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PROGRESS REPORT

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

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

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

Compiled by
Eleanor Dunn

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QUARTERLY REPORT ON THE MEDIUM-ENERGY PHYSICS PROGRAM
FOR THE PERIOD ENDING JULY 31, 1972

by

MP-Division Personnel

ABSTRACT

On June 9, 1972, at 12:08 in the morning, an 800-MeV beam of protons was obtained from the LAMPF. Scores of men and women of extraordinary competence and dedication were involved. They came from all parts of LASL and from the nation's laboratories. Moral and practical support issued from the Washington and local staffs of the AEC, from the Joint Committee on Atomic Energy, and from hundreds of future users of LAMPF. The result is a crucial milestone on the path towards an important national goal, established in October 1968, with the release of major construction funds to this project. Having achieved full energy, we can now, with added confidence, proceed to the objective of high intensity, even as we complete and render operational the large and complex experimental facilities for the multifaceted programs which LAMPF is designed to accommodate. We shall then proceed to implement the main purposes for which LAMPF was constructed - improved knowledge of the atomic nucleus, and the application of science and technology to the betterment of life for people everywhere. A summary of the work performed and the progress obtained during this crucial period is presented.

I. SUMMARY

Engineering Support

The approximately 100 h of operation that culminated in the attainment of 800 MeV proved to be gratifying from an operational standpoint. Required maintenance was essentially zero and the overall system performance was highly satisfactory.

A realignment exercise involving both magnetic and optical methodology was completed in the Injector Area. The several misalignments discovered were such that it may be hoped that the resultant repositioning will enhance the low-energy beam transport.

A recent failure of the ceramic dome in Tank 3 will, insofar as the foreseeable future is concerned, formally mark the end of any continued attempt to use domes for the vacuum/high-level rf interface. While they will continue to be employed for the low-level monitoring loops, the experienced life of the large domes is such as to make their continued use injudicious.

The Varian contract for ten klystrons is proceeding satisfactorily. Equally encouraging, Litton would appear to be approaching a tractable solution to the "glitching" and arcing problems which have plagued their contractual efforts to date.

With the attainment of 800 MeV, the majority of the group effort has been shifted to the support of the Experimental Area and is represented in the switchyard, secondary, Biomedical Facility, and Weapons Neutron Research Facility beam lines.

A facility for performing the preinstallation testing of the Experimental Area magnets is nearing completion and will shortly be operational.

Progress on developing a scintillation and light-pipe fabrication facility and a multiwire proportional counter frame is proceeding satisfactorily.

Accelerator Systems Development

Installation and commissioning of the 805-MHz accelerator was completed and, after three weeks of extensive dry-run testing and setup in May, the first 805-MeV beam was achieved very early in the morning of June 9, 1972, nearly a month ahead of schedule. The energy was verified using beam-loading techniques and the delta-ray spectrometer. Equipment problems during this period were minor, an encouraging indication of generally sound engineering.

Emphasis was shifted to setting up the program

for bringing the machine to full-intensity operation. The experimental program was resumed near the end of the quarter, and preliminary matching studies are under way.

Development of application programs, using the central control system, were continued. The power of the control system becomes increasingly clear when the whole accelerator is available to work with.

Scrapers were added to the high-intensity transport line, and considerable progress has been made in achieving reproducible operation.

Tests of the single and multiaperture H^- source were conducted and encouraging results were obtained. Over 2 mA of H^- beam has been achieved. Construction of the H^- injector was continued.

Electronic Instrumentation and Computer Systems

A significant milestone was passed in June when the 800-MeV beam test was conducted entirely through the LAMPF computer-based control system. The success of this test is in part a confirmation of the conceptual design of the control system and a measure of the thoroughness with which it was engineered and tested. Further advances in the state of art of computer control of accelerators can be expected as the full power of the system is exploited.

The installation and wiring of equipment in the switchyard were major tasks this quarter. The control equipment in 20 racks had to be connected to various devices, some crucial to the 800-MeV test. The work on Line A was completed, but Line X will not be finished until August. Work started on a group of programs to provide for control of the magnets in the switchyard.

Preliminary designs for the control systems in Areas B and C were completed. Drawings were prepared to show the locations of all the devices along Beam Lines B, C, EP, and HS. A tentative rack and chassis layout was made for the 24 racks of control equipment. Hardware channel assignments were given to the 1000 data and control signals compiled for the two areas.

The second operator's console with its new hardware was put into operation for the 800-MeV test. Preparations for retrofitting the first console are almost complete.

An additional 16,000 words of core memory were installed on the control computer. This action

greatly eased the core-loading problem.

Several of the operational systems were extended to the switchyard. These included the timing, fast-protect, radiation-safety, TV, communications and video systems.

The first major goal of the programming effort for the data-acquisition computers was achieved when data were acquired through an "underground" program and written on magnetic tape - the fundamental data-acquisition task.

The first CAMAC Branch Driver (MBD) was put into operation. In a demonstration, the MBD acquired data, from a scaler under interrupt control, and plotted the 24-bit data in a simple histogram on a scope. Three additional MBDs were built and tested.

Accelerator Operations

The main activity during this period was an intensification of operator training on accelerator operations in preparation for the 800-MeV beam tests. This was accomplished by scheduling operations for several weeks of three shifts per day interspersed with weeks of two shifts per day. By working with the experimentalists, beam line physicists, and systems engineers, the crews learned and became fairly proficient in running the accelerator and making adjustments to the system to keep the accelerator on-line. Consequently, during the 800-MeV tests, the crews performed their tasks with a high degree of skill and deserve a fair share of credit for the success.

During the next quarter, additional personnel will be assigned to operations to bring the organization to full strength.

Experimental Area

Final design of the Isotope Production Facility has been completed; bids have been received and construction is expected to begin in August. An architect has been selected for the Radiobiology and Therapy Research Facility and design work has been started. Another architect has been chosen for the Weapons Neutron Research Facility and design work is to begin in August.

After the successful use of the switchyard to receive and perform preliminary analysis of the 800-MeV beam, the effort to complete the switchyard for detailed beam diagnostic studies was undertaken. All of the required switchyard magnets are installed

and a shakedown of the power supplies, control systems and instrumentation is in progress. The computer interfacing and data-acquisition systems are nearing completion. The switchyard is scheduled to be fully operational early in the next quarter.

Many of the magnets, power supplies, and other components for Beam Area B (the Nucleon Physics Laboratory), Beam Area C (the High-Resolution Proton Spectrometer) and their respective beam lines have been received and are being tested. Other components such as the LD_2 target for Area B and the instrumentation for both beam lines have reached the final design stage. Detailed layouts of all the components are being made. A great deal of consideration has been given to the proper use of strippers and instrumentation to tune the beam lines and to provide the necessary diagnostic information.

A satisfactory bid has been received for the machining of the Energetic Pion Channel and Spectrometer (EPICS) bending magnets. Progress on the other parts of the system remains in order though some difficulty in instrumentation development has been experienced. The design of the EPICS beam separator has been completed and fabrication is expected to begin soon.

A number of vacuum components for the Low Energy Pion Channel have been received and others are in fabrication. A large fraction of the channel design work is complete.

Extensive users' support has been given to the work on the High-Energy Pion Channel (P^3). Such work has included studies of tune up, beam monitoring, backgrounds, magnet mapping, π - μ separation, and the effects of slit scattering. The design and procurement of the hardware for the channel is proceeding on schedule but much physical preparation of components for installation remains to be done.

Magnet fabrication for the Stopped Muon Channel is well in hand. Four additional power supplies have been requested. Approximately 50% of the support and alignment system has been ordered and the remainder is being designed. Work on the beam line vacuum system and accessories is proceeding on schedule.

All nine of the large, radiation-hardened quadrupole triplets for the transport of the proton beam through Area A and to the beam stop have been received. The preliminary electrical and water fitting

of the magnets has begun.

The target-testing station at the 100-MeV "north port" is nearly ready for use. A modest program to further test Area A and Biomed targets has been planned.

Considerable operating experience has been gained with the de-ionized water systems for Area A. Much remains to be completed on the systems and their eventual connection to their magnet and target loads but no problems have arisen to date.

The delta-ray spectrometer was successfully used in the switchyard to provide an added verification that 800 MeV had been obtained. Checks on beam energy were also made at 226 MeV and 680 MeV as the appropriate modules of rf power were turned on.

The Merrimac gantry has been attached to its shielded enclosure and the combined system has been moved with the gantry hydraulic power system. The final outfitting of the shielded enclosure and the Merrimac Service Area is scheduled to proceed on an as-needed basis.

The stacking of shielding in Area A has begun. The shielding layout is primarily determined by the secondary beam line designers and by the need to supply water and electrical power inside the shielding mass. The stacking of the shielding is expected to continue apace with the installation of the primary and secondary beam line components.

Additional shielding calculations of the neutron-flux spectrum available from the Area A beam stop have been completed. The calculations were performed for use by those interested in isotope-production and radiation-damage studies.

LAMPF Facility Construction

Craft installation of equipment was completed for the accelerator and is now exclusively devoted to the experimental areas. Building construction for LAMPF has been completed.

Physics Research

General Facilities for Preparation of Experiments

General facilities for the preparation of experiments have been established and are being put into effect. The equipment for winding multiwire proportional counters (MWPC) has been used to wind chambers for several groups. The associated electronics, namely wire amplifiers, wire position encoders, and computer interface, have been produced

in large quantities. Standard designs of phototube shields and bases are being procured in quantity. The intention is that MWPC and scintillation counters shall be made available for a large group of experiments.

Helical Multiwire Proportional Counter Development

Development of helical wire proportional counters (HWPC) continued during the quarter, with very encouraging results. A prototype HWPC was tested at the tandem Van de Graaff facility. The measured spatial resolution was 0.6 mm FWHM but, since the beam spot size was unknown, this is an upper limit for the resolution. The counter was operated at rates up to 50 kHz, and it appeared that this rate will be possible for operation with EPICS. Helical chamber electronics development and EPICS logics electronics development is proceeding.

Pion-Absorption Experiment

The data on π production has been examined with a view toward discovering empirical laws governing the cross section. Several approximate laws have been deduced.

Practical Applications of LAMPF

The work presented here is being performed under the auspices of the USAEC Division of Physical Research, USAEC Division of Biomedical and Environmental Research, USAEC Division of Military Application, and the National Cancer Institute.

Biomedical Program

Biomedical Pion-Channel Design

Design studies for the pion channel have become more sophisticated in that they incorporate higher-order calculations for the beam optics. Other studies indicate that coulomb scattering will be within reasonable limits even though most of the channel is air-filled, except for the last five quadrupoles, which are helium-filled. The designing, engineering, and procurement of the channel components are proceeding at a reasonable rate.

Pion-Production Target

Due to space limitations, a 1.5-cm-diam, 5-cm-long, water-cooled graphite target will be used to produce negative pions for the biomedical channel.

Dose-Distribution Calculations and Dosimetry

Calculations of LET distributions were started using the results of the pion-energy-deposition

calculation from ORNL. Dosimetry equipment, e.g., Rossi counters, ion chambers, radiation-damage diodes, electrometers, etc., is being purchased, constructed, or tested.

Treatment Planning

Various sections of the treatment-planning computer program are being written and debugged. One section was adapted from the Stanford pion-treatment-planning code.

Neutron Dose From Pions Stopping in Tissue

When pions are stopped in tissue, some of the components of the resultant stars are neutrons and gamma rays. Recent work indicates that the neutron dose at ~ 5 cm from the edge of the treatment volume will be ~ 1% of the treatment dose. Therefore, the average whole-body neutron dose will be ~ 0.3% of the treatment dose, and the whole-body gamma-ray dose will be negligible.

Shielding

Studies indicate that the shielding between the LAMPF proton beam and the patient will have to be 7 or 8 ft thick in order to not substantially contribute to the average whole-body neutron dose discussed above.

Computer Control System

Work on the computer control system is progressing. Most of the equipment, including the PDP-11/45 computer, is scheduled to be delivered in August. The software for the computer control system is being modified and debugged.

Medical Instrumentation Development

The following equipment is being developed in cooperation with the University of New Mexico School of Medicine: an ECG preamplifier that is less sensitive to rf noise and a balanced coaxial transformer for electrosurgery units, which together will greatly alleviate the problem of taking ECG readings while electrosurgery units are being operated. A new type of electrosurgical scalpel will "seal" arteries as they are cut. An ECG synchronized chest compressor that increases blood pressure by more than 20% and should increase blood flow rates is being tested.

In Vivo Tissue Analysis with Muonic X Rays

Work leading to a more accurate prediction of the muonic x-ray spectrum from tissue is continuing.

This work requires the determination of spectral line shapes with Ge(Li) detectors, as well as the calculation of line yields.

Meson Chemistry

This work is similar to the *in vivo* tissue analysis discussed above. A cascade code is being used to calculate relative muonic x-ray intensities in several light atoms.

Radioisotope Production

Some radioisotopes, e.g., ^{86}Y and ^{123}I , are being produced or will be produced soon, using the LAMPF proton beam at 100 MeV and 500 MeV. Additional data obtained during three series of experiments performed at the Space Radiation Effects Laboratory (SREL) have been analyzed and are being compiled in preparation for publication.

Weapons Neutron Research Facility Beam Line

The beam line extending from the LAMPF switchyard area to the Weapons Neutron Research Facility (WNRF) is under study.

LAMPF Users Group

The Executive Committee of the LAMPF Users Group had a combined meeting with the LAMPF Electronic Equipment Pool Subcommittee (LEEP) of TAP at LASL on July 24, 1972. They received reports from R. E. Mischke on the status of the equipment pool and D. C. Hagerman on the status of the accelerator. In an executive session the Executive Committee incorporated as the LAMPF Users Group, Inc. and became the first Board of Directors. They heard a report from Harry Palevsky (BNL), Chairman of the HRS Working Group, on the status of the High-Resolution Spectrometer and discussed a housing survey and its implications. The Board of Directors called for definite answers on telephones and transportation for users and a doubling of the LAMPF priority housing by next spring.

Users Activities

The activities of the users were mainly in the form of working group meetings at LAMPF. The Biomed. Working Group Subcommittee on Radiation Therapy held a combined meeting with the CRTS Subcommittee for Human Trials on May 31, 1972, to discuss many problems of common interest. There was an organizational meeting for a Radiation Damage Working Group on June 29-30, 1972, which elected Walter Green (LASL, CMS-13) as Chairman and C. Serpan (NAL) as Secretary.

The P³ Working Group discussed tasks for users during its July 13-14, 1972 meeting. A combined meeting of the HRS Working Group Committee and the NPL Steering Committee was an informal series of talks and discussions on the overlapping interests of the HRS and NPL experimental programs.

Liaison Office

The Liaison Office began setting up procedures for processing visiting LAMPF experimenters and expediting their access to services. The office began helping AWU with its administration of the AEC Division of Research travel funds for LAMPF-related experiments. The July Newsletter will be mailed the first week in August. The Liaison Office conducted a housing survey for the Executive Committee and is continuing to study the problems of telephones, transportation, storage, and a handbook for users.

Program Advisory Committee

The PAC (Program Advisory Committee) will meet at LAMPF on September 27-28, 1972.

Research Proposals

There were seven new research proposals submitted this quarter.

Publications

"Beam Measurements on the High-Intensity Proton Injector of LAMPF," Los Alamos Scientific Laboratory report, LA-4961-MS (May 1972).

"Origins and History of the Los Alamos Meson Physics Facility," Los Alamos Scientific Laboratory report, LA-5000 (June 1972).

"Elastic Pion-Nucleus Scattering for Studies of the Nuclear Surface," Los Alamos Scientific Laboratory report, LA-4969-MS (June 1972).

D. F. Jones and E. R. Martin, "A System for Separating Amplifiers from Wire Proportional Chambers," Nucl. Instr. and Methods 98, 535-540 (1972).

E. R. Martin and D. F. Jones, "A Fast Total Information Readout System for Multiwire Proportional Chambers," Nucl. Instr. and Methods 98, 541-547 (1972).

G. R. Emigh, E. A. Meyer, D. W. Mueller, and R. R. Stevens, "LASL Experience with a Duoplasmatron Feeding a 750 kV 'Exact' Pierce Column," Proc. of the Symposium on Ion Sources and Formation of Ion Beams, BNL-50310, 1971.

P. W. Allison and G. R. Emigh, "LAMPF H⁻ Ion Source Development," *ibid*.

M. M. Sternheim and R. R. Silbar, "Model for Production of π^+ and π^- by Protons from Nuclei," Phys. Rev. C (July 1972)

R. L. Burman, "Pion Beams at LAMPF," published in the Proceedings of the Intern. Seminar on Pi-Meson Nucleus Interactions, Strasbourg, France (September 1971).

Papers Prepared for Publication; Papers Submitted at Conferences

D. W. Mueller, "Observations and Calculations for a Duoplasmatron with Exact Pierce Extraction," submitted to Nucl. Phys. A (June 1972).

R. R. Silbar and M. M. Sternheim, "Model Dependence of Pion-Nucleus Total Cross Sections," submitted to Phys. Rev. C (March 1972).

J. H. Koch and M. M. Sternheim, "Models for π^+ - 16O Scattering at 270 MeV," submitted to Phys. Rev. C, Comments and Addenda (April 1972).

H. A. Thiessen, D. M. Lee, and S. E. Sobottka, "A Bifilar Helical Multiwire Proportional Chamber for Position Sensitive Detection of Minimum Ionizing Particles," submitted to Nucl. Instr. and Methods (May 1972).

L. S. Kisslinger, R. L. Burman, J. H. Koch, and M. M. Sternheim, "Elastic Pion-Nucleus Scattering for Studies of the Nuclear Surface," submitted to Phys. Rev. C (May 1972).

R. J. Jacob and G. E. Hite, "Extension of Boundary Dispersion Relations," submitted to Phys. Rev. D (July 1972).

J. E. Spencer and H. A. Thiessen, "Some High Resolution Techniques for Use with Negative Ion Beams," submitted for the 1972 Proton Linear Accel. Conf., Los Alamos, NM, October 10-13, 1972.

W. V. Hassenzahl, "An Algorithm for Eliminating the Duodecapole Component in Quadrupole Magnets," and "A Computer Controlled Magnet Measuring Facility," submitted for the 4th Intern. Conf. on Magnet Tech., BNL, September 19-22, 1972.

A. Harvey, "Radiation-Hardened Magnets Using Mineral-Insulated Conductors," submitted for the 4th Intern. Conf. on Magnet Tech., BNL, September 19-22, 1972.

L. Rosen, "Status of Construction and Experimental Program for LAMPF," presented at the 6th Intern. Cyclotron Conf., Vancouver, B. C., July 18-21, 1972.

D. E. Nagle, "Status of LAMPF," to be presented at the 3rd All-Union Nat. Conf. on Particle Accelerators, Moscow, USSR, October 2-4, 1972.

R. F. Thomas, Jr., and Satish Dhawan, "Standard Software for CAMAC," to be presented at the IEEE 1972 Nucl. Sci. Symposium to be held in Miami, FL, December 6-8, 1972.

M. A. Paciotti, "The LAMPF Biomedical Facility," to be presented at the 3rd All-Union Nat. Conf. on Particle Accelerators, Moscow, USSR, October 2-4, 1972.

D. W. Mueller, "Observations and Calculations for a Duoplasmatron with Exact Pierce Extraction," to be presented at the 2nd Intern. Conf. on Ion Sources, Vienna, Austria, September 11-16, 1972.

J. R. Parker, J. H. Richardson, and J. D. Easley, "A New Beam-Spill Control System for LAMPF," to be presented at the 6th Intern. Cyclotron Conf., Vancouver, B. C., July 18-21, 1972.

L. R. Biswell, D. R. Machen, R. E. Rajala, and R. J. Thomas, Jr., "A Long Distance CAMAC Branch via Data-Link and Microprogrammed Branch Driver," to be presented to the IEEE 1972 Nucl. Sci. Symposium, Miami, FL, December 6-8, 1972.

J. E. Spencer and H. A. Thiessen, "Tune-Up Procedure for a High Resolution Transport System," to be presented at the 4th Intern. Magnet Conf., BNL, September 19-22, 1972.

D. E. Nagle, J. W. Doane, Richard Madey, and Alfred Saupe, "Effects of the Passage of Ionizing Particles Through a Liquid Crystal," to be presented at the 4th Intern. Liquid Crystal Conf. at Kent State Univ. Kent, OH, August 21-25, 1972 (Proceedings will be published in Molecular Crystals and Liquid Crystals.)

D. R. Machen and J. M. Potter, "A Satellite Control and Diagnostics Computer System for the LAMPF Injectors," to be presented at the 1972 Proton Linear Accel. Conf., Los Alamos, NM, October 10-13, 1972.

H. A. O'Brien, Jr., C. J. Orth, and M. E. Schillaci, "Proton Spallation Cross Sections at 600 MeV for F, Co, As, Nb, Ta, and Bi Targets," to be presented at the 164th Nat. Meet. of the American Chemical Society, New York, NY, August 27, 1972.

H. A. Thiessen and M. Thomason, "Design of EPICS. A High Resolution Pion Beam and Spectrometer System for LAMPF," to be presented at the 4th Intern. Magnet Conf., BNL, September 19-22, 1972.

H. F. Vogel and J. J. Rosenthal (CMB-6), "Cement Potted Coils for Muon Channel Magnets," abstract submitted for the 1972 Proton Linear Accel. Conf., Los Alamos, NM, October 10-13, 1972.

L. Heller and D. E. Nagle, "Program of Neutrino Experiments at LAMPF," contributed to the 16th Intern. Conf. on High Energy Physics, Chicago, IL, September 6-8, 1972.

II. ENGINEERING SUPPORT

LAMPF Accelerator Structures

201-MHz System

An alignment check of the Tank 1 drift tubes and the Injector Area monuments was made. Four of the 31 drift tubes in Tank 1 and the Injector Area monuments were found to be out of line in excess of the allowable tolerance. The four drift tubes and alignment monuments were repositioned to the axis of Tank 1 and all Injector Area components originally aligned to the Injector Area monuments were re-aligned.

A new drive loop using a Rexolite window was installed in Tank 2 during the shutdown period for realignment. The original loop used in this tank was slightly undercoupled.

The subsequent pumpdown after realignment of Tanks 1 and 2 proved to be evasive. One of the four pumps was replaced with a new pump and one pump was removed for installation of new elements. The used pumping elements were badly contaminated and some were warped to the point of shorting between the cathodes and anodes. These pumps have digested substantial quantities of freon during the past few months from a crack in the rf drive-loop dome. Steps are being taken to overhaul all of the 201-MHz 2400 liter/sec ion pumps on a routinely scheduled basis.

The ceramic dome, coated with lithium-based material and installed in Tank 3, failed by implosion after 370 h of operation and was replaced with a Rexolite window. Tanks 2, 3, and 4 now have rf drive-loops with Rexolite windows. Tank 1 still has a ceramic-dome window that has performed satisfactorily for more than 18 months but is scheduled for replacement as soon as the new model is available.

Approximately 400 h of high-voltage operation was logged on each of the 201-MHz amplifiers this reporting period. The equipment performed satisfactorily during the continuous run for 800-MeV tests.

The prototype 2661 tube on loan from BNL was run successfully at 600 kV. A prototype 4664 tube was received from RCA for evaluation. Although this tube has a lower gain, it exhibited the same fifth harmonic problem encountered with the other 4664 tubes.

A study is under way to upgrade the resonance controllers in an effort to make them compatible with computer-based turn-on.

Phase and Frequency Reference

The original design for the phase control for both the 201-MHz and 805-MHz systems referenced these two signals to the multiplier outputs such that the phase relationship was dependent upon the integrity of the 201-MHz to 805-MHz multiplier. The phase control has been modified so that the 201 MHz is referenced to the 201-MHz output of the multiplier and the 805 MHz is referenced to the 201-MHz driveline. This permits the signals, as seen by the two drivelines, to shift together and maintain phase coherence if the multiplier output should shift for any reason.

Failure of the interface amplifiers began to occur regularly after about 2,500 to 3,500 h of continuous operation, which was considerably less than expected. An investigation revealed that the filament transformers in these amplifiers were delivering 29.5 V rather than their rated 26 V. All circuits were modified to correct this condition and the control system rearranged such that the amplifiers are turned on and off in parallel with the klystron and modulator filament supplies. These two changes should substantially increase the life of the interface amplifiers.

Both the 201-MHz and 805-MHz driveline amplifiers have continued to perform well. The 201-MHz driveline amplifiers have now accumulated 14,000 h of operation without a failure and the 805-MHz amplifiers have accumulated 6,500 h of operation with one failure.

805-MHz Systems

Final installation of quadrupole doublets, beam diagnostic gear and vacuum systems was completed just prior to attainment of the 800-MeV beam tests.

The original order for 45 Varian VA862-A klystrons is now complete and all but one has been tested and accepted. An order for ten additional klystrons has been placed with Varian and delivery is expected to start in August.

Two Varian klystrons failed during the past quarter. Both have cracked mod-anode ceramics and, in each case, water was found in the modulator.

The manufacturer has stated that broken ceramic insulators is the most common cause of failure in tubes of this type, usually caused by water in the modulator. A program is under way to find and repair water leaks.

Fourteen of the 25 klystrons ordered from Litton have been received, three of which were rejected. Four of the 11 that were accepted became inoperable after less than 1,000 h of use. The output glitch problem has been brought under control but the high-voltage arcing problem is still severe. Several design changes have been initiated to lower the electric fields in the region of the gun in an attempt to mitigate the arcing problem.

The Varian klystrons have now accumulated more than 105,000 filament hours and 79,000 plate hours with four failures. The Litton production klystrons have had four failures after accumulating 7000 filament hours and 5000 plate hours.

Switchyard

All magnets for the switchyard were placed in the tooling dock, were measured and fixtured for the offset alignment reference line. Final precision alignment of the switchyard facility is in progress. All 18 magnets, several beam boxes, centroid monitors, and beam diagnostic gear are being placed in final position. Fabrication of the vacuum systems components is being done in-house by heliarc welding, furnace brazing and clean firing in the H₂ furnaces. This work is nearing completion and most of the vacuum systems are in place.

Lines B and C

An order has been placed for nine twister magnet alignment mounts with delivery scheduled for August. Approximately 25% of the Line B magnet supports are on hand. Drawings for the LB-BM-04 and -05 magnet supports have been completed and sent to potential suppliers for quotation. Design drawings of the magnet supports for LB-BM-06 and -07 and the large 17° bending magnets for Line C are complete and in the process of final checking. Quotations were received and an order had been placed for three 2400-liter/sec ion pumps and 12 power supplies required for the HRS. Fifty percent of the pumping elements in these pumps will be of the noble gas type to handle the relatively large volume of He which will diffuse through the mylar windows.

Area A

Preliminary line layouts of the four secondary Area A beamlines (Stopped Muon, LEP, EPICS, P³) were made to facilitate proper shield-stacking. The vacuum system for Line A is in the process of redesign, which was necessitated by the recent change in the original parameters and addition of several large components to the evacuated volume.

Two orders have been placed for the three major magnet support assemblies required for the LEP line. Additional orders are placed for miscellaneous sub-assemblies and parts are on hand for the two quadrupole doublet assemblies.

Biomedical Beam Line

Drawings of the basic assembly of the quadrupole triplet have been completed, quotations have been received, and the vendor is being selected. Drafting has started on the first two bending magnets. The mineral-insulated conductor order for the first five magnets in this line is 80% complete.

Detail drawings of the last five quadrupole magnets is approximately 50% complete and the conductor order will be awarded after review of the bids.

Design of the third bending magnet for this line is nearing completion and preliminary designs for magnet and shielding support structures is under way.

Magnet Power Supplies

Installation of the fourth transition region (201-805) main line bending magnet is complete. All 12 of the TR quadrupole focusing magnet power supplies have been modified such that the current output can be adjusted from the Computer Control Room (CCR).

One of the surplus power supplies received from the Princeton Particle Accelerator Laboratory (PPA) is being set up in Area A and will power magnets for preinstallation tests. The problem of interconnecting the supply with the remotely located incoming ac connector, control interlock chassis, regulator chassis, and magnet interlocks has been resolved and preinstallation testing of magnets should start within the next two weeks.

Installation of the nine power supplies for the switchyard magnets was completed and tests were conducted with dummy loads, using their regulators and control systems. Power supplies for magnets LA-QD1, LA-QD2, LX-QT1, LX-QT2, and LX-QT3 have all powered

their respective magnets. The Alpha power supplies for the bending magnets in Lines A and X arrived and have passed acceptance tests. The remainder of the 56 power supplies being purchased from Acme Electric Co. were received and are being acceptance-tested.

A basic design review of the power supply control and regulation system was conducted which resulted in a completely different philosophy of packaging and in considerable simplification. This new concept should provide a system with more flexibility and greater reliability. Drawings for this repackaged unit are 75% complete and procurement of some of the 60 to 70 units will start within the next two weeks.

Specifications for internally regulated power supplies to be used in the Biomedical Line have been sent to several suppliers for quotation.

A facility to build scintillation and light-pipe assemblies is being established and the first assembly is in the process of fabrication.

A surplus 16-in. lathe was acquired and is being modified for use in the winding of the helical chamber frames for multiwire proportional counters. The swing is being increased to 20 in. and slowest speed of 35 rpm is being reduced to 7 rpm by modifying the drive gearing.

The seven magnets on loan from the Cambridge Electron Accelerator Laboratory (CEA) were received. Two of these magnets will be used in secondary beam lines and the remainder will become part of the magnet pool.

Design engineering studies for Line D-WNR components have been started.

III. ACCELERATOR SYSTEMS DEVELOPMENT

805-MHz Accelerator System Commissioning

Achievement of 800-MeV Beam

The accelerator and target were ready by June 5, 1972, and the quest for 800-MeV beam began at 0000 hours on the morning of June 5. The first indication of full-energy beam was obtained at about 1700 hours on June 8 as determined by beam loading, the primary method used for tuning the accelerator field parameters. A plot of the beam loading in each module is shown in Fig. 1. Measurement of the energy was achieved at 0008 hours on the morning of June 9, with the evidence shown in Fig. 2 of an 800-MeV peak obtained by the delta-ray spectrometer in the target area. The 800-MeV beam was achieved nearly a month ahead of schedule.

During May, a great variety of work was completed, including completion of the high-power testing of accelerator structures, magnet installation and alignment, vacuum work, control system setup, calibrations, etc. During the two weeks of dry runs that were conducted in May, a major concern was to bring together an efficient set of programs to use during the 800-MeV tests. The resulting set ran well, and the power of the control system was dramatically demonstrated by the efficiency of operating from the central control room as compared with local operation. The computer was used extensively to conduct hardware test and calibration activities.

Also during May, the Δt procedure was used to determine the settings for modules 5-10, as detailed below. This reduced the amount of tuning effort required during the final run.

The problems encountered with equipment during May and particularly during the final run were remarkably few, an encouraging indication of generally sound engineering.

805-MHz Accelerator Structure Tuning

Final module frequency and stopband checks were completed for the remainder of the 805-MHz linac structures with the vacuum manifolds installed. The set of the special-purpose tuning tools and tuning-measurement gear was put in storage in case further adjustment of any part of the accelerator is required.

Information on the many operations of the tuning procedure has been collected and a report on this subject is in preparation. Previous summaries of

Fig. 1. Plot of beam loading in each module during first 800-MeV run. Upper trace shows beam current along the 805-MHz linac, with ~ 3 -mA peak at 800 MeV. Lower trace shows beam-loading power correction applied to the 805-MHz linac modules. The dips to the baseline are missing data.

Fig. 2. Verification of 800-MeV peak obtained on June 9, 1972. Indication at right of the 800-MeV peak detected by the delta-ray spectrometer.

the installation, tuning, and initial test data are being checked and updated. A new summary of 805-MHz structure data will be issued shortly.

Accelerator Systems Performance and Development

General

The emphasis was shifted from installation and commissioning for the initial 800-MeV beam to planning and setting up the effort required to proceed with development of the machine to full-intensity operation. Work was initiated toward defining scope, schedules, and methods for carrying out the program and falls into three rough categories. First is the direct experimental and theoretical program dealing with the actual beam performance and evolution of tuning strategies. Second is the

continued improvement of the equipment for reliability and efficiency, and third is the investigation of new techniques.

RF Field Control

Effort has been concentrated on the development of a maintenance facility for the phase and amplitude control systems and the low-level rf equipment. The maintenance facility for these systems is still in the study phase but is nearing final definition. Installation and setup of maintenance equipment will begin as soon as space is designated. The equipment for checkout of phase and amplitude printed circuit boards is being built and should be completed in a few weeks. The writing of procedures for maintenance and checkout of this equipment is also under way.

A second area of effort is the planned improvements of the 201.25-MHz phase and amplitude controllers. These controllers are built and will be bench-checked soon. Before actual installation the bin wiring must be modified to accept the new controllers. Along with this effort, improvement to the buncher controllers is also planned.

A passive multiplier from the 201.25-MHz drive line to the reference input of the 805-MHz drive line's phase controllers was installed as the final link in the drive line control system. Detailed testing of the drive line systems must now be carried out.

805-MHz Accelerator Module-to-Module Field Adjustment

Prior to the initial 800-MeV run, the At procedure was used to determine the proper rf amplitude and phase set points in modules 5-10. During the initial 800-MeV runs, the phase set points for the remainder of the 805-MHz modules were set from beam-loading considerations.

A beam-loading program was written for the SEL 840-MP computer. This program measures the beam loading in a module as the phase of that module is scanned, and produces a beam loading-vs-phase curve on the display scope. By comparing the experimentally obtained curve with a theoretical curve, one can estimate a reasonable phase set point for each module.

Beam Loss in the 805 MHz Accelerator

In order to avoid excessive beam loss in the 805-MHz portion of LAMPF it is necessary to: 1) keep

the beam on axis by steering and 2) match the transverse emittance of the beam to the admittance of the accelerator.

A simple and straightforward steering algorithm was developed two or three years ago. This steering method assumed steering magnets and beam-position monitors in each module. Since the position monitors are not yet functional, it may be necessary to use some of the wire scanners as a temporary substitute.

A program has been written for the SEL 840-MP computer that will attempt to match the beam to the accelerator. The matching procedure uses the 12-wire scanners in modules 5-8 to determine the rms beam widths at the wire scanner locations. If the beam is not matched to the accelerator, then the wire scanners will show a noticeable oscillation in these rms beam widths. Transition region quads will then be systematically adjusted in an effort to minimize the amplitude of the oscillation in beam width.

It is believed that the bulk of the beam loss incurred during the 800-MeV run will be eliminated by proper matching across the transition region and through the initial modules of the 805-MHz linac. This investigation will form the major part of the experimental program for the next quarter.

Admittance of the 201.25-MHz Linac

Since the introduction of an automated technique for measuring the linac's transverse admittance over six months ago, it has been established that while the vertical admittance of Tank 1 was quite acceptable, the admittance in the horizontal plane indicated serious problems. This was further borne out by the fact that for best beam transmission during regular linac runs extreme steering was required at the linac entrance. Several approaches were taken to determine the nature of the problem. The resistance of the electrical leads to each quadrupole was measured to insure that no turns were shorted. Two series of admittance measurements were made while systematically shorting quadrupoles singly and in pairs in an attempt to discover a misalignment. It was impossible to single out by this method, any one or two adjacent drift tubes as the source of the difficulty.

A Hall-effect probe designed to seat in the bore of the drift tube was used to detect any asymmetry in the quadrupole fields relative to the drift-tube bore. None was found. A second probe similarly

designed but emitting a small point source of light at its center (termed the tail light) was built to optically check the physical alignment of each drift tube. Although each drift tube was initially positioned with an accuracy of ± 0.003 in., four of the drift tubes in Tank 1 were discovered to be misaligned by ten times that tolerance.

Using the measured position of each drift tube, the admittance of Tank 1 was calculated numerically with the PARMILA program and found to be in very close agreement with earlier experimental results. As a result of this study, four of the drift tubes were realigned to restore the admittance. Subsequent tests with beam confirm that the best beam transmission is now achieved by injecting straight into the linac, with no steering.

Developments in the Use of Central Computer Control

As mentioned above, the capability to operate from the central control room kept pace with accelerator installation, with the development of a set of general plotting, parameter control and display programs, and some reprogramming of some of the applications programs to take advantage of improvements made to the consoles.

Several additional programs were needed and developed for the 800-MeV test, including further evolution of the 805-MHz rf system control and monitoring, a general facility status program which provides a continuous display on two lines of the character scope, as well as use of some of the general plot programs to determine power line phasing and power supply stability over the whole facility.

An effort was initiated in collaboration with the control computer personnel with the aim of understanding the fundamental limitations of control performance obtainable with the present system.

Diagnostic Equipment Development

The design of a device for switching the control capabilities of a single-emittance control system to any one of six different emittance stations was completed during this period. Fabrication and installation of the device were initiated and are ~ 25% complete.

A program for completing the development of the beam-position monitors was begun in a joint effort with the controls group.

Transport Area Studies

Considerable progress was made during this quarter in the optimization of the high-intensity beam-transport system. This work is outlined in detail in the following sections covering the injector program.

Injector Programs

The High-Intensity Injector Program

Ion Source and 750-kV Accelerating Column

The duoplasmatron ion-source assembly III a/11 has been operating for over a year in the H^+ injector dome. The only replacement part required during this time has been a new cathode, CT-3, which was installed after cathode CT-2 failed last March.

The filament storage stand has been enlarged to include a vacuum storage container for a fully assembled ion source. Three individual ion pumps, each 10 liters/sec, are provided for the filament stations and one 50-liter/sec pump has been added for the ion source storage unit.

The filament outgassing stand has been improved by the addition of a mechanical refrigeration unit so that efficient use can be made of the titanium sublimators available within the 150-liter/sec ion pump of this stand.

The spare ion source for the H^+ injector (Mark III b source) has been modified to provide it with a sidewall hydrogen gas feedline and an outlet for measuring the hydrogen pressure in the arc region of the source. All three Mark III sources now have sidewall gas leads. The Mark III b source has been reassembled and was run successfully on the 500-liter/sec test stand after installation of the sidewall gas tubes.

Magnetic field measurements have been made on the Mark III b source in the expansion cup region. A knowledge of the magnetic fields in this region of the source is of interest in order to understand changes in beam size that have been seen at the end of the 750-kV accelerating column and in the ion source magnet current. Figure 3 shows the configuration of the Mark III b source; Fig. 4 shows the results of some of these measurements.

Work has been continued on the effort of understanding the spreading of the beam in the Pierce accelerating column. Detailed analysis is being carried out on the intensity profiles obtained from

Fig. 3. The configuration around the Pierce anode lip and magnet vectors at the plane are shown for 2-A magnet coil current (no arc).

Fig. 4. Results of some measurements of magnetic fields in expansion cup region. The variation of the magnetic field along the axis and with current at 0.25-in. downstream from the Pierce anode lip are shown. The coil has about 1000 turns.

the pepper-pot measurements that have been made in order to obtain information about the transverse velocity components in the accelerated beam. This velocity spread is presumably directly related to the temperature of the ions extracted from the source which in turn may be the origin of the $1.5\text{-}\pi$ cm-mrad emittance of the 750-kV proton beam.

The accelerating column in the H^+ injector has remained on-line since it was installed two years ago. The first bleeder resistor failure in this two-year period occurred in June. For perspective, there are 144 bleeder resistors between 750 kV and ground potential.

A major reduction in the arc-down rate at low-duty factor was achieved by removing the cable between the C-W dome voltage top and the potentiometer recorder in the injector control room. These arc downs have been attributed to pickup of transients on the 180-ft-long cable which leads into the

sensitive C-W voltage-control circuits. During the 800-MeV tests, there was only one arc down over a 93-h operating period during which the injector was run continuously with low-duty beams.

Beam Transport System

Work continued this quarter on optimizing the operation of the beam transport system using the additional quadrupole lenses which were recently installed. A new beam has been empirically determined using beam-diagnostic systems on the beam line and is now being employed for beam-scraping studies. The beam has been adjusted to produce minimum beam size in the two bunchers. Prototype beam scrapers have been built and installed and initial studies on scraping the halo of the proton beam have been undertaken. The beam cross section, at an intermediate viewing screen TDVS02 showing the central beam spot and halo structure that remains after a single scraper was installed in the straight-out section of the TA beam-line, is shown in Fig. 5.

Subsequent tests (run with the new beam, two additional beam scrapers installed in the beam line, and the injector run in its normal mode of operation) resulted in the transportation of 30-mA-proton beam currents to the entrance of the linac and the acceleration of 21 mA to 5 MeV, as shown in Fig. 6. This current is 30% greater than the required design current for LAMPF. Further increase in accelerator beam current was limited by the inability of the first tank rf system to provide enough power to compensate for the beam-loading.

The scraper apertures have a second application in transport tune-up. Because they are designed to permit only the core of the beam to pass on axis, the number of possible steering combinations is reduced. A steering algorithm incorporated into a computerized tune-up program will be based on step-wise steering to maximize beam through each aperture. After further evaluation each scraper will be replaced by one capable of taking higher amounts of beam power.

After 800-MeV beam tests were completed, an extended shutdown of the linac was made for alignment checks and other work. During this time a new linac axis was determined and the last section of the H^+ beam transport line in the injector area was realigned to this new axis. The initial portion of

Fig. 5. Beam cross section at TDVS02 showing the central beam spot and the surrounding halo. This cross section shows the result of beam scraping in the initial straight-out section of the TA beam line. The graticule spacing is 1 cm/division.

Fig. 6. Oscilloscope traces of proton beam current at the entrance to the linac at TDCM03 (top trace) and at the exit of Tank 2 showing 5-MeV accelerated current (bottom trace). Both traces have 10 mA/division on the ordinate and 100 μ sec/division on the abscissa. The second pulse on the top trace is a 40-mA calibrating pulse.

the H^+ beam line is still aligned with the original alignment axis. The offset between the two portions of the beam line is principally in the vertical plane and occurs between the final two 30° bending magnets where a vertical steering element is located. This offset should pose no problem in the beam transport but the initial portion of this beam line will be realigned to the new linac axis at a future shutdown.

The prototype H^- viewing screen, design-tested last quarter, has been used to fabricate viewing screens for both the H^+ and the H^- beam lines; four

Fig. 7. Viewing screen for H^+ and H^- beam lines. of these units have now been installed on the H^+ beam line. This design permits installation of viewing screens on both the H^+ and the H^- beam line without obstructing the line of sight required to set up alignment systems on the linac axis. A photograph of this new beam viewer is shown in Fig. 7.

The H^- Injector Program

Accel-Decel Ion Source

Work was completed on accel-decel systems this quarter. Calorimetric measurements were made of the extracted positive beam current into the charge-exchange canal with a 10/30/10-kV voltage distribution. The extracted positive current peaks at 13 mA with 2.3-A arc current, thus 5.6 μ A per ampere of arc current was obtained. The computer prediction from the CULHAM code is 17.2 mA and 13.5 mA for H^+/H_2^+ ratios of 75/25 and 0/100, respectively. Thus, the observed extracted positive current is between 76-100% of the predicted current, depending on the actual H^+/H_2^+ ratio in the beam. The extracted current was observed to increase rapidly with accelerating voltage for fixed arc current and the measurements scaled up very closely to the expected $v^{3/2}$ dependence when the potential distribution was increased to 15/45/15 kV.

An accel-decel source was then built with a closed-gas-flow system and with short accelerating gaps to overcome the high gas flow and the voltage sparking problems. Computer studies of this design indicated that a 134-mA beam should be obtained with a 75/25 H^+/H_2^+ ratio and with a 15/60/15-kV potential distribution and that 2.7 mA of H^- beam current

should be obtained. The actual H^- yield obtained with any potential distribution was very low; a maximum of 130 μ A of H^- beam was obtained with this design with a 10/70/10-kV potential distribution. A grid was inserted in the canal (to create more electrons) but seemed to have no other effect than to intercept some beam; nor did a modified expansion cup improve the H^- yield.

Thus, either focusing problems or the lack of adequate space charge neutralization prevents any of these designs of the accel-decel system from reaching expected yields of H^- beam current. Work on this type of source has been discontinued.

Multiple-Aperture Source (MAS)

Experiments were begun on multiple aperture sources for both a 7-hole and a 19-hole source. A photograph of the type of source is shown in Fig. 8. In theory, each aperture should produce a 17-mA proton beamlet at 15 kV. Hence, the 19-hole-array system should yield 321 mA of protons and 6.4 mA of H^- beams; this yield should, of course, increase with increasing extraction voltage. The initial 19-hole-array experiments have resulted in 1.2 mA of H^- beam current at 15-kV extraction voltage rising to 2.5 mA at 24-kV extraction voltage. Similar tests with the 7-hole array produced an H^- yield of 2.2 mA at 22-kV extraction voltage. Evidently not all apertures are fully supplied with plasma using our duoplasmatron source.

It was observed that the individual beamlets can be focused into the Faraday cup in a good image

Fig. 8. Details of the multiple-aperture H^- ion source.

of the extractor aperture plate and that the brightness of the outer holes is much less than that of the holes near the center. The emittance of a 1-mA H^- beam was measured to be 2.5- π cm-mrad (750-kV equivalent), and this beam could be focused into the required 2-mm aperture.

Future experimentation on this source will include a 37-hole-array extractor plate model and complete calorimetric proton and H^0 measurements. Work remains to be done in this type of design to improve the efficiency of source operation in order to obtain more reasonable source lifetime and power and gas consumption.

Single-Aperture Source (SAS)

Work continued on tests of the SAS that will be used in the initial H^- injector. Experiments carried out with a flat-plate-extraction geometry have yielded H^- beam currents up to 2.2-mA peak at 34-kV extraction voltage and up to 1-mA peak when run in a more conservative mode of operation.

Certain features of the SAS and MAS are similar and are likely to be present in all future designs of the LAMPF H^- source. There are basically two processes leading to H^- ions in these sources:

- a) $H_2^+ + H_2(\text{gas}) \rightarrow H^- + \text{other ions},$
- b) $H^+ + H_2(\text{gas}) \rightarrow H^- + \text{other ions}.$

The highest currents to date have been reached with the first process as evidenced by simultaneous momentum energy analysis, even though the LAMPF duoplasmatron yields 80/20 H^+/H_2^+ ion beams. Independent experiments with deuterium gas have shown that $p + D_2 \rightarrow H^0 + D_2^+$ occurs in the expansion cup region at 5- μ pressure at a rate which yields roughly equal H^+/D^+ beams; hence, the source will effectively produce a large H_2^+ in our application where there exists a 5- to 10- μ pressure of H_2 gas in the expansion cup region.

This H_2^+ production process will have three effects:

- 1) There will be a mixture of two H^- beams produced with energies differing by half the extraction voltage (which typically is varied from 15 to 30 kV).
- 2) There will be an energy spread in the main component of the H^- beam (H_2^+ production mode) of up to ± 600 eV due to the H_2^+ dissociations kinematics.

3) The emittance of the H^- beam from the H_2^+ production mode will be larger due to the breakup process. Measurements taken on the MAS show that this effect together with the effect of aberrations in the multiaperture optics leads to ~ 2.5 - π cm-mrad emittance (750-kV equivalent) as contrasted to the 1.5- π cm-mrad observed for the high-intensity proton injector.

At present, H^- ions resulting from both production modes will be injected into the linac, at which point the buncher voltage will have modulated the beam energy by ± 20 kV. Magnetic analysis of the two components at the entrance to the accelerating column is possible and can be implemented later if required.

Several features of the charge-exchange source operation are not completely understood. Both the MAS and SAS sources perform best when the charge-exchange canal bias is adjusted so that a large current of electrons (produced by gas ionization in the canal) goes back into the source, possibly focusing the proton beam. Also, it is apparent that most of the potential H^- beam is lost due to poor optics or space-charge blowup. Solution of these problems would lead to higher beam currents and more conservative source operation.

The H^- Construction Program

Details on the design of the SAS H^- ion source that will be used in the initial operation of the H^- injector are still being tested. Tests with a flat-plate extraction geometry indicate that considerably more current may be realized from the preliminary low-current H^- ion source than was predicted several months ago when the injector-source design was started.

Calculations have been done for the column injection lens and tests have been carried out to verify that this lens can focus the ion source beam into the specified 2-mm aperture at the column entrance. Calculations have also been carried out on the proton extraction from the plasma surface using the CULHAM ion source code.

The design and procurement of H^- ion source parts is well under way. About half the source parts for the H^- injector have been built or ordered and the rest are now being designed. These parts should be completed for installation in September.

The duoplasmatron for the H^- injector was assembled and has been run on the 500 liter/sec test stand. Some remachining was required to make parts fit again after a second hydrogen firing was successfully accomplished; the second firing was necessary to close leaks in porous sections of the Ferrovac E iron used in its construction. Preliminary emittance tests have been carried out but their interpretation was masked by effects of the extraction geometry employed. An additional accelerating electrode is being added beyond the extraction electrode in order to correct this condition.

The accelerating tube for the H^- column was successfully bonded on the second try. The polycarbonate bonding agent used in this trial was applied in a methylene chloride solution and thermocouples were attached to the top and bottom ceramics to monitor temperature of the tube more closely. The results of the previous unsuccessful bonding indicated there was only a narrow temperature range between melting required for a successful bond and overheating which led to degradation of the polycarbonate. Careful examination on this second bonding showed smooth fillets with no evidence of degradation due to overheating.

The accelerating tube was strength-tested with a lateral load of 200 lbs (Fig. 9) applied at 20° rotational increments to check for weak areas of bonding. This type of loading corresponds to three times the torque the tube will experience when cantilevered horizontally during column assembly. The tube was then helium-leak-checked and showed zero leakage when bagged with helium.

The excess polycarbonate was removed with methylene chloride so that the titanium surfaces can be masked right up to the ceramic. The tube will now be bead-blasted with aluminum oxide grit to clean the alumina ceramics.

The inner and middle corona rings, pump connectors, and the double-cone assembly have been completed. The ion-pump power supplies are being modified and the pumps will be shipped the last week in July. Fabrication is in progress on the outer corona rings, bleeder resistors, column compression bellows, Ti electrodes and on the exit end cone. Assembly of the entire accelerating column will begin in September.

The installation of the parallel section of the

Fig. 9. Testing system used to load the H^- accelerating column.

H^- beam transport line and of the permanent roughing system has again been postponed because of higher priorities of linac alignment and switchyard construction. The magnet alignment is now scheduled for the end of July and this section of this beam line will then be assembled during August. The remainder of the H^- beam line will be built after the H^- ion source and accelerating column have been installed.

The high-voltage tests of the H^- C-W are now essentially complete and manual controls have been installed in the injector control room. Resistance calibration of the C-W resistance stack has been completed. This C-W generator is now ready for operation except for computer control systems.

Collaborative Programs

Several group members are participating in collaborative efforts with other groups, including work on the EPICS particle separator and the biomedical beam-shaping control system. This work is reported in detail in the reports on those programs.

IV. ELECTRONIC INSTRUMENTATION AND COMPUTER SYSTEMS

Injector Control Systems

There are two injectors on the LAMPF accelerator: one for a high-intensity H^+ beam and a second for an H^- beam. The injector control systems include controls for both ion sources, the two Cockcroft-Walton (C-W) accelerators, and the beam transport equipment leading from both sources to the first linac.

The program of improvements and maintenance on the H^+ systems was continued this quarter. In preparation for the 800-MeV beam test the calibrations for all of the H^+ injector systems were checked and recalibrated where needed. A Fenwall fire-suppression system using freon was installed in the dome of the H^+ C-W and tested. Work on the new beam-current monitoring system was held up pending delivery of the new power supplies and amplifiers. This system will be installed next quarter.

The new rack of control equipment for the emittance gear functioned reliably after its installation last quarter. The low-energy emittance profiles obtained through this equipment were essential to the 800-MeV test. The dedicated Nova computer which controls this equipment failed for only the second time in one year. The trouble was corrected with a minimum of downtime.

Work on the H^- injector was paced by a lack of manpower, but significant progress was made nonetheless. The wiring and equipment installation in the dome is now 90% complete. The prototype printed circuit (pc) cards for the light-links were received for final testing. The 30-kV, 30-mA power supply failed, for a second time, to meet specifications and was returned to the manufacturer for corrective action. The beam pulser was wired and is undergoing tests. Designs were completed for the vacuum control panel, the diagnostic viewing panel, and for the 50-kV extractor voltage dividers. The C-W terminal voltage video amplifier is 80% complete.

The scheduling of wires for nine bins of NIM-module controls for the H^- transport line was completed. The equipment was sent to an outside fabricator for wiring. A water-cooled heat sink was installed between a pair of 100-A bending-magnet power supplies to carry away the heat.

201.25-MHz Control System

The 201.25-MHz control system encompasses modules 1-4, the Transition Region (TR), and the 100-MeV Diagnostic Area (DA). The improvement program in modules 1-4 and the development program in TR and DA were postponed until after the 800-MeV test.

805-MHz Control System

The 805-MHz control system extends from modules 5-48 and includes instrumentation for Sectors B-H. All of the controls were operational by the start of the 800-MeV test and performed well during the test.

Beam-diagnostics studies during that test indicated that separate power supplies were needed for the quad doublet between modules 12 and 13. This need was met temporarily by using two of the five spare focus-magnet power supplies.

A large capacitor in the 805-MHz rf system exploded and induced a voltage surge through unsuspected ground loops causing failures in a water temperature controller and in one of the remote data terminals. Subsequent investigations uncovered several ground loops; all but three were corrected. It will take another catastrophic failure (a rare event) to ascertain if the precautions will prove adequate.

A new operational mode was defined for the 805-MHz area. This one allows the beam to pass through module 13 to a stop between modules 13 and 14. A new run-permit mode was implemented to accommodate this type of operation.

Switchyard Control System

The switchyard control system encompasses the equipment in a Y-shaped area connecting the end of the accelerator to Experimental Areas A and B-C.

The month of May was spent wiring the 20 racks of control equipment to various devices in the switchyard. This task continued until the start of the 800-MeV beam test. By setting priorities and by closely supervising the contractor, it was possible to get the crucial devices operational. Those devices included the vacuum ion pumps, a fast-acting valve, a quad doublet, the beam-current monitors and wire scanners for Line A, the run-permit system, the water system, and the temporary beam stop for Line A. Controls for the delta-ray spectrometer, the energy-measuring device, were designed, fabricated and installed.

Following the 800-MeV test, the wiring and device hookup for the remainder of the switchyard began. These tasks were complicated by the fact that some temporary wiring had been installed for the test. By the end of July, the jobs defined by the original schedules for Line A were completed. Work is still in progress on the magnets, valves, and diagnostic devices for Line X. The process of checking the controls, channel calibrations, chassis installations, modifications, and additions should be finished in August. The channel lists in the control computer are being updated as this work progresses.

The first of the new transistorized current shunts performed satisfactorily for the 800-MeV tests. The regulation exhibited by this unit was approximately one part in 10^4 . The other ten shunts required for the switchyard were fabricated and tested.

A flip coil will be used to measure the bending-magnet fields to a high precision. A multiplexed digital voltmeter (DVM) will read out the integrated signals. Controls for the flip coil, DVM, multiplexer, and I/O unit were completed. This equipment will be installed next quarter.

Experimental Area Control Systems

Planning for the experimental area controls continued this quarter. Numerous discussions were held between personnel in the controls group and the beam-line designers.

Preliminary designs for the control systems in Areas B and C were completed. Plan drawings showing all of the devices along Beam Lines B, C, EP, and HS were prepared. An arrangement of 24 racks and 4 data acquisition-and-control terminals (DACT) was made for Equipment Room B. A tentative rack and chassis layout for the instrumentation and controls was drawn. Hardware channel assignments were given to the 1000 data and control signals compiled for the two areas. The task of preparing this information for the control computer was started. The procurement of NIM control modules and the preparation of wire schedules will begin next quarter.

Work continued on the development of special controls for the High-Resolution Spectrometer (HRS). The drive motor, controls, and position encoder for the HRS drive system were received. Fabrication of a module to interface the CAMAC dataway to the motor

drive amplifier for the NMR position control was completed. A prototype incremental encoder for monitoring the probe position was tested. The first production unit and the first motor drive amplifier should be ready in August.

A prototype CAMAC pc card for eight channels of stepping-motor control was designed, fabricated and tested. Production units will be built as needed for beam-line control.

A prototype regulator for the power supplies driving the H_T (trim) windings was fabricated and tested. The final design with supporting documentation is in progress.

A magnet-position sensing system based on a taut wire was developed and tested. Numerous electronic circuits had to be devised for this development. The equipment for two channels (up-down, left-right) was built into a NIM bin and is ready for tests on a magnet.

Thermistors are used to measure water temperatures along the accelerator. In order to use these devices in the target areas where the temperature excursions are much larger, a new curve-fitting technique must be devised so that the temperature measurement will give the required accuracy over the large temperature spans. Work on this project is being aided by members of the computing division.

A readout system is being developed for a helical bifilar proportional chamber. A timing analysis of the readout electronics was performed to insure that timing problems will be minimized in the final version. The prototype readout unit is scheduled for integration with the chamber early in September.

LAMPF Data Terminals

Each module of the accelerator is connected to the control computer by a data-acquisition-and-control terminal. Sixty DACTs were operational for the 800-MeV test. Four more will be installed to handle the controls for Experimental Areas B and C.

Additional test devices were built for the analog data system (ADS). These devices were required to automate the testing of the ADS through the control computer.

The DACT in the transition region was modified to handle 35 analog command channels in addition to the 128 channels of analog data. Similar expansions will be required for the DACTs in areas B and C.

The drive circuit for the stepping motors was redesigned to make it more noise-immune and reliable; new pc boards will become available next quarter.

Central Control Room (CCR) Systems

The second operator's console with its new hardware was put into operation for the 800-MeV test. The hardware included one trackball module, two slew modules, and three function button modules. The software to support the operation of the console was completed a few days after the hardware was installed.

The programmable function buttons proved to be a valuable innovation. Each operator can have a program card which defines what function each button performs. To increase the readability of the program cards, the panels are being modified to use two-color buttons. A soft green glow will be used as background illumination and will change to amber when the button is turned on.

To satisfy the need for two (and probably more) storage scopes on each console a multiplexer was designed, built, and installed on CIU#2, the interface unit which connects the second console to the computer. This multiplexer will handle 11 storage scopes and provide the capability for writing the same display on any or all of the scopes. Software to support multiple-scope operation is being debugged.

Preparations for retrofitting the first console continued. All the interconnecting cables between the console and CIU#1 were installed. The new analog slew chassis for CIU#1 was completed and tested. The new hardware will be ready early in August. The retrofitting will require two weeks with most of the effort going into modifications on three of the CIU#1 chassis.

Preliminary work has started on the third console which will be needed early next year. The shell of the console is in storage. Most of the hardware assembly work will be done by an outside fabricator.

LAMPF Control Computer

The LAMPF control system is organized about an on-line digital computer. The computer, a SYSTEMS SEL-840MP valued at \$500,000, performed without a failure during the four-day 800-MeV test. Only three failures occurred during the whole quarter: a

tachometer on a magnetic tape drive wore out; a bearing in the card-reader froze; a high-voltage supply on the graphics display scope failed. None of the failures took the computer off-line.

An additional 16,000 words of core memory were installed on the computer. The work was completed in seven consecutive days. A simple change was made in the executive program to incorporate the new memory into the system software. No problems have been logged against the memory since its installation.

A CAMAC crate controller for the 840MP was assembled and wired along with an I/O chassis to interface the controller to the computer. The CAMAC system will be used to control equipment associated with the HRS.

Programming

In preparing for the 800-MeV test, one of the problems was the monitoring of the 805-MHz rf systems. If any one of these 44 systems tripped, then it had to be reset and brought back to full power before an 800-MeV beam was possible. A program was written to display all the necessary information about these and other systems on just two lines of the character scope. Each system was represented by a single character position within the two lines. Based on data collected and analyzed by the computer, a pre-defined character or number was written in the position in one of four colors. The operator could tell at a glance which units, if any, were malfunctioning and the nature of the fault. An automatic fault-resetting capability was incorporated into the program to handle the straightforward situations. The complex situations were handled by an operator or by the program which automatically turns on and runs up an 805-MHz rf stand.

Several programs had to be developed to support the operation of the new hardware developed for the second operator's console. A diagnostic program was written to aid in troubleshooting problems during the installation phase. The other programs integrated the function buttons, trackball, and slew knobs into the system software so fast that the operator was unaware that a computer was doing all the work. Another two weeks of programming will be needed to finish programs for slew knobs and storage scopes.

Work started on a group of programs to provide

for control of the magnets in the switchyard. The operator interacts with a display on the character scope by specifying the beam energy or momentum or the last accelerating module. The computer makes all three of these quantities self-consistent and then checks that the magnetic fields are set for the given energy. If so, the operator is free to give the run-permissive and drift beam through the switchyard. If not so, the computer will set the currents, appropriately based on a table of calculated values or on empirical data previously stored. The operator can choose to have the magnets set quickly to an approximate value or, more slowly, to a precise field. Options are available to work with any magnet, to record new settings, and to display pertinent information about each magnet on the storage scope. A monitor program will alert the operator to any variations in the prescribed settings. This software will be used during the first switchyard tests in August. A major evolution of these programs is expected as operating procedures are developed.

Work continued on the reliability of the system software. A major advance was made in handling the magnetic tape drives. The programs which control the operations of the drives were revised to provide a high degree of error-checking with appropriate recovery procedures. When a condition is detected for which there is no recovery, the computer operator is given the opportunity to remove the offending tape. The new software had ramifications in several major programs, all of which were revised.

Major and minor changes and additions were made in several programs. The program which facilitates the testing of accelerator hardware was revised to survive across computer crashes. A new option was added to the repertoire of hardware tests. The 805-MHz rf recovery program was modified to cope with unexpected conditions discovered during repeated trials. Work continued on the beam recovery program; it was expanded to handle the run-permit situation in the injector. A change was made in the data-gathering program so that it now flags data collected during the time a fast-protect condition existed. The program which facilitates the on-line debugging of new software was rewritten to operate from either operator console. A new list of changes can be expected for next quarter.

Distributed Operational Systems

The systems described below are essential to

the operation of the facility. They span the length of the accelerator and are being extended into the experimental areas.

Timing System

The timing system serves to synchronize the rf and beam turn-on throughout the accelerator. The master timing unit is under control of the computer.

Prior to the start of the 800-MeV test, the basic timing signals were extended to the switchyard and each of the sector timing chassis was fitted with an outlet for T_{zero} , the master sync signal. During the 800-MeV test, the timing system provided its functions flawlessly.

Fast-Protect (FP) System

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

The FP chassis for the switchyard was installed and the system was put through a final check before the 800-MeV test. The system provided protection throughout the week-long run. As presently designed, the system will inhibit the beam from all injectors if any malfunction is detected in the accelerator or in the switchyard. At some future time, it may be desirable to be more selective about which injector is shut down. If so, the system can be modified accordingly.

Run-Permissive (RP) System

The RP system is hardware which can inhibit the beam upon detection of any abnormality in the machine interlocks or the personnel safety system.

The final portions of the RP system for the accelerator were tested and pronounced operational for the 800-MeV test. Preliminary consideration was given to the RP system in the switchyard where the control computer will perform all of the checks which are energy dependent.

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.

The personnel safety system for the accelerator was operational for the 800-MeV test. The extension of the system to the switchyard is about 80% complete. All designs, drawings, and fabrication were

finished. The warning horns, scram, and reset stations were installed and tested. Work is pending on the warning signs and the permanent interlock circuits at the truck access door. For the 800-MeV test, the beam switchyard circuitry was integrated into the last accelerator sector.

Preliminary designs for the personnel safety system in Areas B and C were completed. All of the safety devices were ordered and deliveries should begin in mid-September.

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.

The task of calibrating and installing all of the area monitor systems for the accelerator and beam switchyard was completed. Crude estimates of the radiation fields expected at three of the switchyard monitors suggest that the sensitivities of two should be increased by 10X and one by 100X. Techniques for achieving both gains are known and will be tried next quarter.

Seven area monitors obtained from surplus were reconditioned and calibrated for use during the 800-MeV test. These units were installed at selected locations to determine shielding effectiveness. They will remain in use until the radiation surveys are completed.

A special neutron detector was installed in a 20-ft-long pipe pointed at the 800-MeV beam dump. By adjusting the location of the detector in the pipe, it was possible to measure the source intensity. A readout in CCR displayed the number of n/sec from the beam dump. By assuming a reasonable value for the neutron/proton yield, an estimate could be obtained for the number of protons impinging on the dump. The calculation indicated an average proton current of 25 to 40 nA, which was consistent with other measurements.

The conversion of the beam-spill monitoring system from a peak-sensitive system to one which controls the average radiation level was completed. A total of 55 monitors had to be modified, calibrated, reinstalled, and checked through to the

computer. All units are back in operation except for those in Sector A where the work is pending completion of beam-dynamics tests in the transition region. A procedure is being developed so the control computer can test the system automatically. A paper describing the new system was presented to the Vth Intern. Cyclotron Conf. in Vancouver, British Columbia.

The beam-spill monitoring system for the switchyard was installed and tested locally. One of the detectors could not be installed because the temporary beam dump occupies its location. Checkout and calibration of the signals to CCR will be done next quarter.

Auxiliary Systems

Communications System

The LANPF communications system includes interphone, paging, telephone, and FM radio services.

The Beam Switchyard (BSY) communications system was completed and put into operation just prior to the 800-MeV test.

The Lab-Office Building (LOB) general announcement system was completed and put into use in mid-May.

The design of the Experimental Area A communications system was finished, and the job was turned over to the installing crafts. The work should be finished in August.

Design work on the paging and communications panel for the second CCR console was suspended until additional experience is gained with the present layout. A temporary paging unit was installed for the 800-MeV test and proved adequate for the current level of operations.

TV System

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

The operations monitoring system was extended to the switchyard. Installation of the trunk lines to CCR will complete the system. A cost estimate and work breakdown were prepared for the system proposed in Experimental Areas B and C.

The last cameras for the access surveillance system along the accelerator were installed. The signals at CCR have yet to be equalized for easy switching among the nine cameras involved. In the

switchyard the wire installation for the truck access was completed. All components for this camera, including the weatherproof housing are on hand. Installation will start when the truck access shield plug and maze are completed.

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.

The video system was extended into the beam switchyard. The job of wiring was completed and the line drivers, buffer amplifiers, and matrix switches were installed. The remaining tasks of calibration and system checkout via the computer will be done next quarter.

Experimental Area Computers

Two Model 20 PDP-11s constitute the first increment of computers in the LAMPF data-acquisition system. One, the so-called terminal computer, is being used by all the experimenters to develop programs, while the other serves as a prototype data-acquisition computer. The reliability record thus far of these computers has been very satisfactory.

Three computers are scheduled to arrive during August. Two of the three are the faster, more powerful Model 45 of the PDP-11 family. All three will play the role of data-acquisition computers; one will be located in the Biomedical area.

The first major goal of the programming effort was achieved this quarter when the "Underground" (UDG) system was demonstrated. The aim of this effort has been to modify the manufacturer's Disk Operating System (DOS) so that it can support the priority task of data acquisition in addition to a background task, e.g., a FORTRAN compilation or data analysis. The approach taken was to embed the data-acquisition code in the DOS monitor in such a way that the experimental apparatus functions in the same way as an interrupt-driven DOS peripheral unit. This approach required a major revision in the DOS loader program and a special magnetic-tape driver. Versions of the UDG system were produced for both the fixed-head (KF) and moving-head (RK) disks.

In the test, a UDG system was created on the terminal computer and transferred to the data-acquisition computer on magnetic tape in accordance with

the operating procedure planned for LAMPF. The system was then made to acquire data through the underground program and write the data on magnetic tape. A provision was made for exchanging data between the underground and a data-analysis or display program. This provision also makes it possible to control the underground from the teletype on the computer. Since the UDG system will accept any sort of data-acquisition program, each physicist can develop an underground program unique to his experiment.

The next step will be to acquire data from a multiwire proportional counter (MPC) and display the results on a storage scope as well as record it on magnetic tape. The MPC is presently being interfaced to the computer and the storage tube display was just delivered.

The computer for the Biomedical Facility will be installed in a multiuser environment. To support this mode of operation, the Real-Time System Executive (RSX) was purchased from the manufacturer. Considerable effort was invested this quarter in getting the software running and in understanding its full capabilities. A few modifications will be necessary to exploit certain features. Work was started on programs to allow RSX tasks to communicate among themselves and to manage the swapping area of the background.

The first applications programs written were for the channel tables which contain all information about the data and control signals (channels) in the Biomedical Facility. The first channel list was compiled and punched on cards. A program was written to process these cards on to the disk in a way that makes the information readily available to other programs. Another program was developed to print the contents of this table. Several iterations will be required before the data in the table stabilize.

CANAC Hardware

Major portions of the experiments at LAMPF will be interfaced to the data-acquisition computers through CANAC hardware. The key element of the interface is the Microprogrammed Branch Driver (MBD) which can multiplex data from up to eight concurrent processes into or out of the computer. The first MBD was put into operation in June. In a demonstration, the MBD acquired data from a scaler under

interrupt control and plotted the 24-bit data in a simple histogram on a scope. The program which performed this task was resident in the MBD and, once initialized by the PDP-11, ran without further attention from the PDP-11. This demonstrated the stand-alone control capability of the MBD.

Three additional MBDs were built and partially tested. The first level of testing was done with the aid of a PDP-11 simulator, a simple console which operates in a single-cycle mode to execute PDP-11 instructions. Three simulators were assembled and tested for this purpose. The second level of testing requires the PDP-11. The three new MBDs should be tested through this level and be ready for assignment by the end of August.

The design of an MBD with a 1024-word memory (expandable to 4096 words) was completed. The larger memory (up from 256 words) was required to buffer the high data rates and to hold programs for preprocessing events to reject those which are obviously unacceptable. The new MBD also has features which will make it capable of stand-alone branch operation with a simulator or remote branch operation with the data link. A prototype of this MBD will be tested in September.

The detailed design of the CAMAC data-link module was completed. A prototype will be built and tested next quarter.

LAMPF Electronics Equipment Pool (LEEP)

A pool of electronics equipment of general utility is being created to support LAMPF users. Temporary quarters for the LEEP were established in an area of the LOB which can be locked. The responsibility for control and inventory of the equipment was assigned to a member of the LAMPF staff. A systematic series of acceptance tests on all LEEP NIM modules was initiated.

V. ACCELERATOR OPERATIONS

LAMPF Operations

The main activity during this period was an intensification of operator training on accelerator operations in preparation for the 800-MeV beam tests. This was accomplished by scheduling operations for several weeks of three shifts per day interspersed with weeks of two shifts per day. By working with the experimentalists, beam line physicists, and systems engineers, the crews learned and became fairly proficient in running the accelerator and making adjustments to the system to keep the accelerator on-line. Consequently, during the 800-MeV tests, the crews performed their tasks with a high degree of skill and deserve a fair share of credit for the success.

During the next quarter, additional personnel will be assigned to operations to bring the organization to full strength.

VI. EXPERIMENTAL AREA

Facility Planning

Design has been completed for the Isotope Production Facility. The project has been advertised and bids received. The low bidder proved to be the Baines Co. of Albuquerque. Construction of this facility, located to the north of Beam Stop A, will start in early August. The stringer housing for the insertion and extraction of targets has been fabricated and is on the site for installation. Stringer fabrication is continuing for later installation.

An architect has been selected and design work is under way on the Radiobiology and Therapy Research Facility. The preliminary concept of an "L" shaped building is being modified to avoid conflict with planned experiments around Beam Stop A.

An architect has also been selected for the Weapons Neutron Research Facility (WNRF) and design work will be started by the architect in August. Transport studies for the beam line to serve the WNRF, particularly in the switchyard, indicate some structural interference. Investigations are under way to determine what modifications, if any, will need to be made to the switchyard truck access. The construction of the maze entrance to the switchyard will be delayed until all interferences are resolved.

Switchyard

During the last quarter the switchyard was made ready to receive beam for the 800-MeV beam tests. Since the successful completion of those tests, a major effort has been devoted to the development of the full beam-diagnostic capability of the switchyard for a continuing program of beam and accelerator performance studies. Many of the diagnostic instruments and two of the switchyard magnets were tested during the 800-MeV tests and their control wiring was checked. Most instruments of Line A were exercised from the SEL-840 control computer. Some deficiencies in the actuators for the instruments were noted and attempts to improve them seem to be successful. The experience gained in the early tests has proven useful in the completion of the switchyard systems.

Work to complete the control systems is progressing satisfactorily. A program for control of wire scanners in the switchyard, and for calculation

of profile parameters, has been written and tested. A program to set and monitor switchyard magnets and to interact with software permissive is being written. The program to collect and reduce data from ISICs and Harps has been designed and is being written. A more detailed plan of ISIC and Harp data acquisition has been designed.

A detailed study of the use of Line X as a spectrometer has been made and some changes in potential use have evolved. The plans for the tuning of the switchyard have been developed to greater detail, but will not be finalized until experience is gained with actual beam transport.

The completed collimator assembly has been installed in the beam channel and the preliminary alignment and He leak-testing have been completed. No leaks were found in the stainless steel vacuum enclosure or the eight actuator assemblies for the collimator jaws. Final alignment and calibration of the collimator jaws for deflected Line X and Line A is in progress. The special beam tubes for the area between LA-EM-02 and the collimator have been received, cleaned and installed.

Beam boxes for the 200-wire ion chambers, LA-II-02X and LX-II-01X, have been received, cleaned and installed. Leak-testing will be done in place in the beam line after installation of the ion chambers.

Twenty instrument stands and related beam boxes have been installed in the switchyard for the following instrumentation:

Wire Scanners (WS):	4 in Line A	Completed
	2 in Line X	90% complete
Ion Chambers (ISIC):	1 in Line A	Completed
	1 in Line X	90% complete
Centroid Monitors (CM):	4 in Line A	Completed
	(6 in. & 4 in. nom. size)	5 in Line X
Zinc Sulphide Screens:	1 in Line A	Completed
	1 in Line X	Completed

Seven linear actuators for the above instruments have been completed, assembled to the instrument, and calibrated; three more actuators have been assembled and are ready for assembly to the instruments.

All components for the beam-line plumbing in the switchyard have been fabricated or are on hand; installation work is almost complete. Preliminary alignment of the magnets and instrument beam boxes has been done.

Beam Area B - Nucleon Physics Laboratory (NPL)

A number of hardware items are being designed or fabricated. The long-awaited Area B crane has been installed and is undergoing final acceptance tests. The design of electronic equipment and computer interfacing for the beam transport system has reached the stage of rack layouts and channel descriptions; wire scheduling and procurement of signal conditioning equipment will begin soon. Shop drawings are nearly completed for stands for the magnets in the LD₂ cave; remote-coupling cooling-water connectors for these magnets are under design. Shop drawings for the stripper foil mechanism have been completed. Detailed layouts of the neutron collimator mechanisms are being made. A final, detailed layout of the LD₂ target is being made; the refrigerator and compressors for this target are being plumbed for testing. Detailed layouts of the Line B beam stop are in process. The assembly of the polarized proton target cryostat is nearly completed and should be ready for test in the near future.

Beam Area C - High-Resolution Proton Spectrometer (HRS)

An order for the last two magnets in Beam Line C (LC-QM-04 and LC-QM-05) was placed and the steel fabrication is to start at the beginning of next quarter. Two other magnets in the beam line and the spectrometer, LC-QM-12 and HS-QM-01, are being fabricated and delivery is expected in September.

A number of hardware items for Beam Line C were received during the last quarter. These included all nine twister quadrupole magnets, the detector chamber for the spectrometer, and the vacuum chambers for the spectrometer. Most of the power supplies for the beam line magnets have arrived. Regulators for these power supplies are to be installed at LASL.

Completion of the fabrication of the two large bending magnets for the spectrometer was delayed by handwork required to meet the specified tolerances. A final trial assembly for one of the magnets has been successfully completed by the vendor and shipment of the large steel pieces has started. All four coils for these large magnets are already on hand at LASL. Prior to shipment of these coils, the various acceptance tests were performed as

specified. Upon receipt of each coil at LASL, a visual check was made to check for any shipment damage.

Fabrication of the spectrometer structure was finished and erection of the structure in Area C will start in early August.

Field-measurement and pole-chamfer studies on the 6Q29s were completed. Their nose pieces have been shortened and field measurements will be performed. Existing field measurements are being analyzed.

Designs for the secondary emission monitors (SEM), beam scanners, steering magnets, etc., have been completed. Thermal tests on the SEM foils indicate that the design should be adequate for 0.1% accuracy. Detailed layouts for the beam scanners are waiting to be checked. Detailed layouts remain to be done for the SEM, beam collimators, steering magnets, and current monitor at the stripper as well as for their various beam boxes. A magnet is available which appears suitable for the current monitor at the stripper. These projects must proceed in order to avoid delay of the beam line vacuum system.

The beam-scanner electronics have all been received and tested. The discriminators had a threshold of 100 mV rather than 50 mV as requested so these will have to be replaced or returned. With the possible exception of the discriminators, all of the electronics will be placed in Equipment Building B.

Spectrometer calculations indicate that a theoretically best resolution on the order of $\delta p/p = 10^{-5}$ is possible for a solid angle $\Omega = 3.6$ mrad and momentum acceptance of $\pm 1\%$. The necessary fields at entrance and exit of the dipoles can be obtained by an adjustable nose piece (11 parts) associated with each field clamp. A design for this nose piece now exists, but drafting assistance is critically needed if the parts are going to be made in time for the magnet measurements in Area A.

The optics of Beam Line C indicate that an additional quadrupole after the target will allow a reduction in the size of the beam dump and vacuum pipe by a factor of ~ 3 . An attempt will be made to acquire this quad from the LANP magnet pool.

The layout of the test-wire monitors along Beam Line C and the HRS exists. As soon as wire-loading tests are finished, these monitors can be ordered. Additional drafting assistance will be

required to define the actual lines along the magnets and to define the connecting brackets to the various magnets.

Energetic Pion Channel and Spectrometers (EPICS)

The first set of bids for the EPICS spectrometer bending magnet machining order was opened in mid-May. Because the lowest bid was considerably above our estimate, several design changes were made to simplify fabrication and reduce cost, including breaking the job up into several packages which can be fabricated by different vendors. As a result, the second set of bids included quotations a factor of two lower in the price than the first set. The price of these magnets, including steel, coils, vacuum chamber and fabrication, is ~ 75¢/lb, making these magnets the cheapest ever purchased for LAMPF. A two-month delay in the placement of the orders for the fabrication of the magnets was required to accomplish this cost reduction.

The present status of the EPICS magnets is given below:

Channel Magnets

Raw steel	delivered	
Coil fabrication		25% completed
Steel fabrication		5% completed

Spectrometer

Quadrupoles		25% completed
Raw steel for bends	on order	
Coils for bends	on order	
Steel fabrication for bends	on bid	

The schedule calls for delivery of the first channel magnet in October. The spectrometer quadrupoles will be delivered in August. The delivery date for the spectrometer bending magnets is not yet certain but is expected to be early in 1973.

Progress on EPICS instrumentation has been slow due to difficulties experienced in developing an amplifier/discriminator for the helical chambers. Four working prototypes have now been obtained and a final version is in progress. Design of the read-out system is nearly complete and fabrication will begin shortly. It is expected that the complete electronics for one chamber will be available in mid-September. The PDE-11/45 which is destined for EPICS has been shipped from the vendor. After installation and an initial shakedown period, it will be available for programming and interface

checkout. A document defining the control requirements for all EPICS systems has been completed, and design of controls electronics can now begin.

The EPICS beam-separator design has been completed and all drawings are complete with the exception of the voltage divider assembly and the high-voltage transmission line. Fabrication is expected to begin soon.

Some vacuum feedthrough components have been ordered as well as the mineral-insulated magnet cable.

To minimize drafting effort, the voltage divider and the high-voltage line will be built and tested from sketches. Group CMB-6 is assisting in fabricating the brazed kovar/ceramic portions of the voltage divider; high-voltage metal film resistors have been ordered for the divider which will be lab-tested as soon as possible.

One C-W power supply, acquired from the Princeton Particle Accelerator Laboratory (PPA), has been disassembled and requires some repair, primarily replacement of numerous broken resistors. Construction of the driver amplifier for the 40 kHz transformer and the feedback control electronics is under way; the C-W will be tested as soon as the driver is complete. Unfortunately, the original electronics were discarded before the C-W was shipped to LANS and only a few circuit diagrams are available.

Low Energy Pion Channel (LEP)

Vacuum system components received during this quarter were a 150-cfm pump package for pumping the channel, a 10.6-cfm utility pump package, two 6-in. valves and the center vacuum tank. Fabrication of the doublet vacuum tanks was begun.

Detailed drawings have been completed for the rad-hard collimator-actuator (for the solid-angle-defining slits), momentum slit, and proton absorber. Design continued on the beam plug, bending-magnet vacuum tanks, and counting area.

P³ High Energy Pion Channel

The program, RAYPORT, which was written to simulate the tune-up procedure, has been debugged. The iterative procedure of design and testing of tune-up algorithms has begun. RAYPORT is a Monte Carlo program which transports randomized rays through the channel and simulates the measurements to be made on these rays by a series of MEPC. The

program then uses these measurements to form a figure of merit and its numerical derivatives, which are used by the optimizing codes to find an optimal tune. Using this code it is also possible to do first-order optimized-channel design which includes the inequality constraints imposed by apertures.

Since June, a number of P³ users have arrived and have begun working on the following projects:

1. RAYPORT studies of the tune-up algorithms;
2. design of beam-monitoring systems;
3. calculations of various background radiations;
4. programs to process field maps of experimental magnets;
5. study of the efficacy of a differential Cerenkov counter for π - μ separation;
6. a code to incorporate the effects of slit scattering in beam calculations.

In the past quarter two major revisions were made to the physical layout of the channel: 1) a set of horizontal slits was added between the first doublet and the first bending magnet, and 2) the decision was made to use the surplus Cambridge Electron Accelerator Laboratory (CEA) magnet ORPHEUS rather than the PPA 30D40 at the third bend. The addition of the horizontal slits increased the drift space between adjacent magnets by eight inches. No changes in drift space were required to use ORPHEUS.

A closer look was taken at the water requirements for the channel. Heat loads, based on the necessary magnetic fields for maximum momentum beam and normal beam, were calculated.

Detail design has been completed on the vertical and horizontal slits and the degrader which operates between the second and third doublet. Fabrication drawings of the devices are now being checked. Two remote-disconnect and retractor vacuum-flange mechanisms are being fabricated. These are not of the standard design, but are special devices which were necessary to adapt the surplus PPA slits.

All of the PPA quads have been replumbed with copper tubing and ceramic insulators. An order has been written for the fabrication of $\sim$ 50% of the required magnet support structures.

Stopped Muon Channel (SMC)

The magnets for the muon channel may be considered in three classes: epoxy-insulated conventional magnets, concrete-insulated radiation-hardened magnets, and septum magnets. At the end of

this quarter all conventional magnets have been delivered as have the cores for the concrete-insulated magnets. The coils for three of the four concrete magnets have been completed and tested; the remaining coils are being fabricated. The coils that have been received have been cycled from room temperature to operating temperature over 200 times, and all ensuing cracks have been repaired. The first completed rad-hardened magnet (a 12-in. quadrupole) has been assembled and preliminary tests will begin soon. Some design work is being done on the septum magnets, but these have low priority.

The bulk of the power supplies for the channel have been on hand for more than a year and operating experience with them is being acquired. Bids for four additional supplies have been requested.

An order has been placed for the support structure and alignment stands for $\sim$ 50% of the SMC. Design work has started on the remaining magnet supports. Design of the horizontal and vertical pairs of beam jaws is $\sim$ 75% complete.

A prototype vacuum beam pipe has been fabricated to fit inside the 12QE20 elliptical quadrupole magnets, and is shown in Fig. 10. This welded beam pipe is fabricated from type 304L stainless steel. It has been tested with a full vacuum and a deflection of $\sim$ 0.1-in./side was measured. With this deflection and the 1/8-in. material, the 12-in. quadrupole will have a useful diameter of $\sim$ 11-1/2 in. Design work is partially complete for the rest of the vacuum system.

Primary and Secondary Beam Transport

The switchyard magnet status is listed below:

Bending magnets: All switchyard Line A and Line X bending magnets are in place awaiting alignment. The monitor magnets are installed in the power supply equipment aisle above the shielding.

Quadrupoles: All 6-in. quadrupoles required for initial Line A and Line X operation are in place. The remaining 6-in. quadrupoles are ready for installation when Area A becomes operational. The 2-in. quadrupole doublet for Line X is ready for installation. The quality of these 2Q19M/6 quadrupoles is particularly satisfying: they were designed by a hand-conversion from the dipole magnet pole configuration shown in Fig. 11 (used on the H10III69M/4 bending magnets). The end chamfer was

Fig. 10. Vacuum beam pipe for a 12QE20 magnet.

Fig. 11. Shim-antishim combination for switchyard quadrupoles.

scaled from that used on the 6-in. quadrupoles and no prototyping was done for the 2-in. bore quad. The low $n = 3$ component comes from assembly tolerances of ± 0.001 in., which the "adjustable box" configuration makes feasible (Fig. 12). The first 2-in. quad triplet is assembled and ready for alignment; the second triplet will be assembled soon. Both are expected to be installed before the next beam is delivered to the switchyard. The switchyard-to-power-supply wiring (mineral insulated) is installed for all the magnets now in place. Ceramic seals are used in the switchyard tunnel, and epoxy seals are used in the service aisle. The insulation resist-

QUADRUPOLE SECTION

Fig. 12. Quadrupole section.

ence of the completed dc wiring installation for the bending magnet strings in Line A is 40GΩ, and for Line X is 15GΩ. In addition to providing a radiation-resistant power cable, the m.i. wiring used here is inherently self-shielding and, during 300-MeV beam tests, no noise pickup in the detector circuits could be attributed to the SCR power supply driving the magnets.

Beam Line B: The five mineral-insulated C-magnets, C7III32M/16, have been received at LASL.

Beam Line A Transport: All nine m.i. target cell triplet quadrupoles are now on hand, and the first is being fitted with its electrical and water connections.

Characteristics of the magnets which have been measured are listed in Tables I and II. The target set in 1970 for bending-magnet quality was $\int B \cdot dl$ constant to 7.5×10^{-5} .^{*} The total cost of the switchyard magnets is \$247,991, compared to a 1970 budget estimate of \$250,000. Neither of these figures includes the in-house cost of applying ceramic seals and other work which has been done at LASL.

The beam switchyard for Line D to the WNEF has been calculated. These calculations show that a kicked proton beam may be transported with 4-kG bending magnets requiring modification of neither the seven-degree provision in the switchyard's collimator nor the vacuum chamber between the collimator and the two-degree bending magnets LA-EM-01

^{*} H. A. Thiessen, informal communication.

TABLE I
SWITCHYARD BENDING MAGNETS

Type	No.	P/N	Resistance (Ω)	I.R. G Ω	Deviation of $\int B \cdot dl$ Over Useful Width			Water Flow (300 psi)	Designation (position)
					240A	4"	125A		
H22III17M/4	5	239098	0.055 at 75°F	12.0	3.0×10^{-5}	2"	4.3×10^{-5}	9.6	LA-BM-01
	2	239095	0.054 at 72°F	24.0	1.05×10^{-4}	6"	2.65×10^{-4}	10.5	LA-BM-02
	4	239097	0.056 at 75°F	30.0	3.5×10^{-5}	$3\frac{1}{4}"$	1.5×10^{-4}	10.6	LA-BM-04
	3	239099	0.057 at 75°F	16.0	5.4×10^{-5}	2"	3.2×10^{-5}	10.5	LA-BM-05
	1	239096	0.055 at 75°F	15.0				10.9	Monitor
H10III169M/4					300A	4"	150A		
	1	243669	0.104 at 68°F	2.6	3.2×10^{-5}		5.3×10^{-5}	8.0	LA-BM-03*
	3	243671	0.106 at 68°F	0.86	1.7×10^{-5}		4.7×10^{-5}	7.2	LX-BM-01*
	2	243670	0.106 at 68°F	1.3	7.7×10^{-5}		1.1×10^{-4}	6.2	Monitor
					257A	7"	150A		
H13III199M/4	2	241609	0.141 at 75°F	1.5	3.0×10^{-5}		8.8×10^{-5}	11.5	LX-BM-02
	1	241608	0.140 at 70°F	2.3	4.8×10^{-5}		1.1×10^{-4}	8.5	LX-BM-03
	3	241610	0.141 at 75°F	1.6	1.05×10^{-4}		5.0×10^{-5}	10.4	LX-BM-04

- Notes: 1) All H22III17M/4s are installed with water connections upstream.
- *2) LA-BM-03 and LX-BM-01 are already installed. LA-BM-03 has the water connection upstream, LX-BM-01 has the water downstream.
- 3) LX-BM-02 and LX-BM-03 have the water connections downstream.
- 4) LX-BM-04 has the water connections upstream.
- 5) LA-BM-01 and -02 should be connected in series in one water circuit, with two flow switches, one for each magnet. Similarly, LA-BM-04 and -05 should be in series. Flow will be 7.5 gpm per circuit.

TABLE II
SWITCHYARD QUADRUPOLES

Type	No.	P/N	Resistance (Ω)	I.R. GR	N = 3 (180A)	N = 6 (180A)	Water Flow (gpm at 300 psi)	Designation (position)
6Q22M/5	0	Prototype	0.436 at 80°F	6.0	0.16	0.3	4.7	LA-QD-01
	4	242986	0.343 at 80°F	10.0	0.048	0.202	5.1	LA-QD-02
	5	242987	0.35 at 75°F	10.0	0.04	0.18	5.3	LA-QD-03
	2	242983	0.34 at 72°F	1.1	0.066	0.133	5.8	LA-QD-04
	1	242984	0.33 at 75°F	4.0	0.015	0.127	5.2	LX-QT-01
	6	242985	0.33 at 80°F	15.0	0.01	0.19	5.3	LX-QT-02
	7	243040	0.33 at 75°F	7.0	0.04	0.12	5.3	LX-QT-03
	3	242982	0.325 at 75°F	0.6	0.007	0.195	5.8	Spars
2Q19M/6	5		0.37 at 72°F	1.2	0.036	0.056	8.4	LX-QD-01
	8		0.38 at 72°F	1.2	0.032	0.094	8.0	LX-QD-02
	6				0.025	0.019		LA-QT-02
2Q9M/6	1				0.006	0.064		LA-QT-03
	2				0.010	0.125		LA-QT-04
	4				0.070	0.245		LA-QT-01

Note: LX-QD-01 and -02 should be connected in series in one water circuit, with two flow switches, one for each magnet. Flow will be 5.5 gpm per circuit.

and LA-BN-02. All second-order aberrations are insignificant.

Beam transport calculations through Area A and Area A-East have been continued to meet changing target criteria. The final round of calculations is to be completed soon. The required profile and current monitors for the areas have been specified.

Experimental Area Equipment and Experimental Area Support

The 100-MeV north port is nearly ready for target-testing. The box with three targets installed is now in place on the mounting rails. The targets are:

- 1) an ATJ graphite radiation-cooled wheel for station A-1
- 2) a ZTA graphite 1-cm-diam water-cooled target with a copper jacket for the biomed facility
- 3) an ATJ graphite target in a nickel water jacket, also for the biomed facility.

Target-testing in the 100-MeV north port has been delayed because of other accelerator tests. Target work should begin in about a month. A graphite wheel will be tested first for 50 h in a 300- μ A average beam. A molybdenum wheel is to be tested second, followed by the ZTA biomed target.

The main beam stop has been completed, leak-checked and installed in the north port. The collimated beam stop and spreader has been water-flow-tested and installed in the box. The box has been placed on a new support and alignment device which will facilitate removal and replacement when radioactivity levels are high. The water distribution system to the beam stops and targets is being assembled.

Conservative calculations were made on some intermediate-density ($\approx 4 \text{ gm/cm}^3$) ceramic wheel targets. These calculations show that in general the ceramics of interest will fail in the beam due to thermal stresses. More accurate calculations are being pursued using three-dimensional computer codes for the temperature distribution in the vicinity of a macropulse. This temperature distribution will then be programmed into a thermal stress code.

The designers of the biomed facility would like to have a graphite water-cooled target of the highest density possible. A ZTA target of density 1.9 was developed and tested at the electron prototype accelerator and will be further tested in the 100-MeV

beam. An increase of 16% in pion flux could be obtained if pyrolytic graphite could be used instead of ZTA. Design work is proceeding on a 1.5-cm-diam pyrolytic target. The problem is somewhat complicated by the fact that pyrolytic graphite shrinks from thermal contraction when it is placed in the beam. A suitable jacket material must be found to maintain a tight fit between the graphite cylinder and the water jacket.

The X06 process water system was operated continuously for 137 h during the successful attempt to obtain the 800-MeV beam. The operation included the use of the X06 ion exchange system. A water resistivity of over 6 MQ-cm was achieved and maintained during the period. The system performed in a very satisfactory manner, however, some minor rework of the control system appears desirable.

All of the magnets that have been rough-aligned have been connected to the switchyard process water manifolds. All of the power supplies and monitor magnets located in Equipment Building A have been connected to the X01 process water system. The installation of the process water mains and branches is complete in Area A and Area A-East. These distribution systems have been cleaned and flushed and are now available for use. The contractor has completed the installations of the waste-resin holding tank. The airlift pump installed in this tank is performing efficiently.

For Area A, the work on the drawings for the valve caves is continuing. Work is continuing on the drawings for the connecting lines from the valve caves to the secondary beam-line manifolds.

A system to monitor and control dipole magnets with an NMR gaussmeter has been laid out. The gaussmeter, a Spectromagnetic's Model 5200, will be interfaced to a digital control computer and will provide information enabling the computer to calculate field strength. The system is being designed such that the computer can cause the gaussmeters to track field changes. Difficulties have been encountered which are associated with the poor signal-to-noise ratio (S/N) at some field levels. Improvements in S/N have been achieved by modifying the gaussmeter and by constructing additional signal recovery electronics. Electronics to digitize and transfer the NMR information to the control computer via a CAMAC interface have been designed and are under construction.

Magnetic field measurements have been completed on all the switchyard magnets. Some of the magnets sustained coil damage and had to be measured several times. After each disassembly the field characteristics varied by as much as three parts in 10^4 in absolute value and by one part in 10^4 relative $\int B \cdot dl$ across the gap. Thus, for each remeasurement the and shims had to be changed to optimize the field distribution. The implication of this is that if the magnets are disassembled in the future, they will have to be remeasured.

The twister quadrupole 6Q29R/7 for Beam Line C has been measured with several combinations of pole chamfer, field-clamp position and bolt extension. The first guess of a 0.4-in., 45° chamfer was not sufficient to correct the integrated field when the field clamp was installed. A slightly larger, 0.5-in., 45° chamfer was required. The integrated field $n = 6$, duodecapole component was reduced to zero at all field levels with the configuration shown in Fig. 13. Since the central field $n = 6$ component is also negligible, this end geometry is optimized for 6-in. quadrupoles with the same coil shape and pole contour and is independent of magnet length. The values of $n = 6$ and $n = 3$ are listed in Table III.

Fig. 13. Pole-end configuration of twister quadrupole 6Q29R/7. (Duodecapole component $> 0.1\%$ at all field levels for this geometry.

TABLE III
HARMONIC CONTENT AND FIELD GRADIENT IN 6Q29R/7
TWISTER QUAD RELATIVE TO $n = 2$
AS A FUNCTION OF CURRENT

Current (A)	Field Gradient (G/in.)	$n = 3$ (%)	$n = 6$ (%)
400.44	1202.4	0.042	0.034
800.26	2255.1	0.070	0.034
600.36	1794.8	0.017	0.032
400.11	1204.2	0.029	0.032
199.71	603.8	0.020	0.035

Work is continuing on a manual which will contain sufficient information to enable beam-line engineers and experimental physicists to operate the measuring gear. The manual will consist of: 1) a detailed description of the mechanical and electronic components; 2) a set of standard operating procedures for the various types of measurements performed (this will include step-by-step procedures for answering the questions asked by the computer); 3) a section on how to operate and use the Supernova computer; 4) a section on the system programs developed for stepping-motor control, etc. These will be useful if anyone is interested in developing machine language programs.

Several of the approved experiments will require liquid hydrogen targets. In the interest of safety and perhaps economy, refrigerator targets will be used instead of reservoir targets. The target requirements of the first round of experiments are all within the capability of a 20° , 10-W refrigerator which is already available at LAMPF. A quotation for another identical refrigerator has been received and will be ordered as soon as funds are available. If large targets or targets with large heat deposition are required, some consideration will be given to reservoir target systems.

The Mark I delta-ray spectrometer was used successfully to measure proton energies during the 800-MeV beam tests in June. Improvements in the form of shielding, a new detector, a very thin target, and non-radioactive water for the detector thermoelectric refrigerator are being installed. Work has begun on the problem of using a dedicated Nova computer to pre-digest the spectrometer information for the Central Control Room (CCR) computer. The necessary interface hardware is complete, but

considerable software remains to be developed.

An order has been placed for a sample set of graphite foils with a 1-5-mil-diam holes on center. These foils will be tested at 100 MeV to check for possible stress-crack problems around the holes and at the clamp. An attempt will be made to determine the mechanism of heat transfer from the foils. Radiation is expected to play a predominant role under the proposed operating conditions, but the determination of the amount of conduction cooling is important since it may influence the design of the clamp.

A reactor test of radiation damage to m.i. magnet components has been completed. A test section of directly cooled m.i. cable, complete with ceramic seals and water insulators and thermal switches was irradiated in the Omega West Reactor (OWR) to a total dose of $\sim 5 \times 10^{11}$ rad. One hundred volts dc was applied to the conductor, and the water was maintained between 0.1 and 1 mΩ-cm resistivity to duplicate the m.i. magnet conditions. The conductor-to sheath insulation was lost soon after the start of the irradiation, thermal-switch operation became erratic, and the insulator resistance decreased. Initial post-irradiation examination shows that the soft-solder from the seals had melted and shorted the seals and eventually grounded the loop. The water insulators themselves measure 0.7 and 1.7 GΩ (compared to $> 5 \text{ TΩ}$ before irradiation). Further examination will be conducted on the insulators (especially an examination for internal deposits) and a thermal analysis of the m.i. cable will be made. The switch operating temperatures have been measured and found to be changed and unstable compared to the initial measurements. Slight corrosion has been observed inside the tubes, and additional observations will be made. The ceramic seals show radiation discoloration and a pattern of, at least, surface cracking. All of the components were radiographed prior to the test and post-test radiographs are to be made. It is believed that the unexpected damage to components occurred during a period of marginal performance of the water-cooling system.

Seven bending magnets on extended loan from CEA have arrived. In addition, a surplus C-magnet has been acquired from Ames Laboratory. Two CEA magnets are to be used in beam channels; ORFÈVE in P^3 , and KARNE in the test channel. The remaining magnets are designated for the LAMPF Electronics Equipment Pool

A table of characteristics is given in Table IV.

Remote-Handling

The Merrimac gantry was hoisted to the 6990-ft level of the service area and mated to its box. The box has been rotated in place and carried back and forth over short distances with the gantry; the gantry system is working well. No work was done to finish the Merrimac box during this quarter. The box-lead-glass windows (old Beetle windows) are being refurbished by an outside company.

Two additional hot-cell windows were removed from the RMD building at Jackson Flats, Nevada. Ten windows are now on hand. Nine windows are required for the hot cells which leaves one window box for mockup and equipment setup work. The hot-cell roof covers have presented a problem due to the use of reject steel slabs in the construction of doors and ways. The slabs were sufficiently bowed to cause interference. The doors are being jacked up and shims placed on their roller assemblies. The door-opening and work-platform system has been checked out and works very well.

Detail design of the target-handling mechanism for Target A-1 is complete and it is being fabricated in-house.

The fast-rabbit system which remotely places and retrieves a sample from the proton beam ahead of Target A-1 has been rescoped to avoid the immediate need to make detailed engineering and design effort. The new scheme is to provide a large-diameter pipe extending to the north of the main beam line. The pipe will be long enough to ensure that the shielding can be unstaked to expose its end for future addition of a rabbit mechanism. The pipe will be filled with shielding and flanged off until needed.

The stands for the target cell triplets have been designed and are being fabricated in Albuquerque. The stands provide horizontal and vertical adjustments for the magnets. The adjustments are to be powered by high-torque pneumatic stepping motors that are in the prototype stage. The success of these motors depends on the development of an air cylinder that has no organic seals and a reasonably low leak rate. Simple modifications to an inexpensive commercial air cylinder appear to solve the development problem.

TABLE IV
CHARACTERISTICS OF MAGNETS ACQUIRED FOR LAMP

Quantity	Designation	Type	Gap Height (in.)	Gap Width (in.)	Gap Length (in.)	Max. Field (kg)	Weight (tons)
3	ORPHEUS EURYDICE CALLIOPE (CEA)	N with 38-in. circular pole tips	5	32	32	16	21
1	HELEN (CEA)	N	6	18	36	20	12
1	KAREN (CEA)	N	3	12	36	17	7
1	SCYLLA (CEA)	N	10	22	48	18	38
1	ODYSSEUS (CEA)	N	11	17	48	18	33
1	C-Magnet (Ames)	C with 30-in. circular pole tips	6	20	20	~ 12	12

Machine tools have been cut by the millwrights in the staff shop in the basement of the Harrison service area and await the necessary electrical hook-up.

The drafting requirements for completion of the main and secondary beam lines have been recataloged and updated to provide an aid to administrative scheduling.

Shielding

The temporary beam-stop shielding for Line A was installed in the switchyard for the initial 800-MeV beam. Part of the temporary Line X stop was installed at that time and the balance of this stop has been completed. A temporary shield closure of the switchyard truck access was installed early in June and was removed after the successful beam operation. The same temporary closure will be used for the beam-diagnostics studies. The permanent shield in this entrance will not be installed until later this year. Based on monitoring results of the first 800-MeV beam, additional shielding has been installed in the vertical shaft to the thin-target area.

Installation of stacked shielding around the meson targets in Area A has been started. One-foot-thick steel slabs have been installed on the floor around TSA-1 and TSA-2 and around the process water lines that run in this lower level. Because of the irregularity of the concrete floor slab (maximum variation up to 1-1/2 in.) these initial steel slabs have been leveled by shimming, and have been grouted into place. The leveling provides a level platform on which to stack the remaining 22 ft of steel slabs and concrete blocks.

For the initial 800-MeV beam tests a shield of ~ 6 ft of cast iron has been placed across the switchyard entrance to Area A. This will be modified after completion of the tests to fit into the final shield around TSA-1. Design work has been started on the upper shield for Area A and for the 28-A shield. Preliminary layouts have been completed for the neutrino experiment shield. Stacking drawings for this shield have been started. Design has started on Area B stacked shielding and for the shielding plug for the Line B beam stop access shaft.

Figure 14 is a corrected version of an erroneous graph which appeared in LA-4899-72, Quarterly Status Report on the MFP Program for the period ending January 31, 1972 (p. 39, Fig. 23). The neutron spectrum was reported to be at 30 cm into the shielding when it was actually that calculated for a 60-cm penetration.

For purposes of shielding studies, a neutron source spectrum has been generated for the region around the primary proton beam stop. Though not for the actual dimensions of the stop itself, the spectrum has been calculated for those neutrons occupying a volume defined by a cylinder 20 cm in radius and 42 cm in length oriented coaxially with the proton beam. The ORNL transport code WHIC has been used to model the expected neutron yield from this volume as a result of impinging 800-MeV protons.

Since WHIC has a 15-MeV cutoff for the transport of nucleons, it is necessary to employ a low-energy transport code to estimate the low-energy contributions. In this particular case, the LANL-developed code ANK was used. The full-energy-range neutron spectrum appears in Fig. 15. For the portion of the

Fig. 14. Energy spectrum of neutron flux penetrating 60 cm into shielding at right angle to beam stop.

Fig. 15. Full-range energy spectrum.

spectrum above 15 MeV, NMTC was used to start 47,500 protons at 800 MeV which resulted in 34,687 escaping neutrons. The low-energy portion was calculated using ANDY, with its source being generated by an NMTC calculation for 4000 incident protons (800 MeV)

producing ~ 28,900 neutrons of energies of 15 MeV or less inside the specified volume. Those neutrons were then transported by ANDY. This source tape was cycled ten times in ANDY, thus simulating the low-energy yield for 40,000 incident protons. Figures 16-20 show the neutron spectra falling into the angular intervals 0-10°, 40-50°, 90-100°, 130-140°, and 170-180°, respectively, with the angle measured with respect to the beam direction. Some improvement in statistics is needed.

Fig. 16. Neutron spectra in angular intervals 0-10°.

Fig. 17. Neutron spectra in angular intervals 40-50°.

Fig. 18. Neutron spectra in angular intervals 90-100°.

Fig. 20. Neutron spectra in angular intervals 170-180°.

Fig. 19. Neutron spectra in angular intervals 130-140°.

VII. LAMPF FACILITY CONSTRUCTION

Craft-Equipment - Installation Activities

Zia/LACI crafts provided about 3,000 manhours of installation assistance during this period. Control wiring was pulled and terminated in the beam switchyard, Service Aisle A and Experimental Area A; magnet and ion pump stands were set in the beam switchyard and magnet power supplies were set in Service Aisle A.

The L. E. Meyer Co. completed all accelerator cooling water and vacuum hook up work and has now completed 99%, versus a scheduled 100%, of the X01 through X08 cooling water system extension into the primary A beam line.

Fabrication of the HRS support frame was completed and installation is now 82% complete, compared with a scheduled 99%. A contract for Merrimac chemistry laboratory furniture installation was bid and awarded to Western States Mechanical Contractor for \$46,681. This work is now about 2% complete.

Building Construction

The Experimental Area Phase II contract is now 99.6% complete compared with a scheduled 98.9%. Service Aisle D is the only portion of this package for which beneficial occupancy has not as yet been taken; however, a lengthy list of punch list items remains to be cleared for all other portions of this contract.

Experimental Area Phase III has progressed to 99.9% completion, versus a scheduled 100%, with only a few punch list items remaining to be accomplished.

VIII. PHYSICS RESEARCH

General Facilities for Preparation of Experiments

Scintillation Counters

Three trial phototube base designs have been wired and are being tested for the EMI 9813B phototubes. Scintillating plastic is on order.

Readout and Coding Electronics for Multiwire Proportional Chambers (MWPC)

The contract to build the printed circuit (pc) boards and chassis for handling up to 8600 digital signals from proportional wire chambers was let to Eberline of Santa Fe for construction of the chassis, and to Sparton Southwest of Albuquerque for the pc boards. These units are being checked as they are received from the contractors. The chassis are showing surprisingly few mistakes, but the pc cards have been disappointing in the quality of component-mounting and soldering. At the end of this quarter, approximately 16 decoder units, sufficient to handle 3200 proportional wire signals, have been checked out and certified for use. These units have been checked through the Supernova computer and are stable, reliable, and relatively simple to troubleshoot. A great deal of interest from outside users has been manifested in this unit design, and engineering drawings have been sent to several groups contemplating early experiments at LAMPF.

MWPC Amplifiers

Most of the off-chamber amplifiers fabricated by Virginia Polytechnic Institute (VPI) have been received, and about 3000 amplifiers have been checked out and are ready for use. Another thousand remain to be repaired.

The parts for 4000 on-chamber amplifiers have been ordered, and the circuit design is firm. Some small details on board layout remain to be worked out before bids can be requested.

The multilaboratory effort to standardize on a hybrid fabrication for MWPC front-end electronics appears to be bearing fruit. Prototype units have been received from Fairchild, and ten laboratories are now evaluating them. This evaluation will be completed early next quarter. It is hoped that these hybrid units will reduce overall system costs and substantially simplify implementation of proportional counters into the experimental programs at LAMPF.

Computer Interfaces

The single-chassis interface between the decoders and the Supernova or PDP-11 computers has been completed and checked out. It worked perfectly the first time it was tested and has proven free from crosstalk, noise pickup, and signal droop, which usually characterize control units driving long lines. This unit interfaces up to 40 MWPC decoder modules (8000 wires) into either computer at data-transfer rates up to one million 16-bit words/sec. It packs two 8-bit decoder words into a 16-bit computer word before transfer, and thus permits the maximum data-transfer rate possible for a given computer cycle time. This unit, the decoders, and amplifiers as built, constitute a reliable data system for multiwire proportional chambers. The system is noise-free, even with cable runs up to several hundred feet, and in electrical environments found in the experimental areas of LANFP.

Helical Wire Proportional Counters

The development of helical wire proportional counters has continued this quarter and substantial progress has been made. A single wire helical chamber was constructed and tested at the LASL tandem Van de Graaff facility. The chamber had dimensions of 18.5 cm x 15 cm overall with an active area of 1 cm x 18.5 cm. A 12-MeV proton beam was elastically scattered from a gold target and momentum analyzed with a spectrograph. The helical chamber was placed 11.25 cm behind the focal plane and the elastically scattered protons passed through the chamber at an angle to the normal of 57° .

Two tests were made, count rate and resolution. For the resolution tests the momentum slits at the entrance to the spectrograph were reduced. The measured spatial resolution was 0.6 mm FWHM. Since the spot size at our chamber was unknown, this gives an upper limit for the resolution of the chamber. For the count rate tests we measured the timing peak position, the FWHM and FWTM (full width at tenth maximum). Measured values for a 1 kHz count rate and a 50 kHz count rate indicated no change in the peak positions, no change in the FWHM and only a 15% increase in the FWTM in going from 1 kHz to 50 kHz. Since no pileup rejection was employed, it appears that count rates of at least 50 kHz can be handled by these chambers. Additional measurements are anticipated.

The prototype fast amplifier/discriminator for the helical chamber was tested and found to be satisfactory. A final printed circuit was designed and fabrication of the first production models is under way. The anode wire amplifier designed by MF-3 was evaluated and tested and was found to be satisfactory. A complete readout system using both of these units has been designed and fabrication will begin shortly. We expect to have the complete electronics for one helical chamber ready to test in mid-September.

EPICS Fast Electronic System

We completed design of the fast electronic system for the EPICS system. After a first proposal, all users comments were incorporated into a final design. The same electronics will be used for channel diagnostics and for the spectrometer detectors. The total requirement for electronics from the pool is approximately \$45,000. Included in this requirement is equipment already on hand. A significant amount was procured from surplus or was used on previous LASL experiments.

Cerenkov Counters

Considerable progress was made in the design of two Cerenkov detectors. The first is a threshold gas counter for detecting electrons. This will be used both for channel tuneup and for early experiments. A second design study is for a differential counter for separating pions and muons in the large phase space of the beam transmitted by the spectrometer. So far, there appear to be no difficulties which would prevent such a counter from working. Detailed studies of the optical aberrations and the light collection system are now under way. The EPICS Working Group provided all of the manpower for this work.

A design study for a system to allow EPICS to operate in the 150° to 180° region has been made. It appears practical to use a pool magnet, a 32-in. diam. circular pole tip magnet (either ORPHEUS or EURIDICE) to deflect both the incoming beam and the scattered beam at the scattering target. We envisage occasional use of such a setup for backward scattering experiments as required in the EPICS experimental program. Detailed studies will now begin, with the aim of minimizing the cost of adding the backward angle feature at some later date.

Design Studies for a Pion Form Factor Experiment

Monte Carlo studies are continuing on the experiment to measure the electromagnetic form factor of the charged pion. Dr. James S. Ball, a visitor from the University of Utah, gave valuable assistance with this work. Several errors were discovered in some of the theoretical papers that were used as a basis for the Monte Carlo program. These errors have been corrected in the computer program, and studies are progressing.

Pion Production from Nuclei

The experimental data for π production from the Berkeley 740-MeV proton experiment has been studied with a view to discovering some empirical general laws for the cross section. Several interesting rules emerge. For π^+ production, the integrated cross section σ_T is proportional to $Z^{1/3}$:

$$\sigma_T(+)=Z^{1/3}\times 24.5$$

where Z is the atomic number. Figure 21 illustrates this law. For π^- production σ_T is proportional to $N^{2/3}$:

$$\sigma_T(-)=N^{2/3}\times 3.33.$$

Figure 22 illustrates this law. The total cross section laws and the other evidence suggest that π^+ production is peripheral and goes via Δ^{++} production and decay, whereas π^- production includes the production of π^0 and subsequent charge-exchange scattering and, hence, involves more of the nucleus.

Another interesting law is that

$$\frac{d\sigma/d\Omega dE}{\sigma_T}$$

is almost independent of Z or A for a large number of nuclei. Figure 23 illustrates this law. The curves for the several elements lie very close together. It suggests that very few details of nuclear structure can be involved in pion production at this energy.

These features of the pion production have stimulated some theoretical work. M. M. Sternheim, MP-20, together with R. R. Silber, T-5, have constructed a simple, semiclassical model for the production of pions from nuclei. The existence of extensive data from the Berkeley experiment provided the impetus for this work. It was found that including the effects of charge exchange and keeping the angular dependence of the pion path length were

Fig. 21. Positive pion production from nuclei (π^+ $\sigma_T/Z^{1/3}$ vs Z).

Fig. 22. Negative pion production from nuclei (π^- $\sigma_T/N^{2/3}$ vs N).

Fig. 23. The quantity $d^2\sigma/d\Omega dE/\sigma_T$ for 30 MeV π^+ for production at various angles.

necessary to reproduce these data. A remarkably good fit, considering the simplicity of the model, was obtained using only three parameters. A paper on this work was prepared and submitted to the Physical Review.¹

¹M. M. Sternheim and R. R. Silber, "Model for Production of π^+ and π^- by Protons from Nuclei." (Submitted for publication in Phys. Rev. C, July 1972).

Nucleon-Nucleon Interaction Experiments

The cross sections for the n-p forward elastic scattering experiment have been produced, studies of systematic error contributions are under way, and the student (A. Barsbach, Princeton) is writing his thesis.

IX. PRACTICAL APPLICATIONS OF LAMPF

Summarizes work being performed under auspices of USARC Division of Research, USARC Division of Biomedical and Environmental Research, National Cancer Institute, and USARC Division of Military Application.

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

Biomedical Pion Channel Design

Previously, design studies for the pion channel have been carried out only to second order in the beam optics. The ray-tracing program, NOTER, has now been used to extend the calculations to a higher order. Results for the pion beam properties at the momentum-dispersion plane are consistent with the earlier second-order calculations. Work is proceeding to extend the higher-order calculations to the end of the channel.

Engineering drawings of the basic assembly of the entrance quadrupole triplet were completed; bids for the fabrication of the triplet were received, and a vendor was chosen. Engineering drawings for the first two bending magnets have been started, as well as a design for the last bending magnet. Drawings for the five beam-shaping quadrupoles are ~50% complete. Engineering studies of the automatically controlled beam stops and slits are continuing.

A purchase request for magnet iron is being prepared and a purchase request for cable for the last five quadrupole magnets has been submitted.

Bids have been requested for two different magnet power supply configurations. One is an integrated power supply/regulator package; the other is a basic supply to which the LAMPF-developed regulator system would be adapted. The configuration that results in the most suitable combination of cost and delivery date will be chosen.

Detailed engineering design of a multi-level support structure for the shielding and channel components was started and is in progress.

Recently completed was a study that indicates that the multiple coulomb scattering of pions traversing the channel will be within acceptable limits, assuming the aperture of the last five quadrupoles is helium-filled and the remainder of the channel is air-filled. This arrangement, if followed, will result in a savings of the order of \$20-40k, since the

problems of designing and fabricating a complex helium container with gas-tight ports for slits and other devices will be eliminated.

Pion-Production Target

Both a stationary, water-cooled carbon target and a rotating-wheel carbon target were considered. The rotating target would be cooled by thermal radiation. It was decided, for reasons of space limitation, to use a water-cooled target, 1.5 cm in diameter and 5 cm long.

Plans were made to test a high-density graphite target in the 100-MeV proton beam and to begin development of a higher-density pyrolytic-graphite target.

The target insertion and removal mechanism will fit through an 18-in.-diam port located directly above the target position.

Dose-Distribution Calculations and Dosimetry

Calculations of LET distribution were started using the results of the pion-energy-deposition calculation from G²NL. The main effort thus far has been to collect stopping-power information for heavy ions in tissue.

Plans have been made to purchase or construct instruments to be used for dosimetry, e.g., Rossi counters, ion chambers, radiation damage diodes, etc. These instruments will be tested in other beams prior to the operation of the biomedical beam line. A Shoaka-thinble-ion-chamber system with associated electronics has been set up and the response to ⁶⁰Co gamma rays and neutrons has been determined in air and in a Lucite phantom.

A second integrating-electrometer NIM module is nearing completion. This unit will be compared to the first one for the purposes of discovering any problems of reproducibility. Two new operational amplifiers will be checked out in this unit; improved drift characteristics may be realized. The present design appears to be very stable down to currents of 10 pA and is useful at 1 pA if balanced once every 24 hours (approximately). Total drift ranged from 0.5% to 2.5% in 24 hours at 1 pA, but was less than 0.3%/24 h at levels of 10 pA or higher. The ambient temperature fluctuation during the recordings was typically 3 to 5°C. A shielded input-selector switch will also be tested.

Treatment Planning

The dose-calculation section of the treatment-planning program has been written and debugged. This section uses a moderately simple calculational model of the beam; the depth-dose function is an adaptation of one used by G. Li at Stanford in their pion-treatment-planning code. A visit was made to Stanford to discuss treatment planning and their pion biomedical effort in general. The final section which outputs the dose data is still being written.

Neutron Dose from Pions Stopping in Tissue

The neutron-dose spatial distribution resulting from pion "stars" has been calculated for a "tissue-equivalent" material consisting of C, N, O, and H using a multigroup, neutron transport code, ANDY, developed at LASL. The "stars" were assumed to be uniformly distributed throughout a 1-liter spherical treatment volume centered within a sphere of tissue of 40-cm radius. The results are shown in Fig. 24. If the total dose within the treatment volume is taken to be 10^{-9} rad/n⁺ stopped, then, at ~5 cm from the edge of the treatment volume, the dose has dropped to 1% of the treatment dose. Further calculations show that the γ -ray contribution to the dose external to the treatment volume is ~2% of the neutron dose and, hence, can be ignored.

Fig. 24. Dose Distribution In Tissue From Star Neutrons

A table showing the dose delivered to specific organs for a few particular treatment sites is being prepared and should be more informative for radiotherapists.

Shielding

The required thicknesses of steel shielding for the biomedical cave have been calculated with an approximation technique that treats the neutron spectrum from the target as a sum of bins of discrete energy. In traversing shielding, each monoenergetic bin is assumed to generate a $1/E$ spectrum that cuts off at its bin energy. The spectrum is normalized at the entrance of the shield so that at an equilibrium distance into the shield, the $1/E$ spectrum has attenuated to the same level as given by neutron transport calculations (made at ORNL for concrete). This approximation technique is being compared with the special case of 90° scattering from the Area A beam stop as calculated in detail by Group MP-6; at present, the results differ by roughly a factor of five to ten in the neutron flux.

The steel shielding thicknesses are determined so that personnel neutron tolerances are met assuming 1 mA of protons onto a 5-cm-thick carbon target. A collimator following the target will probably be required to reduce the size of the neutron source presented to the neutrino area; the neutron flux produced in the collimator is comparable to the neutron flux from the carbon target as measured in the biomedical area. The average whole-body dose due to star neutrons is 0.3% of the tumor dose in a one-liter volume; this dose already exceeds an original tolerance of 0.25% average whole-body dose. Therefore the shielding in the patient direction will be 7 to 8 ft thick, in order to limit the dose due to neutrons penetrating the shield to somewhat less than 0.1%.

Computer Control System

Work on the computer control system is progressing satisfactorily. The control console is being assembled in the laboratory. The layout of the control panels has been determined. The control philosophy has been fairly well-defined. Prototypes of some of the digital electronics in the console have been obtained for evaluation as to noise susceptibility. Several control panels are in the drafting state, and fabrication of some of these will begin

soon. The control console should be nearly completed within three months.

The orders for the major items of the control system have been monitored regularly. Most of the equipment, including the PDP-11/45 computer, is scheduled to be delivered in August. Plans had been made to buy an "equipment enclosure" (i.e., a prefabricated structure to house the control system) with installation to begin in the late fall. Unfortunately, the cost of this approach is unknown and delivery by November 1 now seems unlikely.

The software for the computer control system is also progressing. An effort was made to firm up the control channel list and control interface details, e.g., magnets, magnet power supplies, targets, beam diagnostics, dosimetry, communications, etc. This has not been completed. A decision was made to utilize a Real Time Executive software system (RSX), being marketed by Digital Equipment Corp., rather than relying solely on the modified Desk Operating System (DOS) being used in the other experimental areas. The RSX11-B version has been obtained and is running on a PDP-11 in the Operations Building. A few special features are being added that will be required for our application. Unfortunately, RSX11-B is being extensively rewritten and the newer version, RSX11-D, will not be available until next spring. We will start with RSX11-B and switch to RSX11-D when it is available. The changeover will not be simple. The CAMAC interface with the control computer will be tested during the coming quarter. Early in the quarter, the trunkline wiring requirements will be specified so that negotiations can be started on an installation contract.

Medical Instrumentation Development (In cooperation with the UNM School of Medicine)

An ECG preamplifier has been designed which is far less sensitive to electrosurgery noise than any commercial unit tested thus far. In addition, a balanced coaxial transformer has been developed which may be used on the output of standard electrosurgery units to reduce stray rf currents. This reduces both the rf noise interference and the probability of patient electrocution or rf burns. It is planned that prototypes of each of these units will be installed at Bernalillo County Medical Center. A paper that describes this work is being prepared for

the journal, *Anesthesia and Analgesia ... Current Researches*.

A new type of electrosurgical scalpel has been developed for trial use by surgeons at UNM Medical School. This device allows the surgeon to cut and to coagulate tissue simultaneously, without any ill effects on adjacent tissue. A current application involves the removal of arteries for a coronary transplant. Previously, many small branch arteries were cut and had to be tied off as the major artery was removed. These arteries are now cut and "sealed" in seconds with the electrosurgical scalpel. Surgeons feel that this technique will result in large savings of operating time and more reliable sealing of the small arteries. Experiments with animals will continue so that further utilization of this scalpel may be investigated.

A primate test has been performed using the "ECG-Synchronized Chest Compressor." This chest compressor was proposed by members of the surgery staff at the UNM Medical School. It was found that blood pressure could be increased by more than 20% when the external pressure was applied at the proper time; however, data on cardiac output were inconclusive. At least two more primate tests are planned, one of which will probably involve the direct measurement of coronary flow rates. A realization of increased coronary flow rate as a result of synchronized chest compression would be a strong indication of the therapeutic value of the technique.

In Vivo Tissue Analysis with Muonic X Rays

Discussions are being carried out with other groups planning to do muonic x-ray measurements at LAMPF in order to avoid any duplication of efforts in setting up experiments. In particular, investigations are under way into the possibility of having equipment (e.g., irradiation sample holders, shielding, detectors, and electronics) common to more than one experiment.

In order to more accurately predict the muonic x-ray spectrum from tissue, better information on spectral line shapes, in Ge(Li) detectors, is being sought. Once this information is available, it will be combined with the results of calculations of line yields. These calculations are being made using a computer program that computes transition probabilities for muons cascading down atomic energy levels.

Meson Chemistry

A cascade code is being used to calculate relative muonic x-ray intensities in several light atoms (e.g., C, N, and O). When the Ge(Li) detector arrives, a library of empirical lines using isotopic sources can be generated. Muonic x-ray spectra will be synthesized for those target materials to be used in actual experiments. These dry runs should prove very useful in planning the experiments.

Radioisotope Production

The data obtained during three series of experiments performed at the Space Radiation Effects Laboratory (SREL) have been analyzed and are being compiled in preparation for publication. The large amount of thin-target cross-section data at 600 MeV for approximately two dozen targets provides a solid basis for the future use of the Isotope Production Facility at LAMPF. Comparisons of the thin-target data with predictions derived from Rudstam's empirical systematics equations, including subsequent modifications, are being made. Also, thick-target yields from Fe, Nb, and Bi have been obtained. The interlaboratory comparisons with Battelle Northwest Laboratory and Aerojet Nuclear Corporation using Fe and Cu targets generally show good agreement, lending confidence to our analysis techniques.

Preliminary experiments are now in progress or are being planned using LAMPF test beam of 100 MeV and 500 MeV, initially at the few- μ A current level. A Zr target ($2 \times 2 \times 1/2$ -in. thick) is being irradiated at the beam stop that has been located after module 13. This target is being irradiated by 100-MeV protons for the purpose of producing ^{88}Y (107 day half-life), which will be used in Safeguards experiments in Group A-1 at LASL. Larger quantities of this isotope can be extracted from the Mo target wheel that will soon be tested in a 250- μ A, 100-MeV beam. An additional Mo or Zr target may be inserted at this location. The total amount of ^{88}Y desired is of the order of a few curies.

Weapons Neutron Research Facility Beam Line

The beam line extending from the LAMPF switchyard area to the Weapons Neutron Research Facility (WNRF) is under study. The latest design of this beam incorporates 26 bending magnets, 21 quadrupoles, 2 collimators and ~700 ft of vacuum pipe. The designing and engineering of most of the components in

this beam line will be done in MP-Division. Prior to obtaining funding for a proton storage ring at the WNRF, it is planned that a proton beam only will be transported to the WNRF. (An H^- beam will be needed for the proton storage ring.) The WNRF proton beam will be $\leq 2\%$ of the total LAMPF proton beam.

X. LAMPF USERS GROUP

Executive Committee

The Executive Committee met in Los Alamos on July 24, 1972. At this meeting they incorporated and became the first Board of Directors of the LAMPF Users Group, Inc. This action followed the wishes of the membership of the Users Group as expressed in the balloting (338 yes, 15 no) on the question of incorporation. During a combined session of the Board of Directors and the LAMPF Electronic and Equipment Pool (LEEP) Subcommittee of the TAP, R. E. Mischke presented a status report on the LAMPF Equipment Pool, followed by Donald Hagerman's report on the accelerator and the Scheduling Committee. In executive session, the Board heard a progress report from Harry Palevsky, Chairman of the WNS Working Group. A slate of proposed nominees was received from a Nominating Committee. Millard Howard reported the results of the housing survey requested at the last Executive Committee Meeting. George Igo presented a list of proposed speakers for the Sixth LAMPF Users Meeting to be held at Los Alamos on November 13-14, 1972. LAMPF Director Louis Rosen met with the Board and discussed informally the general outlook and plans for the completion of the facility.

In actions taken by the Board, Millard Howard was asked to obtain definite answers on the questions of telephones and transportation for experimenters at LAMPF. The Board unanimously agreed to recommend to LASL Director Harold Agnew that he double the LAMPF priority housing by next spring. The Board appointed Gerald C. Phillips as parliamentarian for the next LAMPF Users Group Meeting.

Users Activities

The Subcommittees on Radiation Therapy and Human Trials held a combined meeting at LAMPF on May 31, 1972. Morton M. Kligerman announced that the architect for the biomedical facility had been chosen and discussed the proposed time scale. There followed a discussion of the site visit for the Pre-clinical Studies in Pion Radiotherapy, which the National Cancer Institute requested the University of New Mexico resubmit following the original LASL proposal. There was considerable discussion about what studies to conduct. William Shlaar discussed treatment planning and his work on developing a

computer code to handle this using the first beam model. Richard Hutson reviewed the beam line proposal. There was a discussion of related proposals and the relationship of in-house work and outside proposals. Robert D. Moseley gave his ideas on tumor localization and the task of his new Subcommittee. Louis Rosen answered questions on LANPF and future plans. The review and discussion of anatomical sites was followed by a discussion on the logistics of the trials. A brief discussion followed concerning the feasibility of having two proposals, one to cover the Cancer Research and Treatment Center at UNM and the other for clinical trials.

An organizational meeting for the Radiation Damage Working Group was held at LANPF on June 29-30, 1972. The attendees received briefings on LANPF, the data-acquisition systems, preliminary work on dosimetry, preliminary design of the experimental facility, and work in progress at other laboratories. During their stay, the attendees toured LANPF, the hot cells in the CNR building, and the Tritium Facility. Austin McGuire (LASL, Office of Special Projects) addressed the group on funds for LANPF. At the close of the meeting, the Radiation Damage Working Group chose Walter Green (LASL, CNB-13) as chairman and C. Z. Serpan (Naval Research Laboratory) as secretary.

The P^3 Working Group held a meeting at LANPF on July 13-14, 1972. The purpose of the meeting was to outline the specific plans to bring P^3 on the air, with emphasis on which tasks Users' help is needed. Robert Macch talked about the fine-tuning procedures for the channel. Magnet measurements were discussed by William Hassenzahl. Ralph Minehart is building and testing a differential Cerenkov counter for use in P^3 . Ray Crittenden is looking at the general problem of beam monitors. Peter Gram described a focusing spectrometer for use in Experiment #34. After Richard Mischke discussed a CAMAC test setup, several items that need Users attention were discussed: 1) background calculations, 2) beam calculations, 3) muon contamination, 4) flux code, and 5) momentum resolution using ray-tracing program.

At a combined meeting of the NRS Working Group Committee and the NPL Steering Committee, Roy Thaler commented on the theory of the nucleon-nucleon problem, in order to set the stage for discussions on

overlapping areas of interest. M. Palevsky, J. Simmons, and M. Willard spoke on the proposed research programs at the two areas.

Liaison Office

The Liaison Office is working out the procedures for processing experimenters who will be visiting LANPF. We hope to insure the visitor of getting the necessary services required with a minimum of paper work. We have begun to handle those users who are supported by the new ANU-administered ABC Division of Physical Research travel funds. To date there are 9 scientists at LANPF who received or are receiving these funds. The July Newsletter is presently being printed and will be mailed by the first week in August. The Liaison Office also conducted a survey of approved experimenters in order to ascertain their housing needs, as directed by the LANPF Users Group Executive Committee. Other problems presently being studied are: 1) transportation for users, 2) telephone services for users, 3) storage service for users' equipment, and 4) preparation of a Users Handbook. Major mailings handled by this office were: 1) ballots to members of LANPF Users Group concerning incorporation, 2) announcements of working group meetings, 3) announcement of the Conference on Particle Accelerators in Radiation Therapy to the members of the Users Group interested in the biomedical and biological applications of LANPF.

Program Advisory Committee

The Program Advisory Committee (PAC) will meet at LANPF on September 27-28, 1972. The deadline for receiving proposals to be considered at this meeting is August 15, 1972.

Research Proposals

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

- 116 "The Quasideuteron Photoeffect in ^{12}C at 130 MeV"

Barnett C. Cook, Spokesman

John E. E. Baglin, Alfred S. Bureau,
Barnett C. Cook, Richard C. Morrison
(Iowa State Univ. and Ames Laboratory
of USAEC)

- 117 "High Resolution Study of the Neutron Pick-Up Reaction"

G. Igo, Spokesman

G. Igo, R. Rolfe, R. Strang, J. W. Sunier,
C. A. Whitten, Jr. (UCLA); E. R. Flynn
(LASL); S. Vigdor (U. of Wisconsin)

- 118 "Fragment Emission from Pion Interactions with Complex Nuclei"
N. T. Porile, Spokesman
 N. T. Porile, Graduate Student (Purdue Univ.); B. J. Drapesky, R. A. Williams (LASL)
- 119 "Cross Sections of Simple Nuclear Reactions Induced by Pi-Mesons"
Sheldon Kaufman, Spokesman
 S. Kaufman, Ellis P. Steinberg (ANL); Gilbert Butler (LASL)
- 120 "Measurement of the Polarization Asymmetry and the Differential Cross Section of Pion-Nucleon Charge Exchange from 160 to 500 MeV"
D. I. Sober and B.M.K. Nefkens, Spokesmen
 D. I. Sober, B.M.K. Nefkens, K. C. Leung (Univ. of California, Los Angeles); C. F. Huang (LASL)
- 121 "Interaction of Stopped Negative Pions with Complex Nuclei"
R. E. Segel, Spokesman
 R. L. Burman (LASL), J. P. Schiffer, I. Moyer-Schutzmeister, R. E. Segel (ANL)
- 122 "Pionic Atom X Rays and Nuclear Distributions"
R. Kunselman, Spokesman
 R. A. Jenkins, R. J. Powers (Virginia Polytech. Inst.); R. E. Walsh (Coll. Wm. & Mary); R. Kunselman (Univ. of Wyoming)