeting, LA-4874-MS, are in the final stages of preparation and will be distributed to all members soon.

Executive Committee and TAP

Meetings of the Executive Committee and the TAP were held on 10 November 1971, in conjunction with the annual meeting. One of the principal topics for the Executive Committee was a consideration of establishing the Users Group as a nonprofit corporation. Several advantages in identifying the organization as a clearly defined legal entity were noted, especially if the group's future activities should expand into broader services for users that involve contractual arrangements. It was decided that further information and draft papers of incorporation were needed before taking this issue to the full membership.

The Executive Committee also recommended to the LAMPF administration that a Scheduling Committee be set up, and that its actions be guided by the recommendations of the Program Advisory Committee (PAC) with regard to assignment of scientific priority among the approved experiments.

At the TAP meeting, a number of topics were discussed, including beam monitoring, separated isotope targets, cryogenic targets, progress on the biomedical area, and test channels. Detailed reports were given on production targets, the equipment pool, shielding design, plans for radiation-safety activities, and methods of running low-intensity beams. Actions were taken by the TAP (1) to set up a subcommittee on cryogenic targets, (2) to continue committee work on policy recommendations for the equipment pool, (3) to recommend the purchase of two data-acquisition computers this fiscal year, (4) to study further the computer and electronic needs as a whole, (5) to recommend that a crane be installed in Area B, and (6) to recommend that provisions be made for a test channel with an attempt to build it with surplus magnets.

Research Proposals

The following new research proposals have been received since the previous Quarterly Status Report:

- 107 "Activation Analysis Near the Beam Stop"
Victor A. Ryan, Spokesman
John C. Hill (Texas A&M Univ.); E. Gerald Meyer, Victor A. Ryan (Univ. of Wyoming); in consultation with B. J. Dropesky, J. D. Knight (LASL), others from LASL, and Graduate Students from Texas A&M Univ. and Univ. of Wyoming
- 108 "Excitation Functions of Simple Pion-Induced Reactions"
H. S. Plendl, Spokesman
S. Kaufman, E. P. Steinberg (ANL); P. J. Karol (Carnegie-Mellon Univ.); H. S. Plendl (Florida State Univ.)
- 109 "The Study of the Microscopic Structure of Collective Modes by Medium Energy Protons"
E. R. Flynn, Spokesman
E. R. Flynn, N. Tanaka, J. Spencer (LASL); Ole Hansen (Niels Bohr Inst.); N. Hintz (Univ. of Minn.); B. Zeidman (ANL)
- 110 "Below Threshold Kaon Production Rates with the p^3 Pion Beam"
William G. Simon, Spokesman
W. G. Simon, Lee Schick, Raymond Kunselman, Glen Rebka, Graduate Students (Univ. of Wyoming)
- 111 "Search for New Neutron-Rich Nuclides Produced by Fast Neutrons"
John C. Hill, Spokesman
John C. Hill (Texas A&M Univ.) in consultation with B. J. Dropesky (LASL)
- 112 "Determination of the Mass of ^{64}Ge by the Double Charge Exchange Reaction"
R. J. Peterson, Spokesman
R. J. Peterson, C. S. Zaidins (Univ. of Colorado)
- 113 "Radiation Damage and Helium Embrittlement in Elevated Temperature Reactor Structural Alloys"
Charles Z. Serpan, Jr., Spokesman
C. Z. Serpan, Jr., H. H. Smith, and J. A. Sprague (Naval Research Laboratory)