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A PROGRESS REPORT

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Quarterly Report on the
Medium-Energy Physics Program
for the Period Ending April 30, 1972

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

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

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LA-4982-PR

A Progress Report

UC-28

ISSUED: July 1972

Quarterly Report on the
Medium-Energy Physics Program
for the Period Ending April 30, 1972

Compiled by

Eleanor Dunn

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I. SUMMARY

Engineering Support

Four significant milestones were reached, ahead of schedule, during this report period: the H_2 furnace brazing of the 805-MHz structures, the installation of the side-coupled structures, the installation of the 805-MHz rf amplifiers, and the successful completion of the first 1.25-MW klystron rebuild.

All devices (magnets and their power supplies, beam tubes, bucket rotator, etc.) have been installed in the Transition Region.

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

The production and testing of klystrons are continuing on schedule. Varian has completed its contract for 45 klystrons and has started production on a supplementary contract for an additional ten. Litton is still experiencing difficulty with multipactoring. To date, more than 91,000 high-voltage hours have been logged on the 1.25-MW klystrons.

Engineering support for the Experimental Area continues to receive substantial emphasis. Work in the switchyard and on Beam Lines A and X is on schedule and support for the Biomed cal and Secondary Lines is proceeding satisfactorily.

Accelerator Systems Development

All installation and commissioning work on the 805-MHz accelerator is about two weeks ahead of the schedule set up last quarter. Two weeks of final checkout and dry runs are scheduled for May and the machine should be ready to begin looking for 800-MeV protons by June 5, 1972.

Equipment was installed to obtain the 45° deflected 100-MeV beam, and preliminary experiments were conducted.

Accelerator structure tuning was completed. The intrusion of a TE_{113} mode required addition of two suppression posts in some of the longest bridge couplers.

The Δt procedure for adjusting the amplitude and phase of the field in the first eight 805-MHz modules was successfully demonstrated. The required amplitudes appear to be substantially higher than expected; the reasons are as yet unknown.

Development of the high-intensity injector continued. Two new quadrupole lenses were added to the initial part of the transport line, and alignment was checked. These additions have improved the capability of the transport system in providing higher current to the linac.

In the H^- source development program, measurements were made on the ion intensity capabilities of the duoplasmatron to get a current-calibration of the source and to learn its limitations. Several new extracting structures were tested, one of which yielded 1.5 mA H^- into a 7-mm Faraday cup. A multiaperture source has been built. Column injection optics were studied, and 470 μA were focused into a 2-mm apertured Faraday cup as required by the column optics. Construction of the 100- to 200- μA injector continued.

Electronic Instrumentation and Computer Systems

The primary task of installing the accelerator control system was pushed in anticipation of the 800-MeV beam test. The bulk of the activity was concentrated on device installation and hookup in the 805-MHz area. After each system is checked out, it is maintained in a state of readiness by a computer-automated test procedure.

A continuing program of improvements and maintenance was carried out on the injector control systems. The emittance-measuring equipment and programs were transferred to the NOVA computer in the Injector Control Room (ICR). Significant progress was made in the installation of the controls for the H^- injector.

The control system in the Transition Region was completed to the point that it could be used to guide a 100-MeV beam into the diagnostics area.

Wire schedules were completed for most of the equipment scheduled for the switchyard. The hardware channel assignments were reviewed against the need for high data rates from certain diagnostic devices. Development work was completed on a transistorized shunt which will allow several magnets connected to the same power supply to be controlled independently. Preliminary designs were started for the control systems required along Beam Lines B and C. Development of special controls for the High Resolution Proton Spectrometer (HRS) was continued.

Tests showed that the reliability of the software for the control computer had been increased by a factor of three over the past several months.

A major modification was made in the beam-spill monitoring system. The system now triggers on the average rather than the peak beam spill. Electronics to meet the new requirement were developed and the retrofitting was started.

The first two computers for the LAMPF data-acquisition system were put into operation. The development of software is on schedule for the first test in June.

The CAMAC branch driver is in the final stages of checkout on the PDP-11 computer. Three other units are in various stages of fabrication.

A total of \$250,000 has been spent for equipment for the electronics pool to support LAMPF users.

Accelerator Operations

The group responsible for operation and light maintenance of the accelerator had a modest personnel increase and, with assistance from support groups, accelerator experimental programs can be sustained on a normal work week of two shifts with an occasional week of three-shift operation. Operation personnel have gained considerable experience in running the accelerator both in local and computer modes. The ultimate goal is to run the accelerator and do the major portion of systems diagnostics and faults analysis from the computer control room.

A modest start has been made on a formal operator training program.

Experimental Area

Switchyard services and equipment installation have been intensified in an effort to have the switchyard ready for beam by June 1, 1972. The PERT system has been supplemented by a detailed scheduling chart. A number of the switchyard magnets have developed faulty coils, but repairs are proceeding satisfactorily. First beam tests require only two quadrupoles, which should be no problem. Installation of the power cabling, the water systems, and the instrumentation conduits is almost completed. Progress is being made on the switchyard instruments and the collimator.

The final design for the Isotope Production Facility was completed for review, and the conceptual design report for the Radiobiology and Therapy Research Facility was transmitted for AEC review. Planning work and the conceptual design report have been carried out for the proposed Weapons Neutron Research Facility.

Steady progress is being made on final design for supports, cooling-water systems, control system, liquid deuterium target, and the neutron collimator for the Nucleon Physics Laboratory. On the High Resolution Proton Spectrometer (HRS) project an order has been placed for the two large bending magnets in Beam Line C; all of the magnets are in procurement or have been received. Spectrometer fabrication continues with good progress on the magnet coils and slight delays on the magnet steel machining. The design and development of the beam strippers is proceeding.

Further detailed design studies have been carried out on the Energetic Pion Channel and Spectrometer (EPICS) system. The results are in agreement with the earlier predictions of system performance. A favorable bid was received for channel magnet fabrication and the order has been placed. All components of the spectrometer magnetic system are on order except machining for the bending magnets, which is on bid. Good progress has been made on the EPICS particle separator.

All magnets for the Low Energy Pion Channel are either on hand or scheduled for delivery during the next quarter. Work on the magnet accessories continues. The bulk of the support stands were designed and ordered, or placed on bid.

A change in the magnet used for the final bend in the P^3 Channel has been made. This change releases a large flexible magnet that is very suitable for magnet-pool use. Progress has been made on a computer code to be incorporated into the on-line analysis of the P^3 tuneup procedure. A number of cracks in the epoxy insulation in magnets received as surplus from the Princeton-Penn Accelerator have been repaired.

A substantial amount of the work involved in equipping the magnets at the start of the Stopped Muon Channel with concrete insulation has been completed successfully. Improvements have been made in beam-spot-size calculations and in the control system for the channel.

Four of the nine large quadrupole triplets for Beam Line A target cells have been delivered. The delivery schedule for the balance is expected to be maintained. The current and profile monitor configuration for the target cells has been generally specified.

A beam-stop system has been built and installed at the "north port" in the 100-MeV test area.

Work continues on the process water systems, with much of the basic apparatus and its instrumentation installed; installation is being carried out on the water mains to the valve caves in Area A.

Alignment monitors have been set for the switchyard and Area A. The alignment survey has been extended into Areas B and C.

The delta-ray spectrometer has been improved and installed in the north-port beam line. Delivery of beam-line instrumentation hardware for 800-MeV beam tests is nearly complete. Considerable experience has already been gained in the 750-keV beam for the harp, profile monitor, centroid monitor, and high-sensitivity current monitor. The prototype profile monitor has achieved better than 0.5-mm resolution with a 10- μ A beam (average) at a pressure of $\sim 10^{-5}$ Torr. Improvements in the circuitry for the high-sensitivity current monitors have eliminated beam-synchronous interference troubles.

The LAMPF Users Equipment and Electronics Pool (LEEP) has been established. About ten bending magnets of various types and sizes are now available as pool equipment.

The Merrimac system is nearing completion. A prototype Merrimac door was assembled and tested successfully.

Detail design of the target-handling mechanisms for Targets A-1 and A-2 is progressing.

The installation of in-place shielding in Area A-East and around Beam Stop A has been completed. About 200 tons of Navy salvage steel was put to economical use. Backfilling of the switchyard, Area B, and Area C has been completed. Installation of temporary beam stops in the switchyard has started. Design of the main shielding in Area A continues.

Transport code studies of shielding for pion beams and for the neutrino facility continue. Efforts are being made to extend the treatment to

thermal neutron energies and to deep-penetration situations.

Physics Research

Helical Multiwire Proportional Counter Development

Substantial improvements were made in the development of the helical wire proportional chambers; a new bifilar helical system is working and offers important advantages for some applications.

General Facilities for Preparation of Experiments

Preparations were continued for a number of specific physics experiments. The winding machine for wire chambers was operated satisfactorily and a number of chamber planes have been wound.

Pion-Absorption Experiment

Analysis of the data on the (π^+ ,p) and (π^+ ,2p) experiments continues at the Los Alamos Scientific Laboratory, the University of Virginia, and the University of British Columbia.

Theoretical Physics

Theoretical physics investigations of the interactions of pions and kaons with the nucleus were continued. During the quarter, papers based on the following studies were submitted for publication: (1) An investigation of the scattering of pions from ^{12}C and ^{16}O was carried out, using a somewhat novel form of the off-shell π -nucleon scattering amplitude. (2) A study was made using the optical model of the energy dependence of the total cross section and of the total elastic cross sections for π -nucleus scattering. The study is relevant to recent CERN data on C and O, and to a proposed LAMPF experiment; specifically, it shows that calculations of the famous shift of the Δ resonance in nuclei depend strongly on the assumed off-shell pion-nucleon scattering amplitude. (3) Calculations were completed showing the K-mesic-atom energy level shifts and widths imply a complex nuclear potential with a real part which is attractive, not repulsive, as had been previously predicted in the literature. (4) A study of perturbation theory for optical potentials was completed.

Practical Applications of LAMPF

Biomedical Program

This work is sponsored by the AEC's Division of Biology and Medicine.

Biomedical pion channel design has continued this quarter, following the general philosophy outlined in the last quarterly report. No difficulties have been encountered, and engineering design of most long-lead-time components is under way. Studies have been made of optimum target choice for the biomedical beam line, with a carbon target looking best at this time. Extensive shielding studies have been completed and the requirements transmitted to the Engineering Group. The biomedical channel control system design is progressing, with many of the peripheral devices for the computer now on order. Work on assembly of the control console will start next quarter. Collaboration with the University of New Mexico Medical School is continuing, with two joint projects under way at present.

Radioisotope Production

Another series of experiments were performed at SREL during February. The purpose is to eliminate discrepancies in data which have come from several sources. A survey of the potential radioisotope market is being undertaken in collaboration with BNL and the AEC.

LAMPF Users Group

The Executive Committee held its first meeting of 1972 during the San Francisco APS meetings. In addition to filling the six two-year terms on the TAP, the Committee appointed ten advisors to TAP for 1972. The dates for the Sixth LAMPF Users Meeting are November 13-14, 1972. Also accepted at this meeting were the drafts of the proposed Articles of Incorporation and By-Laws for the LAMPF Users Group, Inc.

At the Spring TAP Meeting (March 20-21, 1972) the TAP heard reports on the FY-73 budget and the status of the accelerator and facilities. The TAP then concentrated on the LAMPF Equipment and Electronics Pool (LEEP). A report on separated isotope targets was accepted by the TAP as a policy recommendation to LAMPF.

Following the Spring TAP Meeting, the Executive Committee met. It was voted to conduct a housing survey, the results of which will be distributed to LASL and local realtors. Also, consideration was given to the formation of a new working group on radiation damage. The appointed Nominating Committee will select a slate of officers for the next general election.

The EPICS Working Group and two subcommittees of the Biomedical Applications Working Group (Physical and Biological Dosimetry and Isotopes and Diagnostics Applications) held meetings during this reporting period. The Biomedical Applications Working Group formed a new subcommittee, Tumor Localization and Simulation.

The Liaison Office mailed to the membership the Proceedings of the Fifth LAMPF Users Meeting and the latest Newsletter. The proposed Articles of Incorporation and By-Laws are being prepared for mailing to the membership for approval. The LAMPF Users Group now totals 797 members.

Two more proposals for research at LAMPF were received since the last quarterly report.

Publications

J. H. Koch, M. M. Sternheim and J. F. Walker, "Complex Eigenvalues of a Coupled-Channels Model," Phys. Rev. C 5, 381 (1972).

H. C. Bryant, P. A. Lovoi, and G. G. Ohlsen, "Production of Pulsed Particle Beams by Photodetachment of Negative Hydrogen Ions," Phys. Rev. Lett. 27, 1628 (1971).

R. A. Jameson and R. S. Mills, "Two Dimensional Search and Interpolation on a Distorted Rectangular Grid. Program SI-PH1-G2D," Los Alamos Scientific Laboratory report LA-4891-MS (February 1972).

L. Rosen, M. E. Schillaci, B. J. Dropesky, and H. A. O'Brien, Jr., "Use of LAMPF for Isotope Production," briefing to the AEC Division of Isotopes Development, December 15, 1970. Los Alamos Scientific Laboratory report LA-4587-MS (February 1972).

L. R. Biswell and R. E. Rajala, "A Microprogrammed Branch Driver for a PDP-11 Computer," Los Alamos Scientific Laboratory report LA-4916-MS (April 1972). (Also to be published in Proc. of 1972 DECUS Spring Symp., Maynard, Mass., May 26, 1972, and submitted March 1972 to CAMAC Bull.)

J. H. Koch and M. M. Sternheim, "The K^- -Nucleus Interaction and Its Interpretation," Phys. Rev. Lett. 28, 1061 (April 17, 1972).

Papers Prepared for Publication; Papers Submitted at Conferences

R. R. Silbar and M. M. Sternheim, "Model Dependence of Pion-Nucleus Total Cross Sections," Los Alamos Scientific Laboratory informal report LA-DC-72-393 (April 1972). (Also submitted to Phys. Rev. C, March 1972.)

J. H. Koch and M. M. Sternheim, "Models for π^{+16}_0 Scattering at 270 MeV," Los Alamos Scientific Laboratory informal report LA-DC-72-423 (April 1972). (Also to be submitted to Phys. Rev. C, Comments and Addenda, April 1972.)

M. M. Sternheim, "Test of Quantum Electrodynamics," to be published in Am. J. Phys. (September 1972).

M. M. Sternheim and J. F. Walker, "Non-Hermitian Hamiltonian, Decaying States, and Perturbation Theory," to be published in Phys. Rev. C (July 1972).

D. E. Nagle, J. W. Doane, R. Madey, and A. Saupe, "Effects of the Passage of Ionizing Particles through a Liquid Crystal," to be published in Molecular Crystals and Liquid Crystals, Proc. 4th Intern. Liquid Crystal Conf., Kent, Ohio, August 21-25, 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 Nuclear Science Symp., December 6-8, 1972. To be published in the Proceedings.

M. M. Sternheim and J. F. Walker, "Optical Models, Decaying States, and Perturbation Theory," submitted to Phys. Rev. C, March 1972.

E. A. Knapp, "Practical Applications at LAMPF," invited paper to be given at Albuquerque Meetings of the Amer. Phys. Soc. on June 5-7, 1972.

M. S. Livingston, "High Intensity Meson Facilities," to appear in Nuclear Spectroscopy, II, J. Cerny, Ed. Chap. I.C.2.

E. A. Knapp, "Accelerators in Research," invited paper to be given at June Meeting of the Amer. Nuc. Soc. to be held in Las Vegas, Nev.

D. R. F. Cochran, P. N. Dean, P. A. M. Gram, E. A. Knapp, E. R. Martin, D. E. Nagle, R. B. Perkins, W. J. Shlaer, H. A. Thiessen and E. D. Theriot, "Production of Charged Pions by 730-MeV Protons from Hydrogen and Selected Nuclei," submitted to Phys. Rev. February 1972.

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

D. E. Nagle, "Medium Energy Physics with the 800-MeV Proton Linac," to appear in the 1973 McGraw-Hill Yearbook of Science and Technology.

M. Klein and H. A. Thiessen, "Program MOTER: A Powerful Tool for Optimization of Magnetic Optical Designs Based on Ray-Tracing," to be presented at IV Intern. Magnet Conf. to be held at BNL, September 19-22, 1972.

N. Tanaka, M. Thomason, J. Spencer, and H. A. Thiessen, "Experience with Prototype Bending Magnet for High Resolution Applications," *ibid*.

H. A. Thiessen and M. Thomason, "Design of EPICS: A High Resolution Pion Beam and Spectrometer System for LAMPF," *ibid*.

R. L. Hutson, H. A. Thiessen and M. J. Jakobson, "A Method of Reducing Chromatic Aberrations and Application to the Design of a Biomedical Pion Beam for LAMPF," *ibid*.

L. Rosen, "Possible Use of Negative Pions and Negative Muons in Therapeutic and Diagnostic Medicine," invited paper presented at Annual Congress of The British Institute of Radiology, London, England, April 20-21, 1972. (Abstracts will be incorporated in the institute's report of meetings.)

L. Rosen, "Nuclear Science and its Future," invited talk presented at a Symposium on Nuclear Science sponsored by the Amer. Phys. Soc. Div. of Nucl. Phys. Washington, D. C., April 28-29, 1972.

W. V. Hassenzahl, "An Algorithm for Eliminating the Duodecapole Component in Quadrupole Magnets," and "A Computer Controlled Magnet Measuring Facility," two papers submitted for the 4th Intern. Conf. on Magnet Technology, BNL.

A. Harvey, "Radiation-Hardened Magnets Using Mineral-Insulated Conductors," *ibid*.

J. R. Parker, J. H. Richardson and J. D. Easley, "A New Beam Spill Control System for LAMPF," talk to be given at meeting of 6th Intern. Cyclotron Conf., TRIUMF, Canada July 18-21, 1972. (To be published in proceedings.)

L. E. Agnew, "A Preview of the Los Alamos Meson Physics Facility," talk presented at the Colloquium at the University of Wyoming, Laramie, Wyoming, February 29, 1972.

H. A. Thiessen, "EPICS: A High Resolution Pion Nucleus Scattering Facility for LAMPF," talk presented at the Colloquium at Carnegie-Mellon University, Pittsburgh, Pennsylvania, April 21, 1972.

W. V. Hassenzahl, E. P. Elkins, and J. K. Novak, "A Computer Controlled Magnet Measuring Facility," to be presented at IVth Intern. Conf. on Magnet Technology, BNL, September 19-22, 1972.

H. F. Vogel and Richard Christian, "3D Magnetic Field Computations and Comparison with Measurement," *ibid.*

H. F. Vogel and R. J. Lari, "Computation of Magnetic End Fields, and Comparison with Measurement," *ibid.*

H. F. Vogel and John Colonias, "Use of Large Computer Programs in Time-Sharing and Interacting Mode," *ibid.*

R. L. Hutson, H. A. Thiessen, and M. Jakobson, "A Method of Reducing Chromatic Aberrations and Application to the Design of a Biomedical Pion Beam for LAMPF," *ibid.*

N. Tanaka, W. Dunwoody, J. Spencer, and M. Thomason, "Magnetic Measurements on the LASL Prototype Magnet," *ibid.*

II. ENGINEERING SUPPORT

LAMPF Accelerator Structures

201-MHz System

Some 500 h of high-voltage operation time were logged on each of the 201-MHz rf amplifiers. A 14-in.-diam Rexolite rf window was installed in Tank 2 and operated satisfactorily for ~ 600 h at duty factors up to 8.4%. Results of this exercise indicate that the Rexolite window may be a satisfactory substitute for either the ceramic disc or ceramic dome. A Li-coated ceramic dome was installed in Tank 3 and operated for 48 h without incident. This investigation is continuing to determine the effectiveness of the lithium-based coating in extending dome life. New drive loops for Tanks 2, 3, and 4 are in the brazing process, and matching ceramic discs are being fabricated by an outside firm.

New interface amplifiers, identical to those used in the 805-MHz system except for the operational mode, were installed in all 201-MHz modules. This modification will improve reliability and enhance interchangeability.

Two modifications were made in the module 2, 3, and 4 hard-tube modulators: The transformers were oil filled in lieu of epoxy encapsulation and the bias-switching diodes were replaced with diodes of a larger type. These changes have allowed satisfactory operation of the modulators.

The high-voltage power-supply transformer for module 4 failed due to severe arcing between laminations. Subsequent examination revealed loose laminations which had been assembled by riveting. It is believed that repeated thermal cycling caused stretching of an improperly seated rivet. This unit has been returned to the supplier for repair.

For the past year, considerable trouble has been encountered in the development of the 4664 amplifier tube for module 1 application. It has been very difficult to operate this tube in a stable mode at high power. This instability is apparently caused by an internal plate circuit resonance of 1029 MHz which is very near the fifth harmonic of the 201.25-MHz amplifier. The tube supplier agrees with this diagnosis and is attempting to find a means of salvaging this tube for LAMPF service.

A spare set of high-power tubes (7835, 4616, 4CW100,000 and 4CW250,000) were ordered and some have been received.

Transition Region (201 and 805)

All Transition Region quadrupole magnet power supplies are installed and have been tested in service. A power supply of the type used to power the 201-MHz drift-tube quadrupole magnets was modified for use with BM05 (the bending magnet which deflects the beam to the north port dump) and a B vs I curve was determined. This bending magnet provides a field of 10 kG at 579.2 A.

The Transition Region magnets were successfully powered to their design fields to direct the 100-MeV beam to the north port dump. However, foreign particles in the cooling system caused partial plugging of water passages and subsequent overheating of coils. The system was shut down, backflushed, and strainers were installed prior to placing the system back in service.

The diode stack in the bucket rotator rf system failed shortly after turn on. This stack of diodes has since been replaced and the system is functioning satisfactorily with the water load.

805-MHz System

Three major milestones were reached during this reporting period: H₂ furnace brazing of 805-MHz structures, installation of the side-coupled structures, and installation of 805-MHz amplifiers were all completed ahead of schedule.

More than 2,000 H₂ furnace heats were run during the past 2-1/2 years. The furnace equipment held up remarkably well during this period with little downtime and is still in excellent condition. At the present time, five heats per week are being run in support of other fabrication activities.

Figures 1 and 2 show the final tank section of module 48 being installed and aligned. This installation activity was started in March 1970.

All of the 805-MHz rf amplifier modules have been installed and operated for at least 250 h. Thirty-nine of these klystrons are Varian and five were made by Litton.

Vacuum manifold welding is complete through module 44 and beam-line hardware has been installed

Fig. 1. Installation of Last 805-MHz Tank Section (Module 48)

Fig. 2. Aligning Last 805-MHz Tank Section

through module 37. The preinstallation testing of the 104-beam-line quadrupole doublet magnets is complete and 94 have been installed and aligned (through module 42). The last of the 70 linear actuators have been assembled, leak tested, and checked for proper

function. The last 75 beam boxes were received and leak tested, and they are ready for installation.

Cooling of the 805-MHz quadrupole doublet magnets has proven to be marginal. Several of these magnets have attained sufficient temperatures to cause trip-out of the high-temperature interlocks. These magnets are presently cooled by the closed-loop module cooling water system. A modification to install a small water pump in series with the existing cooling systems and the quad doublets is in progress. This change will more than double the available cooling water pressure head for the magnets.

Rework of the transformer-rectifiers of all 805-MHz units was required to correct a manufacturing defect in the mounting of transient voltage suppressors. These suppressors were remachined, and new oil was added to those units which had arced severely.

Acceptance testing of both Litton and Varian klystrons has continued. Twenty-five klystrons have been ordered from Litton Industries; six of the ten that were conditionally accepted at their facility have passed acceptance tests. The major problem with the Litton klystrons, as reported previously, is the tendency to multipactor. To date, the 1.25-MW klystrons have been operated for more than 120,000 filament hours and 91,000 plate hours with four failures. The LPT-44 switching tubes have accumulated 101,000 filament hours of operation with eight failures.

Considerable effort was expended in the development of techniques to be used in the rebuilding activities of 805-MHz klystrons. Numerous welding tests were performed to determine the required allowance for weld shrinkage when assembling tube components. The bake-out oven was debugged and is working satisfactorily. The first attempt to rebuild a klystron was very successful. This rebuilt tube has been tested to full power at 6% duty factor and the power-transfer curves indicate that this tube is as good as when new. The tube is being subjected to the acceptance tests that all new tubes must pass. The successful attainment of full power from this rebuilt tube is significant in that it demonstrates the capability of in-house rebuilding of large klystrons.

The basic-frequency and phase-reference system has been in operation at full power for several

months except for scheduled shutdown. Phase and amplitude control of both 805-MHz and 201-MHz amplifier chains is now in operation to insure phase coherence between these two frequencies and to maintain the driveline phase stability equal to that of the master oscillator. The rf source room phase and amplitude control systems are completely installed and computer control of the system has been checked out.

The ΔT experiments require an extremely high degree of phase stability from the amplifiers associated with this system. Quality commercial amplifiers used with the phase shifters were found to be unsatisfactory. A Nuistor amplifier was developed for this application which is phase stable to less than a degree for a period of several hours.

Experimental Area

All switchyard magnet supports have been installed and aligned for Lines A and X beam channels as shown in Figs. 3 and 4. Supports for the twister magnet along with the 1° and 4° bending magnets for Lines B and C are on hand. The design and drafting of Line B quadrupole doublet magnet supports were completed when it was decided that a simpler, less expensive design would suffice. This support was redesigned and is being procured. The design and drafting of supports for Line B "C" magnets and bending magnets 04 and 05 are nearing completion.

The entire Low Energy Pion Channel (LEP) line will be supported on three separate structures.

Fig. 4. Switchyard Magnet Supports

A request for quotation has been sent out for two of these structures and design drawings for the third are nearing completion. An order has been placed for two LEP doublet assembly alignment mounts for the 8- and 11-in. quadrupole magnets (QM01 and QM02).

Considerable effort was expended on establishing the exact beam-line locations for the switchyard and Lines A, B, and C. A set of permanent and removable monuments was installed to facilitate this alignment task while the 800-MeV temporary beam stops are in place. Some problems with floor shifts and building settling have been encountered, which may necessitate a final survey after all major construction is finished.

A complete 10 x 15 ft optical-tooling dock has been set up in a portable 20 x 26 ft metal building in Area A. This facility is necessary to perform the setting of alignment fixtures and tooling balls on the Experimental Area magnets. It will also be used for mechanical inspection of any large assemblies too heavy for a surface plate.

The collimating stand in the Metrology Laboratory is operational and has been used to good advantage. It is essential that frequent routine checks and adjustments of the optical tooling and other alignment gear be performed.

Area A demineralized water fill and supplementary make-up system was designed, procured, and is ready for installation. All switchyard magnet cooling manifolds are on hand and ready for installation as soon as the magnets are set. Lines B and C

Fig. 3. Switchyard Magnet Supports and Alignment Monument

cooling water system design is nearing completion. A flow bench is being assembled for calibration of water-flow switches using master meters covering the range 0.33 gpm to 52 gpm and will be accurate to $\pm 1\%$.

Procurement of vacuum systems for all lines in the Experimental Area is under way. Manifolds, bellows assemblies, and beam-line supports are being fabricated for Lines A and X in preparation for 800-MeV tests. Specifications for both the LEP and HRS roughing systems have been written and quotation requests have been sent to several suppliers. Calculations to determine the high-vacuum requirements for the HRS were completed, specifications for three large ion pumps capable of pumping He were written and requests for quotation were sent to several potential suppliers. The design of a 2-in., high-speed valve for use in the Experimental Area is complete and final drafting is under way. Valves similar to this will be used to throttle the Line X ion pumps to provide the required pressure for proper beam-profile monitoring. Instrumentation for testing thermal switches of all secondary beam line magnets was fabricated and testing is under way. Magnet data and drawings are presently being accumulated in preparation for the establishment of a central filing system.

Power supplies for the switchyard quadrupole magnets have been received, tested, and installed in the switchyard building. Power supplies for the switchyard bending magnets were received but were found to be unacceptable. Modifications that are required for specification conformance are being worked out. Most of the 56 brute-type magnet power supplies have been received, with completion of the order expected within a month.

Construction of the SCR magnet power supply current regulator is under way. The nine regulators required for 800 MeV are expected to be complete by mid-May.

Engineering design was performed on all variations of the Biomedical beam line as parameters are being firmed and final configuration fixed. An order has been placed for all mineral-insulated conductor required for the magnets. Final engineering design and drafting of the magnets are in process.

The question has been raised as to how the magnetic flux would follow the ripple current of a magnet with mineral-insulated conductor.

Some measurements were made on a 11QN22M/9-type magnet operated at $\sim 10\%$ design field level (80 A) with the power supply voltage modulated to 10%. A 10-turn pick-up coil with approximately the area of one of the poles, to insure flux linkage of adjacent poles, was placed in the air gap. As the frequency of the modulated voltage was increased from 0.05 Hz to 180 Hz, the flux ripple was attenuated at 1/583, or -27.7 dB (as shown in Fig. 5), while the modulated current through the magnet decreased by only 1/2.9, or -4.6 dB, as shown in Fig. 6. Above 180 Hz, the ripple flux attenuation rate appeared to increase with increasing frequency as did the modulated current rate of attenuation. The ripple flux vs ripple voltage was about the same as that of a magnet wound with conventional conductor. However, the impedance presented to a power supply by a mineral-insulated-wound magnet will follow a changing function depending on the frequency of the ripple current.

The possibility of modulating the beam of the Biomedical line to change the beam focus point prompted a measurement of the response time of a mineral-insulated magnet to step- or ramp-current function. Using the same setup and measuring technique described above, it was observed that this magnet has a time constant of ~ 0.4 sec.

Fig. 5. Ripple flux over ripple voltage vs frequency.

Fig. 6. Impedance vs Frequency

III. ACCELERATOR SYSTEMS DEVELOPMENT

805-MHz Accelerator System Installation

Status

A great deal of equipment was installed and commissioned during this quarter. Areas of work completed include:

1. Structure brazing completed: 2-11-72
2. All tanks ready for installation: 3-3-72
3. All tanks installed on rails: 3-9-72
4. Major tank plumbing completed: 3-24-72
5. Drive-line installation complete: 4-4-72
6. Klystrons in place in all modules: 4-6-72
7. Accelerator structure tuning completed: 4-27-72

High-power testing of accelerator structures, magnet installation and alignment, vacuum work, calibrations, control system checkout, and other installation work are proceeding ahead of schedule. It is now planned to have the accelerator ready to begin 800-MeV beam tests by June 5, 1972. Two weeks have been scheduled in May for final buttonup and dry runs.

805-MHz Accelerator Structure Tuning

Structure tuning has proceeded on or ahead of schedule in spite of a minor change required for the bridge couplers for six modules. By the end of the reporting period, main- and coupling-cell tuning and final beadpull measurements of field flatness were complete for modules 34-48, the remainder of the 805-MHz linac. In addition, modules 13-17 have been retuned in order to reduce the maximum peak-to-peak deviation of individual cell peak fields. The tank-to-tank field averages in modules 13-48 are within 1%, the rms field scatter within 4%, and the maximum field scatter within 12%.

Of those modules which exclusively used the nose-stretching and "dinging" tools (modules 27-28), only two developed excessive field tilts (greater than 11% on modules 32 and 43) which had to be removed by developing a tuning strategy involving the septum bending tool. These tilts were attributed not to the tools or methods used, but to a dimensional tolerance buildup which added up to a consistent tilt rather than the random tilts normally seen in individual tank sections.

Evolution of the nose-stretching tools resulted from several failures in which bearings broke and were lost (subsequently found) inside the module, finally producing a reliable tool involving a hardened cutter wheel followed by a hardened and ridged follower wheel to flatten the burr, and then a tracking ball bearing. This bearing had to be a relatively expensive miniature precision ball bearing, better constructed and stronger than those which had broken. The "dinging" tool remained a cold chisel and the technique of using it involved a hard blow to drive the copper inward. Light taps or repeated blows only hardened the copper and made the job of raising frequency more difficult. Dinging was accompanied by detuning the coupling cells, which then had to be retuned. The third tool, the septum bender, remained unchanged except for turning down and hardening of the shafts. Ultimately, three complete sets of these tuning tools were made available. A fourth tool, for shaving the nose of the drift tubes to raise frequency, was never needed.

A persistent problem in bridge-coupler tuning occurred when the tank end cells beneath the bridge coupler differed in field intensity by several percent. This would require excessive rotation of the tuning post to equalize the tank field averages which in turn required rephasing of the bridge coupler, additional rotation, rephasing, etc. Between each step a beadpull had to be made. These modules, of which No. 17 was the worst case, were finally solved by this time-consuming iterative process. Additional study of end cell effects might result in improved tuning procedures.

The bridge-coupler phasing for module 44 was found to be highly sensitive to post penetration and the adjacent coupling cells required an anomalous gap. Investigation showed that these difficulties were caused by a TE_{113} resonance that was close to the desired module $\pi/2$ mode in frequency. The TE_{113} mode was oriented with the principal electric field vertical, an orientation for which the existing five horizontal posts had little effect. The unwanted mode was suppressed by shifting it away with the addition of two vertical fixed-length, 1-in.-diam, water-cooled copper posts. These most highly developed bridge couplers are extremely complicated electromagnetic cavities, with six mode-squeezing posts, two frequency tuning posts, the main center

coupling post, two dummy posts, the iris, and two coupling slots. Nonetheless, their use in modules 44-48 resulted in easy and well-controlled tuning and elimination of the anomalous coupling cell gap problem. This fix was also used on module 15 where the problem had appeared earlier. The bridge coupler lengths between modules 15 and 44 were such that this TE_{113} mode was not a problem, although some bridge coupler field distortion is also present in modules 16 and 17. Such distortion requires care in the method used to determine the stopband of the structure.

The stopband of the low-beta modules (5-14) appears to have changed in negative direction according to recent measurements. This is probably due to a permanent set in the sensitive coupling cells after a long time under vacuum. The change in stopband has been as high as ~ 60 kHz negative resulting in some cases in a negative stopband. The VSWR has also been affected in some of these modules with the VSWR moving toward unity and in one case even becoming under-coupled. A beadpull was made on module 12 to see if the main cell field distribution had changed. Small changes ($< 1\%$) in individual cells and some shift ($\sim 1\%$) in the tank field averages were found.

A retrofit operation was completed involving additional E-probes on the downstream ends of the bridge couplers on modules 15-17 and 38-48. This retrofit can continue on the rest of the machine when desired. It does not require retuning or re-measuring the module. Another important retrofit which is contemplated is an additional H-probe near the downstream end cell under the bridge coupler. This probe would allow the total phase shift between tanks in a module to be measured accurately; the additional E-probe allows the same to be done across the bridge coupler itself, thereby allowing all components of the total phase shift to be measured when necessary. However, the extra H-probe is a major retrofit which requires drilling into a main cell and should only be done when and if the phasing of a module becomes so doubtful as to require that this measurement be made. The object of this H-probe is to allow the phase measurement to be made without removing the focusing magnet.

The coupled-resonator model for a linac module was used to calculate the effect of having a

difference in $\pi/2$ -mode frequencies of the two tanks of a two-tank module. The study showed that the principal effect was the introduction of a small phase error. For example, if the two tanks differ in frequency by 20 kHz, with a stopband of -50 kHz for the module, individual cell fields may differ in phase by as much as 1.7° .

Stopband checks and final documentation of the tuning procedures and results are now under way.

Transition Region

Magnets, beam pipe and associated equipment were installed in the Transition Region to accommodate the 45° deflected, 100-MeV beam into the area designated as Northport. Preliminary work with this system has seen 88% of the beam transmitted through the 4 bends and 6 quadrupoles on the line.

The hardware and software required to obtain momentum data from the dispersion of the beam resulting from the 45° bend is completed. Preliminary spectra have been taken, but more running is needed before they can be properly interpreted.

Accelerator Systems Performance and Development

RF Field Control

Experience with the installed 805-MHz fast-phase control systems revealed two minor problems. First, a rearrangement of parts on the production fast phase shifters had resulted in an inadvertent reduction in the modulation bandwidth. A simple reconnection and retuning eliminated this problem. Second, a glitch in closed loop performance sometimes appeared at the bias level where transistor load-switching occurred in the driver circuit. A solution has been designed and will be incorporated after initial 800-MeV beam tests are complete. Trombones were procured to allow easier centering of the phase loops.

Design changes to eliminate integrated circuit failures and a speed reduction circuit were incorporated into the 201-MHz Phase Subsystem stepping motor drivers.

Calibration and checkout procedures for the rf channels to the central control system were written. Work on standardizing calibration procedures for the entire facility was initiated. A computer program was written allowing an operator to interact with

the CCR from the module location when performing calibrations. This concept should also be of great use in future development of the control system. Design was started on procedures for dynamic sweep testing of a complete rf module for maintenance purposes.

Development of the feedforward system continued. Remaining problems include difficulty with ground loops when current transformer signals are shared and noise problems with current transformers having extremely low output.

A simple amplitude control loop was developed to keep the rf output from the 201.21-MHz interface amplifier constant to the totem-pole amplifier, which is quite sensitive to drive level. Some of the reasons for previous drive variations were also found and eliminated: 1) A vendor material substitution on the fast phase shifter was discovered which placed magnetic material near the circulator, distorting the magnetic field. Use of the correct material makes tuneup of the phase shifter for minimum insertion loss variation much easier. 2) Out-of-spec filament transformers on the interface amplifiers were inducing greatly accelerated aging and failures. These improvements make the 201.25-MHz system much more insensitive to parameter changes in the rf drive chain.

The master drive lines were placed under phase and amplitude control, with no problems except that some transients show up due to SCR firing circuits when the big transition region magnets are turned on. These transients are also present when the drive line is not under closed-loop control. Rephasing of the pulse train with respect to the 60-Hz line can solve the problem in this area, but may introduce problems in other parts of the system. Further tests are planned.

805-MHz Accelerator Module-to-Module Field Adjustment

The Δt procedure for adjusting the amplitude and phase of the rf was successfully demonstrated on modules 5, 6, and 7 during this quarter.

The procedure involves the measurement of two quantities, Δt_B and Δt_C , at the module being adjusted. When these quantities are measured as the rf phase is varied, a so-called "variable phase" curve is generated in the $(\Delta t_B, \Delta t_C)$ plane. Close to the design phase this curve is nearly a straight line,

and the slope is related in a known way to the amplitude of the accelerating rf field. Once the field amplitude has been determined, then the phase and energy displacements (from their design values) can be calculated from the Δt_B , Δt_C measurements.

Figure 7 shows two variable phase curves for module 5 taken on March 22, 1972. In the upper left is shown the amplitude set points (ASP), the phase set points (PSP), and the corresponding measured values of Δt_B and Δt_C (in nsec). The slope of the line when ASP = 1451 indicated that the amplitude was slightly too high, so ASP was lowered to 1425.

The data shown in Fig. 7 were not easily obtained. With the amplitude set at what was thought to be near design values, and with a phase that gave maximum beam loading, the variable phase curves that were generated gave confusing results. It was not until the power was raised by ~ 30% that the expected curves were obtained. The Δt measurement for modules 6 and 7 also indicated that correct fields were obtained when the power was increased ~ 30% over what cavity measurements and delivered power measurements indicated was proper. The reason for the discrepancy is unknown.

The Δt procedure is to be implemented in modules 5-12. After module 12, high-precision momentum measurements will be relied upon to do the fine adjustments. The initial coarse adjustments will depend on beam loading and perhaps less precise energy measurements.

Fig. 7. Variable phase curves for module 5.

A computer code, SIMALAC, which simulates the beam's longitudinal motion through the linac, has recently been adapted for use in the SEL 840-MP controls computer. SIMALAC allows one to introduce random phase and amplitude errors and to see their effects on quantities such as beam loading and beam energy. The advantage of having SIMALAC on the controls computer is that it then becomes an interactive system. One can display simulated measurements, such as beam loading, and then input phase and amplitude changes via a trackball or keyboard and immediately observe the effects. SIMALAC is now being used to refine the turn-on strategy for the initial achievement of the 800-MeV beam.

During the initial tests using the Δt hardware, several failures in the transistor rf signal amplifiers necessitated replacement. Nuistor amplifiers were developed and tested, showing excellent characteristics and long-term phase stability. The calibration circuit was modified to check all components in the system except the 10 x 3 matrix switch which has had one reed relay partial failure. The Δt bridges and power dividers were all retuned and diodes were matched for more exact measurements away from nulls. Spare modules for the Δt measurement and control hardware were constructed.

Developments in the Use of Central Computer Control (CCR)

As mentioned above, a program was developed for use in channel calibration which allows an operator at the equipment to interact with the computer. A Local-Computer switch is keyed to direct the computer through the program, and a TV monitor is used to view messages appearing on the alphanumeric scope at CCR. Provisions were incorporated to make this program resume operation at the same point after any interruption in computer service.

Two general programs were written to service the 805-MHz linac. One is a general display program allowing up to three separate graphs to be displayed on the storage scope, showing any desired data vs module number along the entire linac. Numerous easily selected options are available for data processing or display characteristics. The second program allows quick inspection of the status of controls and characteristics of control operation over the entire linac.

Development was initiated on procedures and programming to fit the rf system calibrations into the new standard calibration formats and to use the control system to make the calibrations.

Diagnostic Equipment Development

Prototypes were completed for the stepping motor diagnostic equipment.

The development of a method for switching the control capabilities of a single emittance control system to any one of six different emittance stations was initiated during this period. Local and computer control of the switching operation will be provided. This device will provide for more efficient operation of emittance tests. The design of this system is ~30% complete.

Transport Area Studies

Development of the high-intensity proton beam to the linac was continued with experiments, calculations, and installation of new transport line magnet elements and measurement gear combining to yield significant progress. 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:

Source IIIa/11/CT-2-1.6 was operated for over 2000 h during the past eight months without replacement of any of the parts. Cathode CT-2 severed on March 3, 1972 after 8-1/2 months of use in the H^+ injector. Cathode CT-3 was installed, requiring less than 2 h downtime and an arc was obtained almost immediately at a relatively low activation-heater current of 34 A. The cathode, CT-3, was available from the spare source which was under vacuum on the storage stand. The spare source had been run intermittently for short periods of time, both to insure that the cathode was in good shape (as well as the spare source as an assembly) and to carry out various tests such as experiments with the arc modulator.

There was very little erosion of the nickel gauze on cathode CT-2. The break occurred off-center at the end of the central S bend and appeared to be mechanical rather than the result of erosion or

notching. The coating was still intact over most of the cathode. The surprisingly long life of this source assembly may well be the result of the low duty factor used during the past eight months. Nevertheless, eight months of extensive use without replacement of the cathode, plasma aperture, or any other parts is gratifying even at the low duty factor. Moreover, the plasma aperture is still good after nine months of use, many arc downs, and accidental long pulses associated with faults in the arc modulator.

The arc-down problem associated with modulator faults has been corrected. A simple charging circuit has been installed in the arc modulator to keep sufficient voltage on the delay line to turn off the arc at the end of the beam gate pulse. There have been no failures to date with this circuit. If it continues to function satisfactorily, there will be no need for a comparator circuit.

Circuitry and procedures for simple, periodic testing of the modulator crowbar circuits by operations personnel will be performed first on the ion source test stand. In the interim, maintenance personnel are periodically checking the crowbar circuits on the accelerator.

The hydrogen ion pump, which operated for a year and a half, was returned to the equipment dome after cleaning and replacement of the pumping cells. There are now two hydrogen ion pumps in the dome, each capable of pumping hydrogen at 2400 liter/sec. One will be kept in reserve as planned.

Accelerating Column and Beam Transport

System Tests: Beam intensity profiles across the 750-kV H^+ beam at the exit of the accelerating column were obtained for four beams that were observed with pepper-pot emittance photographs taken last December. Average photographic density at the centers of the main dot sequence in the pepper-pot patterns are shown in Fig. 8 as a function of radius from the column axis. Each of the experimental points is the average for many dots, except near the center of the beam, and the probable errors for the densities shown are small, ± 0.05 . A relative intensity scale is shown on the right-hand side. The errors in the film density measurements imply that the ratios of the highest to the lowest intensities are uncertain by a factor of two. The photographic density measurements again show a relatively

uniform intensity for the center of the beam and a rapid drop-off beyond this. The shallow dip in the center which was seen on the TV intensity scans is now believed to be the result of a malfunction of the TV setup.

Fig. 8. Beam-intensity profiles for several beams studied during the accelerating column beam tests.

Fig. 9. Layout of the TA beam line showing the location of the two new quadrupole lens TAQLO1-Q0 and TAQLO1-Q5.

Using the properties of the beam entering the high-intensity proton beam line obtained last quarter, a new design for the initial portion of this beam line has been carried out with the goal of obtaining a small double waist at the prebuncher. This design employs two additional quadrupole lenses: one at the exit of the accelerating column to provide additional focusing closer to the column, and the other at the entrance of the first bending magnet to facilitate the desired tuning at the prebuncher. A layout showing the initial portion of this beam line as it is now being operated with these two additional lenses is presented in Fig. 9.

In order to incorporate the new lens at the exit of the accelerating column, the initial beam current transformer (TACM01) was removed. A support frame was built onto the front on the initial quadruplet, and the new lens was mounted on and aligned with this quadruplet prior to installation. The new lens, which also has steering coils, was then inserted into the reentrant can on the exit cone of the accelerating column, as shown in Fig. 10. Upon reassembly, the ion source and accelerating column were aligned since on initial installation the necessary alignment monuments were not available. The axis of the ion source and column are now perpendicular to, and in the same horizontal plane as the axis of the linac. As a result of this alignment, very little steering is now required in tuning this beam line.

Fig. 10. Mechanical assembly of the new quadrupole lens TAQLO1-Q0 to the initial quadruplet.

Fig. 11. Horizontal phase-space pattern for a 28-mA proton beam at EM3 for the new design conditions.

Fig. 12. Vertical phase-space pattern for a 28-mA proton beam at EM3 for the new design conditions.

Fig. 13. Calculated beam profiles and phase-space patterns expected at EM3 for the new design conditions.

After the beam line was operational, emittance measurements and viewing screen observations were taken on the new beam now being transported and the results confirmed the general features of the new design. The phase-space patterns observed at the final emittance measuring station (EM3) for a 28-mA proton beam are shown in Figs. 11 and 12, and the calculated beam profiles and expected phase-space patterns for this beam at EM3 are shown in Fig. 13. These observations confirmed that beams could now be transported with a double waist at the prebuncher. Under the normal mode of operation, beam currents up to 30 mA of protons were transported to the line. By programming the extractor-electrode voltage with beam-pulsar voltage and by varying the focusing conditions for the beam at the prebuncher, beam currents > 36 mA were transported to the linac. Thus, the additional flexibility in beam transport afforded by adding these two additional lenses has definitely improved the capability of the transport system in providing a higher current to the linac. Work is still in progress in optimizing transport conditions and in providing beam scrapers to eliminate halo in the beam.

Collector plates have been redesigned, fabricated (at Sandia Corp.), and installed at the EM1 and EM2 stations in an effort to obtain during a single measurement, the entire emittance at these stations.

The H⁻ Injector Program

Research Program

Duoplasmatron Ion Intensity Measurements:

Calorimetric measurements of extracted H⁺ beam from the H⁻ duoplasmatron were made using a flat 5-mil copper plate, 2-in. in diameter, as an extractor and beam stop. Beam heat was conducted away by a BeO insulator to a pair of thermistors used as a calorimeter. Measurements made at various extractor voltages (5-15 kV) and gaps were in agreement, thus all available plasma was presumably accelerated. The following source parameters were varied: 1) arc current, 0-30 mA; 2) anode aperture, 0.037 in. and 0.052 in.; 3) anode (plasma expansion cup); 4) arc magnet current, 0-4000-A turns; 5) gas flow and pressure, 1.4-5 atm cm³/min, 75-270 μ hydrogen pressure.

Fig. 14. Variation of beam current with arc current.

Fig. 15. Layout of an experimental multiaperture ion source.

As Fig. 14 shows, beam current is a linear function of arc current and depends weakly on arc magnet excitation and gas flow. Doubling the anode aperture area resulted in a 30% increase in beam current; eliminating the expansion cup led to a 57% increase. It is worth noting that $Q = 1 \text{ atm cm}^3/\text{min}$ can support only 140-mA current at 100% gas efficiency. Our best efficiency is about 25%, assuming that the same parameters would apply under dc operation as with a duty factor of a few percent. For a 200-mA proton beam (up to 4 mA H^+), a gas flow of 5-6 $\text{atm cm}^3/\text{min}$ and an arc current of 20-40 A is implied. These requirements can be met with the present designs.

Multiaperture Source: A multiaperture source has been built (Fig. 15), and aperture plates with one- and seven-hole patterns are ready for testing. This should deliver 17 mA/aperture at 15 kV, or 120 mA total. A 17-hole pattern can be accommodated as can variations in spacing. It is hoped that the large insulators between electrodes and the pumping bypass channels on the expansion cup will eliminate the problems experienced with an earlier version of this source.

Fig. 16. Layout of an experimental dual-extractor ion source.

Fig. 17. Calculated equipotentials and ion trajectories for an accel-decel system.

Accel-Decel System: In order to shape the plasma surface and achieve focusing, an electrode system with two extractors and a separated charge-exchange canal was built (Fig. 16) and tested using electrode shapes identical with those of the proton accelerating column. Trajectories and currents were calculated with CULHAM, an ion source optics program

which obtains a solution to Poisson's equation by iterations, and for electrode potentials of 15/45/15 kV a focused current of 29 mA is predicted (Fig. 17). A current of 25 mA was measured calorimetrically, a reasonable agreement typical of comparisons with other CULHAM calculations. However, the conversion to H^- ions was poor; 0.4% instead of the expected 2%. Subsequent visual observations of the beam (with a chamber pressure of $2\text{-}\mu$ hydrogen to provide a scintillating medium) showed that the beam blew up in the canal. It is not understood why the beam is not properly neutralized and focused in the canal region.

An accel-decel system using much closer spacing and gas flow from the source confined to the canal has been built, and, using CULHAM, it is predicted that 150 mA can be obtained with 15/60/15 kV on the electrodes. This system differs from our standard H^- system mainly in having larger insulators to withstand the higher voltages.

Tapered Expansion Cup: A tapered expansion cup was used with the standard 60° electrode and resulted in the best H^- current to date, 1.5 mA at 30-kV accelerating potential. An interesting effect was observed during this experiment. Normally, the hydrogen flow through the source and canal gives an expansion cup pressure of $\sim 5\text{-}\mu$ and a canal gas thickness of $50\text{-}\mu\text{-cm}$. If this pressure is increased by adding hydrogen gas at the extractor region, an increase in the amount of H^- produced from H_2^+ ions is observed. Apparently, the reactions $p + H_2 \rightarrow H^+ + H_2^+$ and $e + H_2 \rightarrow 2e + H_2^+$ occur to a large extent in the expansion cup plasma at $5\text{-}\mu$ pressure. When deuterium gas is added, D^- ions from D_2^+ are observed (but little D^- from D^+), lending strong support to the hypothesis. A cross section on the order of 10^{-15} cm^2 is indicated by the results. It seems likely that gas outflow from the source is largely H^+ since the H_2^+ effect is much weaker with source gas flow alone. Of the 1.5-mA H^- beam, over half is expected to come from conversion of H_2^+ to H^- . This process unfortunately leads to a beam with higher emittance than a proton-converted beam. Nevertheless, this is a step upward in H^- current, and further exploration of this geometry is planned.

H^- Injector Construction: Tests have been conducted on the H^- source system that will initially be installed at LAMPF. The H^- beam from this source must be focused to a 2-mm-diameter spot at the column entrance in order to match the column acceptance. The beam will be injected directly into the column without a momentum analyzer except for a weak field electron filter, hence some H^0 beam will enter the column in addition to H^- ions from H^+ and H_2^+ . A small Faraday cup with a 2-mm aperture was built to slide in a tube along the beam axis to locate the focus. A beam current of $470\text{-}\mu\text{A}$ was measured, of which about half is expected to be H^- from the proton beam and half from the H_2^+ beam. With the Faraday cup at a 30° magnetic bend, $280\text{-}\mu\text{A}$ of good H^- beam was measured. It would appear that an initial beam of $200\text{-}\mu\text{A}$ can be satisfactorily delivered to the column, particularly in view of source improvements since this series of measurements.

Fabrication of all of the parts for the Mark III duoplasmatron has been completed except for some required touch-up work. Leaks became evident in both the outer main-body Ferrovac-E iron shell and the inner copper shell after the latter was brazed to the inside of the iron to form the water-cooling jacket. These leaks, two in porous sections of the iron and two in the OFHC copper, have been closed with copper-silver braze material, Cusil, using hydrogen-firing. Some remachining, required after the hydrogen-firing, is under way. The iron will be nickel plated to prevent rusting.

Problems developed in the polycarbonate bonding of the H^- accelerating tube which did not occur on the H^+ accelerating tube presently in use. Leaks occurred at every joint and the bond strength was so low that it would not have supported its own weight on cantilever mounting during assembly. The main cause of failure has been attributed to overheating the polycarbonate during bonding as indicated by the darkened color of the normally crystal-clear polycarbonate. To reduce air bubbles in the bond, a different solvent base, tetrachlorethane, was used this time and may have contributed to the problem by leaving too thin a coating of polycarbonate to insure good bonding.

Tests have been conducted with ceramic dog bone samples to determine the lowest bonding temperature which gives adequate strength. Thermocouples were

attached directly to the ceramic parts for accurate temperature measurement. Also, polycarbonate was dissolved in methylene chloride to duplicate the bonding agent used on the H^+ accelerating tube. Results on a limited number of tests so far look very encouraging with strong bonds and no evident of degradation. Simultaneously, the accelerating tube was disassembled by soaking in trichlorethylene. The ceramics were cleaned by air-firing at $900^\circ C$ for one hour, and can now be reused along with the cleaned-up stress relief flanges. The titanium washers could not be cleaned, so new washers, just received, will be used on the rebond planned for early May.

The double-cone assembly which supports the accelerating tube is nearly completed, and work should start soon on the exit cone assembly. The hydrogen ion pumps are on order and other long-lead items such as the outer corona rings are being fabricated.

The installation of the parallel section of the H^- beam transport line and the permanent roughing system have been postponed until June because of interference with existing beam diagnostic equipment now in use on the H^+ beam line which will not be changed until after the 800-MeV beam tests. The remainder of this H^- beam line will be built after the H^- ion source and accelerating column have been installed.

A prototype viewing screen assembly has been built and tested for the H^- beam line. This design permits operation of the viewing screen on the H^- beam line without interference to other diagnostic systems on the H^+ beam line.

IV. ELECTRONIC INSTRUMENTATION AND COMPUTER SYSTEMS

Injector Control Systems

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

The program of improvements and maintenance on these systems continued this quarter. The arc pulser was modified to produce a full intensity pulse on the first pulse. This was accomplished by using a voltage quadrupler to maintain a charge on the turn-off pulse delay line. The net result was less time lost from operations. An automatic 10-sec delay timer which turns on power to the dome rack after the generator reaches full power was installed to eliminate eight minutes from the turn-on time. Two new quad magnets and a steering magnet were installed at the exit of the high-voltage column. Power supplies, wiring, and a control panel for the magnets were added in the transport area A racks. A flood-control chassis was installed and wired into the control system. The wires to the fire detectors were replaced with shielded wires to prevent false triggering of the detectors on arcdowns. New wiring was also installed for the electron trap. A number of hardware channel assignments and associated wiring were changed to make the data collection process more efficient.

A new beam-current monitor system was tested. This system was designed with a wider bandwidth and better calibration characteristics. Unfortunately, the 20- μ sec step width chosen for the staircase waveform could not be resolved because of the 75- μ sec setting time in the analog data system. A wider step will have to be used. The power supply for the monitor system was repackaged in a narrower NIM bin to conserve space. Work on this project will continue after the 800-MeV beam test.

The programs for running emittance diagnostics in the low-energy transport system were transferred from a dedicated NOVA computer to the ICR NOVA where they ran successfully. A new rack of control equipment for the emittance gear was installed to replace older equipment. The changeover went smoothly.

Work on the H^- injector suffered from a lack of manpower, but significant progress was made

nonetheless. The wiring and equipment installation in the dome is now 80% complete. The balance is dependent on the delivery of equipment from several companies. A new filament power supply was designed. It operates more smoothly, incorporates interlocks, and runs down automatically when the ion source is turned off.

Holes were drilled through the concrete wall and the dome for the installation of the light links. Mounting brackets were designed. Work on a fotofet receiver was given up in favor of the present diode detector receiver. Some parts of this receiver were redesigned and laid out on a new printed circuit card which includes the line driver.

Several power supplies for the H^- injector were tested and found to be unacceptable. They were returned to the manufacturer for modifications. Fire alarms were installed in the C-W power supply room and were checked electrically. All quad magnet power supplies were installed in the Transport Area B (TB) racks. The computer interface units for the Injector B and TB equipment were installed and wired to the junction box. The trunk line wiring from Injector B to ICR was finished. The wire scheduling for TB is 80% complete. The personnel safety chassis was installed along with a key release panel and a status panel. The related drawings were updated.

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 major activity in this area was centered in TR and DA. Wire schedules were completed and the wire was installed. Assistance was given with equipment installation. Devices were connected as they became available. The initial systems checkout of the controls was completed. Drawings and wire records were brought up to date.

The control system was used successfully toward the end of the quarter to guide a 100-MeV beam into the DA. Undoubtedly, the equipment in this area will evolve during the coming months and the controls will have to be modified to support those changes.

805-MHz Control System

The 805-MHz control system extends from modules

5-48 and includes instrumentation for Sectors B-H. The work this quarter was concentrated on device installation and hookup. The following systems were completed through module 48, the last module in the accelerator: beam-position monitors, beam-current monitors, vacuum, water, wire scanners and sector controls. The steering and quadrupole magnets up through module 35 were made operational. All of the analog data systems were calibrated. The ion pump power supplies were modified to correct a fault in the overcurrent trip-out relay. In order to maintain each of these systems in a high state of readiness, an automated checkout test is made periodically using the control computer. If the performance of any system is substandard, an error message defining the problem appears on the printout.

The quadrupole magnets exhibited a high frequency of over-temperature trips during recent tests. There appears to be an insufficient pressure drop in the cooling water system. Pumps are being added to increase the water flow rate. This has required additional controls.

The installation and checkout of temperature controllers was completed. This was followed by the high-power calibration and dynamic testing of each system. The high-power testing will continue in preparation for the 800-MeV beam test.

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.

A major effort went into assembling wire schedules for the control equipment in the switchyard. Most of these schedules related to the computer interface and intrarack wiring in the 20 racks which will house the four control centers associated with beam lines A and X. The prewired racks were delivered and set in place in the equipment aisle above the switchyard. The electrical contractor began pulling wires in the switchyard. Some wire schedules still remain to be coded.

The hardware channels were reviewed after the initial assignments were stored in the control computer. Some channels were reassigned to take full advantage of the parallel structure of the data-acquisition system. This was necessary to accommodate the high data rates required for the beam

diagnostics instruments.

Work was completed on a transistorized shunt which will allow several magnets connected to the same power supply to be controlled independently. All documentation was brought up to date. The chassis and parts for 12 shunt control modules were sent to a vendor for fabrication. A water-cooled shunt chassis was built and sent to the same vendor as a model for six more chassis. Rack plumbing was started for the heat sinks. The 10-V, dc reference power supply was received and installed in a NIM module. No problems are foreseen in meeting the scheduled completion date in June.

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. The topics included magnet power supply locations, magnet dc power distribution, control rack layouts and locations, computer interfaces to the local controls, etc. Work started on a more complete plan view showing all device requirements for the secondary beam lines in Area A.

Preliminary designs were started for the control systems required along beam lines B, C, and EP. Plan drawings showing all of the devices are being prepared. Preliminary lists of channels for monitoring and controlling nearly 200 devices were coded. A conceptual design for additional wiring trays was made, and most of the dc wires to the magnets were ordered. Consideration will be given next quarter to the control philosophy for these areas because of the extra complication of remote readout and control from consoles housed in experimenters' trailers.

A preliminary design was completed for a bipolar current-regulated power supply. A prototype regulator is being fabricated. Measurements of the frequency response of the prototype will provide the data for a final design of the control loop.

Work continued on the development of special controls for the High Resolution Spectrometer (HRS). The drive motor and controller for the HRS drive system was received. A prototype of the HRS position readout was built and tested successfully. The drive motors and position transducer were selected for the target table position readout and control. Several drive motors were considered for

controlling the NMR position, but a final choice is still pending. An interlock was designed to protect the scattering chamber from the HRS magnet carriage.

LAMPF Data Terminals

Each module of the accelerator is connected to the control computer by a data-acquisition-and-control terminal (DACT).

An expansion of the binary data capacity of a DACT was designed. A single expander unit will increase the capacity to 31 twelve-bit words. The expander will be used primarily in the switchyard to read in data from digital voltmeters.

All of the pulse motor driver cards in each DACT were modified to decrease the time required to reach the maximum pulse rate. The modification cut significantly the time required to make certain beam diagnostic measurements. It also overcame a low-speed vibration problem.

A training course covering the repair and maintenance of a DACT was completed. The four participants are now qualified to service the terminals.

Central Control Room (CCR) Systems

The tempo of work on the second operator's console increased markedly during the quarter. The Console Interface Unit (CIU), which connects the console to the computer, was completed, checked out and installed. A total of seven chassis and three power supplies was involved in this endeavor. These chassis handle all of the digital communications between the CIU and the computer and service a substantial number of function buttons, indicator lights, slew knobs, trackballs, and alphanumeric readout devices. Extra capacity for function buttons and status lights was built into CIU-2 so that some information can be duplicated on both (and later on all three) operators' consoles.

The actual console hardware is packaged in removable modules. The trackball module, one of two slew modules, and two of three function button modules were installed on the second console. The status display panel is ready for fabrication. The other modules are scheduled for installation by mid-May. The software to support the operation of the console has been developed in parallel with the construction of the hardware and is being debugged as each device is installed. Tests of the whole

system will be conducted the latter part of May.

A decision was made to add a second storage scope to each console. Long-range plans call for the interfacing of these scopes to be done through CAMAC when the crate controller becomes available. In the interim, the present scope interface will be duplicated and connected to CIU-2. Some additional software features are required to take full advantage of the dual-scope capability.

A new writing surface was built for the second console. It provides more desk space and a recessed location for the trackball. New panels and face plates were fabricated for both consoles and painted dark green to give some eye relief for the operators.

LAMPF Control Computer

The LAMPF control system is organized about an on-line digital computer. The computer, a SYSTEMS SEL-840MP, continued to support accelerator operations on a 24-h/day basis. The central processor performed reliably during the quarter but several of the peripheral units failed. Fortunately, the redundancies built into the system configuration allowed the computer to remain on-line while repairs were effected. As a result, little time was lost from operations.

The quick restart device built last quarter was put into operation. Pressing a single button reactivates the computer after a system crash (usually a software failure) and saves a record of the failure for subsequent analysis.

An additional 16-k word bank of memory was ordered for the computer. The concurrent operation of two operators' consoles coupled with a FORTRAN compilation tends to overload the present 48-k word memory. Delivery and installation of the new memory is scheduled for next quarter.

Work started on a CAMAC crate controller for the 840-MP. The capability to communicate with CAMAC hardware is required for the HRS tune-up problem and for a link to the data-acquisition system.

Programming

The effort to improve the reliability of the system software continued this quarter. One source of problems was diagnosed to be a shortage of core memory when the system was heavily loaded. To warn of this condition, a piece of coding was added to

the system to sound an audible alarm when the limit of core is reached. The operator then knows to drop superfluous programs and displays from execution. As a second step to alleviate the core problem, the input/output program compiled with all FORTRAN programs was reduced to one third of its original size by removing unused options. As a third step, several of the programs which involve operator interactions were rewritten to minimize the time they remain in core waiting for the operator's response.

Several other approaches to system reliability were suggested by analyzing the memory dumps after system crashes. For example, work was started on a new program for handling the character scopes when it was observed that the simultaneous use of both operator consoles caused frequent crashes. Several modifications of this sort were incorporated in the system. The net effect was encouraging. Based on comparable 60-h tests, the reliability of the system improved by a factor of three between November and March. This work will continue until it is deemed to have passed the point of diminishing return.

The magnitude of the programming system and data-storage requirements exceeded the million-word capacity of the disk. A second disk was added. The software for handling the file structure on both disks was modified so the system appears to be one large disk. An effort will be made to keep all critical programs on one disk so that the failure of one disk will not shut down the control computer.

Several system modifications were made in response to the evolving requirements for accelerator operations. For example, the queuing scheme in the program which handles the requests for accelerator data was modified to keep separate track of rf and beam-related data. This change was needed to improve the efficiency of data collection at low beam pulse rates.

Work was completed on Data Scan, a group of programs for scanning, recording, and displaying data from the accelerator. The list of channels to be monitored can be entered through the teletype, the card reader, or internally through program calls. Data from channels being monitored are recorded on the disk. When the data file is full, it is written on magnetic tape for long-term storage and analysis. Display programs were written to process the data and develop a graph of one or more variables versus

time. One powerful feature of Data Scan is its ability to call a program when a variable being monitored goes out of tolerance. This feature is being used in the 201-MHz and 805-MHz rf recovery programs. For example, if the forward power is lost on a module, a program is called into execution to try resetting various fault counters. Failing this, a more sophisticated program is called to perform a thorough analysis of the failure. In this way, the operator need only concern himself with systems giving trouble.

A number of application programs were written. One of them produces a summary report of all signals from the 805-MHz rf water system. Another monitors the signals from the new beam spill monitors and produces a summary periodically or on demand. Work was started on a group of programs to restore the beam in the event of an arcdown. The control program for the operator and the Cockcroft-Walton turn-on program were completed.

Some work was done on the accelerator simulator. This program allows new application programs to be checked under controlled conditions without using the accelerator. A program was written for defining the state of the simulated accelerator via a card deck as well as from magnetic tape. The value of any data channel can be changed on-line through another new program. A third program provides a simple means for specifying what program is to be run in the simulation mode. Other features will be added to the simulator as their need becomes evident.

Effort was invested in a quartet of programs to aid in diagnosing equipment problems. One of the programs automates the testing of any channel on the accelerator. Several new options were added to this program as the result of experience in using it to test systems as opposed to individual channels. A program was written to produce the test signals needed to tune a DACT on-line. Work was started on a program to test any of the analog data systems (ADS) with the same thoroughness exercised in the acceptance tests. This program requires that a rack of special equipment be connected to the ADS. A fourth program performs a less thorough set of tests on the ADS and calculates the gain and zero offset needed to correct the more sensitive data channels.

Distributed Operational Systems

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

Timing System

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

The configuration of the timing system was stabilized this quarter. Requests for modifications were minimal. The backup master timing unit was modified to be fully equivalent to the on-line unit. An oscilloscope to monitor the timing signals was put into operation in CCR. This scope displays for the operators the relations among the various accelerator timing pulses.

Fast-Protect (FP) System

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

The problem of diagnosing the source of fast-protect faults was attacked this quarter with three new computer programs. The first program services the FP interrupt and displays the name(s) of the offending device(s) based on data acquired from the accelerator. In certain situations these data can be misleading. Hence, provisions were made for filtering the data through a series of masks to suppress extraneous information. The second program provides the capability for on-line modification of these masks. The third program allows an operator to test the hardware associated with the FP system and to diagnose faulty circuits. Further progress will require the redesign of several systems feeding information to the FP system.

Work continued on the FP system for the switchyard and experimental areas. A decision was made to locate a FP chassis in the switchyard to service those signals which require the shutdown of all injectors. This chassis, which satisfies the requirements for the 800-MeV beam test, also provides a convenient interim interface for the experimental areas. Further attention must be given to the definition of modes of operation between the various injectors and experimental areas.

Run-Permissive (RP) System

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

The remainder of the wiring internal to the RP system for the accelerator was tested. All that remains is to check the input signals from those devices which were not tied into the RP system during the initial testing. These devices include the quad magnets and vacuum valves in Sectors D-H.

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 checking of the personnel safety system for the remainder of the accelerator was completed. The system is now ready for operation.

Final designs were developed for the personnel safety system in the beam switchyard. The required chassis were wired, tested, and await installation in the rack. Work started on the interconnection wiring diagrams. Orders were placed for warning signs and a special key core. Bids were requested for the fabrication of a personnel barrier gate to be mounted between Sectors G and H.

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 problems with the area monitor detectors (ion chambers) were solved last quarter. The purchase of a special tool provided the capability for filling and sealing ion chambers locally. The four leaky chambers still under warranty were repaired by the manufacturer. Enough chambers are on hand for all the area monitors, with some to spare.

The new electrometer developed for the area monitors was found to be highly stable. Moreover, the operating characteristics from unit to unit proved to be uniform. Consequently, each component of the area radiation monitoring system-- ion chamber, electrometer, log-pump and station unit-- can be calibrated individually. This in turn, means

that each component can be interchanged without requiring a complete system recalibration.

The process of installing these improved components is nearing completion. All of the station units and most of the ion chambers were recalibrated. All of the electrometers were modified, installed, and checked out. The reprocessed ion chambers and new preamplifiers were installed through Sector E and the Transition Region. These systems are now fully operational.

The design of the area radiation monitoring system for the beam switchyard was completed and the area monitors were ordered. The wiring schedule was prepared and delivered to the contractor who started installation of the wires. The wire schedule included wires for a provisional area monitor system acquired from surplus. This system will not be satisfactory for final operation but will serve adequately for initial operation in the switchyard should delivery of the new system be delayed.

The air-velocity meter, which is needed for the system to monitor radiation emitted from the exhaust stack in the Experimental Area, was received for test and evaluation. Its operation in a 1000 R/h radiation field showed no discernible effect on the velocity reading. However, when calibrated against wind tunnel standards, a zero offset was detected which has yet to be explained.

A major modification to the beam-spill monitoring system was made last quarter. The original criteria for system performance dictated that the system protect against excessive radiation in the main equipment aisle by tripping on relatively high-level spills during the beam pulse. The system developed could shut down the beam in less than 10 μ sec.

However, radiation measurements made after beam diagnostic studies clearly demonstrated that activation of beam channel components set the lowest limit on allowable beam spills. Since activation is a function of the average radiation, control criteria should be based on the average radiation level rather than on peak levels.

Electronics to accomplish the new operational requirements were developed and a prototype unit evaluated during operation in the Transition Region. The principal problem encountered was that of matching the extreme dynamic range ($10^5:1$) while

retaining sufficient signal/noise ratio to operate in the extremely noisy electrical environment of the equipment aisle.

The action of the system developed can be illustrated by the conceptual diagram shown in Fig. 18. The current i_s from the detector is proportional to the beam-spill radiation. This current is integrated by capacitor C to obtain its average value. From this a current i_a , representing the allowed beam-spill radiation, is leaked off through the large-value resistor, R_a . The allowed beam-spill current can be adjusted by changing the potentiometer, R_p . When the voltage across C is high enough, the infinite impedance relay, K, is tripped, opening its contacts. These contacts are in series with the Fast-Protect system. When open, the beam is turned off at the injector. With no beam the current i_s drops below i_a and the voltage across C decays until low enough that the relay K drops, allowing its contacts to close. The injector is then turned on again.

The action is such that both pulse width and effective repetition rate are modulated as illustrated in Fig. 19. Propagation time from the point of spill to the injector, turn-off time at the injector, and propagation time back to the point of spill limit the shortest turn-off time to about 25 μ sec. During this time, the spill signal continues to accumulate in capacitor C. The time constants were adjusted so that although a massive spill will not turn off the beam for 25 μ sec, it will hold off succeeding beam pulses for 60 sec. The result is that the average spill-produced radiation is held to an acceptable level until the defect is corrected or until the special operating circumstance no longer exists.

Fig. 18. Conceptual beam-spill control system.

Fig. 19. Beam-pulse modulation by beam-spill control system.

In the conceptual system, the beam-spill envelope is obtained by measuring the instantaneous capacitor current with the resistor R_c . In practice, the envelope signal is recovered by differentiation following the integration. This process, with appropriate bandwidth control, removes some of the electrical noise from the signal.

After the prototype was tested successfully, all drawings were updated and a complete set was sent to a vendor who began fabricating the new PC boards. The 55 station units were disassembled and 43 were sent to the vendor for re-assembly. The other 12 units were assembled locally to meet scheduling requirements for operations. These 12 units were installed through module 12, and were checked, calibrated, and put into operation.

A wire schedule was completed for the beam-spill monitor system in the switchyard. The contractor began installation of the wires.

Auxiliary Systems

Communications System

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

Additional interphones were installed in the Injector B area, the Transition Region (both upstairs and downstairs), and in the beam channel of Sectors G and H.

The paging system for the Laboratory-Office Building was completed except for selecting the wattage tap on the individual speakers. The paging systems for the Equipment Test Laboratory, Nuclear Chemistry, and Operations buildings are in progress.

Work was started on a Paging Selector and Communications Center for the second operator's console in CCR. The unit will be completed early

next quarter.

A separate speaker to monitor the interphone system was installed in the computer room. This speaker allows personnel working around the computer to selectively monitor any communications channel independently of the control room speaker.

The communications system for the switchyard was turned over to the electrical contractor for installation. The system should be operational early next quarter.

TV System

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

The scheduling of wires for the operations TV in the beam switchyard was completed. Work was started on the installation of the wires. The wire schedule for the single-access surveillance camera for the switchyard was prepared. A camera, mount, and weatherproof housing were ordered.

The operations TV systems have proved to be a valuable aid to the task of calibrating channels. A program was written for the control computer which presents a display on the character scope (a TV monitor) in CCR. This display is relayed over a trunk line to a TV monitor located at the equipment being calibrated. An operator at this point can control the process of calibration while the computer monitors and displays the results. This technique cuts the manpower requirements in half, speeds the task, and standardizes the procedure.

Work continued on the scheme to use the operations TV system to record real-time emittance and beam-profile data. An analysis of the vidicon resolution and linearity properties of the TV system (as they related to an earlier set of profiles) disclosed a need for careful calibration of the sensitivity and linearity of the equipment. It was also found that (a) the sensitivity of the system was not adequately independent of line voltage and (b) the geometric distortion of the standard TV monitor was excessive. Therefore, a portable rack of equipment was assembled which includes a high-quality TV monitor, a line regulator, and a means for system calibration. This equipment will be used for further studies next quarter.

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 last components of the video system for the accelerator were installed. The line drivers and buffer amplifiers were calibrated. The final system checkout of the matrix switches from CCR was completed.

To facilitate the use of the video system from the operator's console, a specification for supporting software was prepared. It defines a set of displays and control operations for identifying and selecting the various signals. The specification was reviewed and accepted with several modifications. An interim program to select any signal by its hardware channel assignment was written and released for use.

The design for the video system in the switchyard was completed. The hardware is on hand and has been bench-tested. A wire list for the system was prepared.

Experimental Area Computers

The remaining equipment associated with the first two computers for the LAMPF data-acquisition system was received and accepted. One of the computers is being used to test the CAMAC branch driver while the other is being used to develop programs.

The bulk of the programming effort was spent in making modifications in the manufacturer's Disk Operating System (DOS). The goal is to augment DOS so that it will support the priority task of data-acquisition in addition to a background task, e.g., a FORTRAN compilation or data analysis. The approach being taken is to imbed the data-acquisition code in the DOS monitor so that it functions as an interrupt-driven "underground." In effect, the experimental apparatus becomes a DOS peripheral unit. Provisions are being made for passing information between the underground and a data-analysis or display program. It will also be possible to control the underground from the teletype.

The first test of the data-acquisition system will occur during June when an attempt will be made to acquire data through the CAMAC branch driver and write the data on a magnetic tape. Subsequent tests

will include analysis and display of the data. Further developments in the area of software will be guided by the results of these tests.

Two additional data-acquisition computers were ordered. A PDP-11/20 in the LAMPF standard configuration is scheduled for July delivery. A faster, more powerful PDP-11/45 has been promised in November. Initially, these computers will be used in developing experimental equipment and in tuning up beam lines.

Work on a controller to interface an IBM-729-IV magnetic tape drive to a PDP-11 had to be halted because of manpower reductions. This project was important because several of the 729-IV tape drives were obtained from surplus and could be utilized in the data-acquisition system if such a controller existed. Fortunately, it was learned that the Lawrence Berkeley Laboratory is developing one. Since this controller is being built to the CAMAC standard, it will be fully compatible with the LAMPF system. The prototype model is scheduled for completion in June. Production models should be available by September.

CAMAC Hardware

To facilitate the checkout of the Microprogrammed Branch Driver (MBD), a simulator for the PDP-11 was built and tested. This device has a simple control console and operates in the single-cycle mode to execute PDP-11 instructions. It has proved especially useful in locating wiring and logic mistakes in a new piece of equipment without tying up a computer.

During March the simulator was used to check out the MBD. The first of the two planes contained an excessive number of wiring mistakes, apparently introduced by a new operator using the wiring machine. The second plane contained no errors. The checkout of the MBD proceeded through the I/O portion to the processor, the branch driver section, the channel interface, and finally to the interrupts. By the end of March all portions of the MBD had been checked as thoroughly as possible in the single-cycle mode.

In April the MBD was connected to a PDP-11 and dynamic testing was started. These tests are about 80% complete. The MBD memory and file registers can be loaded and verified. The success of these

operations shows that the arithmetic unit and DEC interface are working correctly. Programs have been written to check the branch driver, the instruction set and the channel logic. The MBD is expected to be fully operational by mid-May.

At each step of the checkout, the drawings and wiring tape were updated to reflect the latest changes. Based on the success so far, the second MBD was wired, assembled, and is in checkout with the simulator. Two more MBDs and a pair of simulators are in various stages of completion. Parts for four more MBDs and two more simulators are on order. Most of these devices will be operational by the end of July. Ten power supplies for the MBDs were received along with three CAMAC crates. Four CAMAC crate power supplies are due for delivery in May.

Bids were received for CAMAC modules to interface a storage scope to a PDP-11. When the total cost of a display system using these modules was compared to the cost of a newly introduced commercial system, the economics favored the commercial unit. Subsequently, an order was placed for five storage-scope display systems.

The first shipment of CAMAC control modules was received. These modules will be used to implement control of beam-line equipment. Modules capable of the following functions were received: binary output, binary input, analog output, pulse output, and analog input from a digital voltmeter or an analog-to-digital converter.

Work continued on a CAMAC module for the data-link system. This system will link each data-acquisition computer having a CAMAC crate to the terminal computer which, in turn, is linked to the large computers at the LASL CCF. Attention is being given in the design to the requirement for operating an MBD remotely over a data link.

LAMPF Electronics Equipment Pool (LEEP)

A pool of electronics equipment of general utility is being created to support LAMPF users. The total expenditure for equipment approached \$175,000 by the end of this quarter with about \$75,000 in equipment money out on bid. The funds were allocated to the following general categories: (1) test and support equipment, 25%; (2) fast electronics (NIM), 40%; (3) slow electronics (NIM), 5%; and (4) CAMAC hardware, 30%. When there was a clear

preference for a specific module or piece of equipment, the item was ordered in the selected quantity. In other cases the item was ordered for test and evaluation. All NIM modules were ordered with LEMO connectors to be compatible with CAMAC.

Considerable thought and discussion have been given to a loan control and maintenance record system for the pool equipment. A computerized scheme for such a system will be developed in the coming months. A PDP-11/05 in a minimal configuration was ordered for the pool as an aid to maintaining the nuclear instrumentation modules.

Neutron Flux and Spectra Measurements

Studies of techniques to measure the medium-energy neutron flux and spectra that will be produced at LAMPF were initiated last summer. Preliminary tests at 200 MeV indicated that threshold detectors would be quite useful. A cooperative program between LASL and LBL was begun to calibrate fission foils in the medium-energy range. Tracks created by the fission fragments in Kimfoils were counted by means of a spark counter. For calibration purposes, these track densities had to be compared to similar tracks created in mica. A preliminary exposure was made last December in a 200-MeV neutron beam at the Berkeley 84-inch cyclotron. Late in March a calibration exposure with bismuth, lead, gold, tantalum, and depleted uranium foils was made. An evaluation of the track densities in mica was completed at the end of the quarter and an analysis of the results will be made.

V. ACCELERATOR OPERATIONS

LAMPF Operations

The Operations Group had a modest personnel increase and, with assistance from support groups, accelerator experimental programs can be sustained on a normal work week of two shifts with an occasional week of three-shift operation. Operation personnel have gained considerable experience in running the accelerator, both in local and computer modes. Experience with computer operation, computer hardware, and status and diagnostic programs has enabled the operators to run the accelerator better and more easily detect subtle difficulties in the various systems. The ultimate goal is to run the accelerator and do the major portion of systems diagnostics and fault analysis from the computer control room.

A weekly operations report was initiated to provide a formal means of transmitting to all groups a summary of the week's operation and to alert support groups to the kinds of service interruptions encountered so corrective action could be initiated and loss of available beam time can be minimized.

A modest start has been made on a formal operator training program. For the time being, the on-the-job training approach coupled with lectures on various subsystems is being used. Effort to acquire additional operations personnel to provide an adequate staff for FY-73 is continuing.

VI. EXPERIMENTAL AREA

Facility Planning

Concentration on the switchyard services and equipment installation has been intensified this quarter in an effort to have the switchyard ready for beam on June 1, 1972.

The conceptual design report for the Isotope Production Facility was approved by the AEC in March and final design was completed for review the last week of April. Fabrication of the insertion and extraction mechanisms has started and a contract has been awarded for fabrication of the mechanism housing. Construction of this project will start after the present Phase III contract is completed.

The conceptual design report for the Radiobiology and Therapy Research Facility was completed and transmitted for AEC review on March 20. The report primarily describes the plant and services of the facility. The final design of this project will proceed on approval of the conceptual design report. In the meantime, work has continued on the preliminary design and building layouts and the establishment of the interfaces with adjacent facilities.

Extensive planning work has been carried out for the proposed Weapons Neutron Research Facility. A new group has been formed in the Weapons Division at LASL to concentrate on this project. The conceptual design report was completed and transmitted to the AEC on April 7, 1972. Beam line transport studies and shielding studies are under way. Facility design funds are available and this work will start on approval of the above report. Construction funds for this project are expected in FY 1973.

Switchyard

Preparations are under way for the first 800-MeV beam tests. The switchyard PERT system has been supplemented by a detailed scheduling chart. The only switchyard magnets required for first beam tests are two of the 6-in. quadrupoles. The current status of the switchyard magnets is:

2° bending magnets: All machining and temperature switch installation is now complete. The first magnet is completely shimmed to meet switchyard requirements, and four remain to be checked. One of these is a monitor magnet.

1-1/4° and 3° bending magnets: The two beam line

magnets and the monitor magnet have been completed, measured, and alignment fixtures have been installed. These are ready to go into the beam line.

11-1/4° bending magnets: The first two of these have been completed, measured and fixtured. The third is undergoing machining of the side shims, prior to measurement and end shimming.

6-in. bore quadrupoles: These magnets (6Q2M/5) have developed faulty coils, showing either water leaks in the cooling coils, or low insulation resistance in the mineral-insulated (m.i.) coils. The defects are believed to be due to corrosion from chloride flux left in the coils during the soft-soldering assembly of the external cooling coils. The defective coils have been repaired by the vendor (the m.i. cable can be patched using "Silfos" brazing alloy without flux) and all coils have been heated to remove the solder, then cleaned with steam and hot water. The resoldering is then done without flux. At present four coils have been rebuilt in this way, three have been repaired, and the remaining 23 have been cleaned. The status of the quadrupoles is: one measured, with alignment fixtures, ready for installation; six measured, but require reassembly and alignment; and one to be measured and fixtured.

2-in. bore quadrupole doublet: The iron parts for this doublet (2Q19M/6) have finally been received. Assembly is proceeding.

Installation of the m.i. cable for the switchyard magnets, the water systems, and the instrumentation conduits is almost completed. Work is continuing in Service Aisle A on m.i. cable terminations and junction boxes.

Beam dynamics calculations have continued in that small variations and improvements of parameters have been added to create sets of decks of cards for each mode of operation.

Tests of prototypes of switchyard instruments have continued, showing satisfactory performance in most cases. More detailed specifications have been developed. The software necessary to handle the various instruments has been designed, and the writing thereof has commenced.

Design and drafting have been completed for the instrument support stands to be used in the switchyard for centroid monitors, ISICs and wire scanners. An order has been placed for 14 stands, with:

delivery scheduled for the end of April.

Fabrication of the switchyard collimator is in progress, with the large vacuum enclosure ~ 80% completed. The graphite assembly is being machined, with completion expected by May 17.

Special beam tubes (rectangular cross section) between the first bending magnets and the switchyard collimator are being fabricated. Completion date for this contract is expected to be June 13.

Stainless steel parts for 16 centroid monitors have been received, and preliminary assembly work has been started. Ceramic spacers required for this instrument will not be available until early May.

Five 6-in. linear actuators are being assembled; the remaining 12 assemblies are due during the first half of May.

Beam Area B - Nucleon Physics Laboratory (NPL)

Three bending magnets (LB-BM-01 through -03) are ready for measurement and one (LB-BM-08) is ready for installation. The four "C" magnets (LB-BM-04 through -07) have not been delivered yet. All quadrupole magnets are ready for installation.

All valves and pumps for the vacuum systems have been delivered. Other hardware is on order. Support stands for the quadrupole magnets and most of the bending magnets have been designed. Stands are now being designed for the last three bending magnets. Drawings for the magnet and power supply cooling-water system are complete, and the system is now ready for bids.

Criteria are being developed for the control system. Design and development of the diagnostic system are in progress.

The final mechanical design of the liquid deuterium target is in progress for the target proper. The refrigeration system is now under study. The cryostat for the polarized proton target is being assembled.

A preliminary sketch of the neutron collimator is shown in Fig. 20. This collimator will readily enable the change of neutron exit angles between 0° and 30° lab.

The stripper handling mechanism is in final design. The beam plug and hydrogen disposal systems are under preliminary study.

Fig. 20. Conceptual sketch of a neutron collimator for the NPL. The collimator will be adjustable in steps from 0° to 30° with respect to a proton beam incident on a neutron production target. The proton beam is bent away by a "C" magnet (not shown).

Beam Area C - High Resolution Proton Spectrometer (HRS)

During the last quarter, considerable effort and time have been spent on placement of an order for the two large magnets in Beam Line C in order to obtain the best price without affecting the performance of these magnets. In order to save overall cost and to hasten the final delivery of the magnets, it was decided to purchase the steel blanks and the machining of the magnets separately.

Various hardware items for Beam Line C are starting to arrive. All of the 1° and 4° bending magnets, totaling five 1° and two 4° bending magnets, were received. Hydraulic and electrical tests on these magnets are being performed in addition to the magnetic measurements. One 6Q29R/7 twister quadrupole magnet was received and magnetic measurements are being performed to determine the best chamfers for the entrance and exit ends of the pole pieces. All the magnet stands except those for the two large bending magnets and the last quadrupole are on site.

Fabrication of the two spectrometer bending magnets is delayed due to the downtime of the large vertical boring mill on which various pieces for these magnets are being machined (see Fig. 21). Only the pole contour remains to be machined before trial assembly of the first magnet takes place. At

Fig. 21. Vertical boring mill being used to machine HRS magnets.

present, the vendor and LASL are working closely to improve the delivery schedule of the second magnet. The first and second coils for the HRS magnets were successfully vacuum impregnated. The first coil has been tested hydraulically and electrically and is waiting for shipment. The second coil is in the testing and inspection stage. The third coil is waiting to be vacuum impregnated. The fourth coil is halfway through the winding.

A number of parts for the spectrometer, such as the detector chamber, scattering chamber, vacuum chambers, etc., have been designed and are either being fabricated or in the process of bidding.

Energetic Pion Channel and Spectrometers (EPICS)

Detailed studies have been made of the final 700 MeV/c spectrometer design in order to provide design data for work on detectors, targets, beam monitors and vacuum chambers. The performance of the channel and spectrometer system have been investigated by use of Monte Carlo techniques over a wide range of momenta and also for the use of multiple strip targets which reduce requirements for expensive separated-isotope targets. In all cases studied to date, the resolution and solid angle are as predicted in earlier work.

Considerable progress has been made in the procurement of magnet components for the channel and spectrometer. A problem that developed with the order for fabrication of the channel magnet steel was resolved. The first bids received were more

than a factor of two above our estimate. The problem was discussed with the vendors and some design changes were made. The new bids came in much closer to our estimate, but approximately seven weeks were lost during the procedure. The current status of the magnet orders is listed below:

EPICS Channel:

Steel	on order
Rad-hardened conductor	partially delivered
Coil fabrication	in progress
Steel fabrication	on order

EPICS Spectrometer:

Quadrupoles	in fabrication
Bend steel	on order
Bend coils	on order
Bend steel fabrication	on bid

Bid opening for the bend steel fabrication order is expected in early May and delivery of the first channel magnet is expected in October.

A design study for a differential Cherenkov counter for use at the focal plane of the spectrometer was started with the aid of Dr. L. Wayne Swenson from Oregon State University, who is visiting LASL for five months. This counter is expected to cleanly separate pions and muons in the very large phase space beam expected at the focal plane. It is clear that we will need to correlate the observed angle of emission of Cherenkov light with the angle of each particle and cannot use the standard arrangement of a coincidence and anti-coincidence ring used in existing DISC counters.

The vacuum system for EPICS has been studied and vacuum pumps have been chosen. Two large turbomolecular pumps will be used on the channel and scattering chamber, while a Rootes blower will be used on the spectrometer. A suitable blower is on hand, and a small turbomolecular pump is available. The pumping speed requirements are being reexamined to see if a smaller pump would be satisfactory.

Good progress has been made on the EPICS Particle Separator design as the result of additional drafting help becoming available. The overall package dimension, including the steel vacuum chamber is 73.5 in. x 73.5 in. x 75 in. Design solutions have been found to the three major problem areas: the wide-gap magnet, the single high-voltage line, and the high-voltage bushing. The magnet has been designed with 64 turns of m.i. hollow conductor

in eight nesting coils. The gap has been reduced to 29.5 in. and the length increased to 29 in. The coil is presently being put out on bid.

The high-voltage line is designed as a series of concentric shells positioned for equal and minimum field intensities. The line will operate at about six atmospheres of either nitrogen or sulfur-hexafluoride. Radiation effects on sulfur-hex are being investigated. The gas-filled line will continue through the shielding to a low-radiation location where it interfaces with an oil-filled line that continues to the power supply. Removal of the separator will require disconnecting the high-voltage line and rolling the device out of its vacuum chamber horizontally after which it can be hoisted vertically. Appropriate shielding must be removed, but Merrimac should not be required.

The high-voltage bushing will clamp equipotential plates which wrap around the main electrode and distribute the voltage of a 1200-MV voltage divider. The high-voltage bushing will be clamped against the high pressure of the line to keep it in compression and an adhesive will be used to seal the surfaces. The ground electrode will consist of rods strong enough to resist electrostatic forces and maintain a flat plane. These rods should reduce the ion-multiplicative exchange which commonly occurs in high-voltage installations. The gap between the electrodes has been reduced to 9 cm which allows the separator to operate at about 300 kV. This voltage is very near the limit for vacuum operation so the facility is still being designed with the option of operating at 10^{-6} Torr through use of a turbomolecular pump.

Low Energy Pion Channel (LEP)

Fabrication was started on the four bending magnets. Deliveries are scheduled during the next quarter. Water manifolds were installed on all four quadrupoles. Installation of ceramic insulators on the m.i. cable should start about May 1.

The bulk of the support stands were designed, detailed, and placed on bid. These items, including the smaller hardware not yet detailed, should be delivered during the next quarter.

Fabrication started on vacuum tanks for the quadrupoles and momentum slits. Design of the vacuum tanks for the bending magnets was started.

A purchase order was written for a vacuum-pump package to pump the vacuum system to its operating pressure of 5×10^{-6} Torr. Designs were completed and detail drawings were started on remote-operation vacuum flanges for the channel in the area of the proton target.

Design continued on a rad-hard collimator actuator (for the solid-angle defining slits), beam plug, momentum slits and proton absorber.

P³ High-Energy Pion Channel

The optics of the P³ High-Energy Pion Channel have been changed slightly to allow the use of a Cambridge Electron Accelerator (CEA) magnet with 32-in. circular pole tips for the third bend. This change releases the 30D40 picture-frame magnet for use in the equipment pool.

A program to simulate the channel tuneup is being written. The program RAYPORT, written by LAMPF Guest Scientist Larry Coulsen (Rice University), simulates the transport of randomized rays through the P³ channel and simulates the measurements made on these rays by a series of multiwire proportional counters. It then uses these measurements to form a figure of merit and its numerical derivatives. The main remaining task is to incorporate a suitable optimizer code into the program. Once finished, the simulation code will be used to test the effectiveness of the tuneup algorithms. Much of this code, particularly the optimizer section, will be incorporated into the on-line analysis of the tuneup procedure.

In the past quarter, a study was made of the space available between magnets that must accommodate various items of hardware, such as beam jaws, remote-disconnect vacuum flanges, etc. It was necessary to design a more compact remote-disconnect and retractor mechanism for the vacuum flanges which connect the magnet manifolds to the beam jaws.

It was decided that the rad-hot water system for the channel will include all of the magnets up to and including the second doublet. The rad-warm water system will cool the remaining magnets.

The location of power supplies is now firm and the dc lead requirements can now be defined.

It has been proposed that the physical interface between Target Box A-2 and P³ will be located ~ 20 in. from the position of Target A-2. At this

location, there will be two windows separated by an air gap. One window will be in the target box and the other will begin the P^3 channel vacuum envelope. The minimum cross section of these windows should be on the order of a 2 in. x 4 in. ellipse.

The five rad-hardened magnets have been received from the vendor. The four quads are still in need of water manifolds and ceramic-metal seals. The bending magnet has the manifold but needs the seals.

The cracks in the epoxy insulation of the Princeton-Penn Accelerator (PPA) coils have been repaired with the help of the Plastics Section of LASL Group CMB-6. It was necessary to build a vacuum potting fixture and some special handling equipment to make this repair (see Fig. 22). Figure 23 shows the cracks in two of the quad coils before repairs were made.

One of the 8-in. PPA quads has been replumbed by replacing the neoprene hoses with copper tubing and ceramic insulators. To reduce the number of insulators required, it was necessary to run the four circuits of each coil in series instead of parallel. Preliminary flow tests indicate that the flow is still sufficient to cool this magnet. If this proves to be the case when we power the magnet, the remaining quads will be modified in this fashion to increase their reliability and resistance to radiation.

Most of the 8-in. quads which came from PPA have been powered and magnetic measurements have been made.

Fig. 22. Vacuum-potting apparatus for repair of epoxy insulation on quadrupole magnet received from PPA.

Fig. 23. Cracked epoxy insulation on PPA quadrupole magnet.

Fabrication drawings and specifications on the support structure for all the components through the second bend are complete.

Stopped Muon Channel (SMC)

During the last quarter, six of the eventual 12 Danby-type quadrupoles (12Q15) were delivered. The field in one of these is currently being measured.

The insulation (with concrete) of the coils for the first four magnets in the channel is being done by Group CMB-6 (see Fig. 24). Of the 16 coils of this type, eight have been delivered from the vendor, seven have been potted, and four have been tested with alternate heating and cooling cycles. The fourth magnet in the channel was originally fabricated with epoxy coils; these have been removed and we are now in the process of installing the concrete-insulated coils.

Work is about one-half completed on the construction of a prototype of the remote control system to be used for the magnets and power supplies. Final criteria have been established for the shielding of the channel.

Drafting work is nearing completion for the two septum magnets to be used to provide beam simultaneously to two experimenters.

Beam-spot size vs muon-transmission rates for a magnetic analyzer composed of two 67.5° bends, have been computed with a Monte Carlo version of the second order TRANSPORT program. Calculations

Fig. 24. Concrete-insulated coil for stopped muon channel magnet.

show that a 4 x 4 cm beam spot contains 72% of the differential flux with $\Delta p/p = \pm 0.2\%$.¹

Primary and Secondary Beam Transport

Four of the large quadrupole triplets for the Beam Line A target cells have now been received. Work is continuing on the remote connectors required to make up the 750-A power connection to these magnets, which are completely inorganic in construction. The delivery schedule on the remaining five triplets is expected to be maintained.

The first of the Beam Line C "twister" quadrupoles (6Q29R/7) has been delivered and measured at LASL. A chamfer of 0.4 in. is now being machined on the pole ends to reduce the $N = 6$ component to 0.1%. The remaining magnets will incorporate this same chamfer after it has been checked. The 10° and 4° bending magnets for the junction between Line B and Line C have been received at LASL.

A quantity of 3/4-in. hollow m.i. cable, meeting all requirements, was successfully produced by the vendor, Pyrotenax of Canada Ltd., and has now been supplied to the coil winders for LEP, P³, Line B and EPICS magnets. The two coils wound to date are satisfactory.

Magnetic field measurements are continuing on the switchyard bending magnets. Side and end shims have been selected which give good field uniformity

in both the central field and $\int B \cdot dl$. Each magnet requires a complete test and shim evaluation as they have differences on the order of one-to-two parts in 10⁴.

Standard operating procedures are being written so that outside users will be able to operate the magnet-measuring gear. These procedures will in the future include details on the use of programs which reduce the raw data to harmonic content, effective length, etc.

The current and profile monitor configuration for the target cells has been generally specified. Some details remain to be fixed.

Experimental Area Equipment and Experimental Area Support

Testing has begun in the 100-MeV test area, which is now called the "north port." The testing consists mainly of beam diagnostics; target testing is scheduled to begin in July 1972.

The installation at the north port includes a target box, a collimated beam stop, a beam spreader and a main beam stop. The main beam stop for the north port has been fabricated. It is shown in Figs. 25 and 26. It consists of a ZTA graphite block with water cooling on the o.d. It is capable of stopping 1-mA average current of 100-MeV protons. It is also a Faraday cup.

The collimated beam stop and spreader water flow problems were analyzed. Water flow equations were derived and an analytical solution reached. The spreader flow is 3 gpm when the collimator is 10 gpm. Fabrication is complete, but a water flow test has not been performed.

Fig. 25. The 100-MeV water-cooled graphite beam stop shown in disassembly.

¹H. Vogel, "Status Report: Magnetic Analyzer for Stopped Muon Channel," Los Alamos Scientific Laboratory, unpublished document, January 31, 1972.

Fig. 26. The 100-MeV water-cooled graphite beam stop shown assembled.

The target box has been modified and is ready for installation. A new support structure for the box was designed and is being fabricated. This structure will allow quick removal and replacement when residual radioactivity levels are high.

Calculations on the window for the 800-MeV water beam stop were completed. Extensive calculations and graphs were made so that a rather complete understanding of windows and foils could be obtained. Analysis was made of SS 316, copper, tungsten, and alloys of aluminum and molybdenum. All of these materials will make satisfactory beam windows for a beam diameter of 3 cm or more. Stainless steel 316 was chosen for its water corrosion resistance and ease of fabrication. The thickness is 0.032 in.

Some analysis work has begun on a biomed target. It appears that a wheel target will not be needed. A stationary water-cooled target of pyrographite or copper looks promising.

Development of the beam-stripper apparatus continues. A firm bid has been received on the various types of graphite stripper foils that were described in the last progress report. These include both the 1 mg/cm² foils with holes of various sizes as well as slits. Orders are being placed for an assortment of these foils as well as for some very thin foils and filaments.

Work continues on the process water systems. The four 3-MW and one 1-MW pump heat-exchanger package assemblies have been installed in their

respective pits. The surge tank systems along with their associated package instrumentation are being installed at the present time. Filling and cleaning of the X06 water system will begin as soon as the installation of the instrumentation is complete. The installation of the ion exchangers and the filters for the seven process water systems has been completed in the basement of the Merrimac Area.

Manifolds for the magnet cooling water have been installed in the switchyard. The final connections will be made when the magnets are placed on their stands.

The process water mains with branches to the valve caves are being installed in Area A. Drawings for nine valve caves in Area A have been completed. Additional drawings are being prepared to show the connecting lines from the caves to the secondary beam line manifolds.

The stainless steel process water lines for Area A-East which were installed as a part of the Phase III contract have been pressure tested and cleaned. These lines have been sealed and pressurized with nitrogen gas to keep them clean. The X01 mains to Area A-East along with the cooling tower water mains are also complete.

Alignment monuments have been set for Line A and Line X in the switchyard and the alignment survey extended into Areas A, B and C. Magnet stands have been set for the Line A-Line X section and are ready for the installation of magnets.

Profile monitors will be inserted upstream of the A-1 and A-2 targets. These monitors will be the primary reference points for alignment and both the primary and secondary beam lines will be referenced to them. The capability will exist for sighting down the beam pipe to determine the position of the profile monitors.

Design and drafting work was concentrated on temporary beam stops, collimators, and diagnostic equipment for the switchyard. Extensive effort was devoted to the meson target areas and their associated mechanical design and shielding layout. Design and drafting support continued on Merrimac, the secondary beam lines, the hot cells and their equipment, and on the radiochemistry pneumatic rabbit systems.

The delta-ray spectrometer is in place in the north port beam line. It has not been operated

since December when it was removed from the transition region, but it will be in use again starting the end of April. A Be target has been installed and the internal collimators have been modified to improve performance.

The delivery of hardware for beam line instrumentation is nearly complete. Parts for the linear actuators, the beam boxes, centroid monitors, and harps are on hand. Assembly of equipment needed for 800-MeV beam tests is on schedule.

The large (6-in.) toroids have arrived and have been shown to work properly. Fabrication of beam boxes for them is under way.

Considerable running experience has been gained with the harp, profile monitor, centroid monitor, and high-sensitivity current monitor in the 750-keV beam. Electronic problems remain to be solved in the centroid monitor's analog processor. The prototype profile monitor has exhibited better than 0.5-mm resolution, with a 10- μ A beam (average) traversing a region where the pressure is $\sim 10^{-5}$ Torr. Design of a production model will be undertaken. The harp has been moved to the north port where it was used successfully to measure the momentum distribution of the 100-MeV beam. A prototype ISIC is also in place in this beam line, so the testing of it will begin soon.

In practice, when installed in a working beam, the problem with high-sensitivity current monitors is not random noise; rather it is pickup, which generally being synchronous with the beam pulses, cannot be eliminated by signal averaging. We have developed an analog signal processor to eliminate this interference. It is a gated circuit that remembers the amplitude and first derivative of whatever background signal is present at the start of each beam pulse and subtracts them from the output. Bench tests of a prototype have shown clean recovery of a 2- μ A (peak) current pulse from a background 20 times larger, even when the beam pulse was riding on a steeply sloping portion of the pickup signal.

The equipment pool committee has been active in specifying much of the fast electronics and test equipment for the LAMPF Users Equipment and Electronics Pool (LEEP). To date, \$175 k worth of such electronics has been ordered. CAMAC equipment purchases are being delayed as much as possible

without jeopardizing the experimental schedule. The development of commercial modules is expanding rapidly. Waiting until the modules are needed for experiments will minimize premature obsolescence.

The experimental magnet pool will be expanded with the addition of five or six magnets on extended loan (minimum of two years) from CEA. Table I lists some of the characteristics of bending magnets now available for the users pool.

Remote Handling

The Merrimac gantry hydraulic system has been installed and checkout is proceeding. Three inches of lead have been poured into the roof of the Merrimac box to provide shielding. The box is essentially ready to be mated to the gantry. The Beetle windows have been shipped to a vendor for cleaning and replacement of broken glass, preparatory to installation in the Merrimac box.

The hot-cell roof covers have been installed by a contractor. During installation it was discovered that one of the doorways would not support the weight because of voids in the concrete beneath the way. Gallons of grout have been pumped into these voids. The mechanism that pulls the doors open and also provides working platforms for Merrimac maintenance has been installed. The system is awaiting checkout.

Four high-quality lead-glass shielding windows have been removed from the RMAD building at Jackass Flats, Nevada, for use in the Merrimac service cells. Two additional windows are scheduled for removal. There will then be enough windows to outfit these hot cells completely.

A prototype Merrimac door was assembled to test the door-opening capability, fabrication and assembly techniques, and floor deflections under concentrated and moving loads. The door weighed in excess of 900 tons. The door operated rather smoothly at a pulling force of about 35 lb force per ton of door weight, which was $\sim 20\%$ less than expected from previous tests on single rollers.

Detail design of the target-handling mechanism for Target A-1 is progressing. This mechanism stores three wheel targets within the beam vacuum and provides the capability of transferring any one of these targets from storage onto the drive motor so that the beam intercepts the wheel at the

TABLE I
Pool Bending Magnets

Quantity	Designation	Type	Gap Height (in.)	Gap Width (in.)	Gap Length (in.)	Weight (ton)	Max. Field kG	Power Supply		
								Current		Volts
1	PPA 18D40	picture frame	6 [†]	18	40	20	17.5	156	1200	130
1	PPA 18D36MKI	H	6 [†]	18	36	17	18	200	800	250
1	PPA 12D24	C	5 [†]	12	24	8	12	50	400	125
1	PPA 12D60	H	5 [†]	12	60	10	20	464	1850	255
2	PPA "Hodoscope Magnets" (no coils)	H	9 [†]	34	18	30				
1	PPA 30D40	picture frame	6 [†]	30	40	34	17	156	1200	130
1	EPICS Prototype	H	3 [†]	24	24	15	21	60	1500	40
1	*CEA ORPHEUS	H with 32-in. cylindrical pole tip	5 [†]	32	32	21	16	93	417	223
1	*CEA HELEN	H	6 [†]	18	36	12	20	116	465	250
1	**CEA SCYLLA	H	10 [†]	22	48	38	18	205	446	459
	or									
	ODYSSEUS	H	11	17	48	35	18	233	500	466

* On loan from CEA for about 2 years starting July or September 1972.

** On loan from CEA for about 2 years starting July or September 1972. Also has one damaged coil.

[†] Variable gap. Gap values given are nominal. Maximum field shown for nominal gap. With suitable spacers these gaps can be made larger but with a subsequent loss in maximum field value.

3 o'clock position. A similar mechanism designed to handle thicker wheel rims is planned for Target A-2.

Shielding

The Phase III construction contractor has completed the installation of in-place shielding in Area A-East and around Beam Stop A. Approximately 200 tons of Navy salvage steel was placed in the tuff shield fill between the radiobiology and therapy target and the proposed neutrino experiment. This is an economical use of this material and should save on shielding material within the Radiobiology and Therapy Facility.

The Phase II contractor has completed the placing of the shielding backfill around the switchyard, over the dome of Area C, and around the Line B and Line C beam stops. This tuff material is being covered with topsoil and will be landscaped.

Designs for the shield stacking for the temporary beam stops in the switchyard and for the switchyard entrance plug have been completed. Installation of the temporary beam stops has started. Their

locations are shown in Fig. 27.

Shielding plugs have been installed in both the horizontal and vertical penetration to the thin target area and in the utility trench between the switchyard and the basement of the Merrimac Area.

Shield walls and covers were fabricated and installed in the radiochemistry cell and the service cell in the Merrimac Area.

Design is continuing on the main shielding mass surrounding the meson targets and secondary lines in Area A. The initial layer of steel shielding made up of 12-in.-thick steel slabs has been designed. Slabs interacting with the process water mains are being placed.

The ORNL code, NMTC (Nucleon-Meson Transport Code), has been used to model various shielding configurations; however, it is limited to transport of protons and neutrons above 15 MeV. To get an estimate of the contributions of the lower energy components ($E_p = E_n < 15$ MeV), the LASL code, ANDY, is being implemented. Figure 28 shows preliminary

Fig. 27. Temporary beam stop locations in Line A and Line X.

Fig. 28. The calculated spectrum of backscattered neutrons from 400 MeV π^+ incident on an infinite concrete slab. The ANDY code, which was used below 15 MeV, has uneven energy groupings.

results calculated for a concrete pion beam-stop model. Five thousand π^+ at 400 MeV were impinged on an infinite slab of concrete. The energy spectrum displays the number of backscattered neutrons per MeV per incident pion vs neutron energy in MeV. Work continues in an effort to extend the neutron spectrum down to thermal energies and below.

The model of the shielding between the neutrino facility and the main proton beam stop calls for some 6.3 m of iron between the stop and the counters. The multigroup methods used by the code ANDY may prove to be inadequate for such a deep penetration study. Thus, it may be necessary to use codes such as MCN, a Neutron Monte Carlo Code, with its continuous-energy representation of the cross sections.

VII. LAMPF FACILITY CONSTRUCTION

Craft Equipment-Installation Activities

Zia/LACI crafts provided installation assistance at a rate of about 1000 manhours per month during this report period. The work performed included wire pulling and terminations in the transition and experimental areas; the setting of Service Aisle A magnet power supplies, beam switchyard magnet stands and 805-MHz ion pump stands; and installation of Merrimac cell door drive, 805-MHz cooling water connections and the H⁻ source cooling manifold.

The L. E. Meyer Co. is now 88% completed, compared with 85% scheduled, with the vacuum manifold connections to modules 24-48 and has completed 55% versus a scheduled 93% of the X01 through X08 cooling water extensions in Experimental Area A. During the period, this company finished the 805-MHz mechanical equipment installation package and was successful bidder, at \$56,400, on an addition package in the same area which is now 40% complete versus a scheduled 54%.

The Beaty Electric Co. has now completed their electrical equipment and rf reference line installation contracts; the Richard Peck Co. finished installation of the Merrimac Service Cell beam and covers.

Lot I of the High Resolution Spectrometer installation contract is on schedule at 90% completion; this package consists of fabrication and installation of the support frame. The award of Lot II, which covers magnet moving and mounting into the support frame, was made by LAAO on February 25 to Southwestern Industrial Contractors & Riggers, Inc. Work on this phase is scheduled to start in August 1972.

On March 23, a contract for \$80,890.50 was awarded to Boone Electric Company, Inc. for installation of government-furnished equipment into the Beam Switchyard. This work is now 50% finished compared with a scheduled 45%, and completion is scheduled for May 26, 1972.

Building Construction

The Experimental Area Phase II contract is now 97.9% complete versus a scheduled 98.9%; beneficial occupancy was taken during this period. Current work includes installation and checkout of devices

in Equipment Room B, the pouring of Experimental Area C floor and placement of top soil over the Area C dome.

The Experimental Area Phase III (Area A-East) contract has progressed to 92% completion versus a scheduled 100%. All backfill is now in place and the mechanical systems are complete except for checkout. Work continues on the electrical systems and on the box girder. It is now estimated that this contract will be completed in June 1972.

Architect-engineering was completed for the Site Work and Utilities Phase III; this package comprises completion of site erosion control, final extension of roads and miscellaneous paving. Bid opening for this work is scheduled for May 9, 1972.

VIII. NUCLEAR AND PARTICLE PHYSICS RESEARCH

Scattering of 20-50 MeV π^+ by Hydrogen and Deuterium

The design studies for this experiment have continued. Improvements have been made in the Monte Carlo simulation by including range tables for π and μ , non-Gaussian tails for multiple scattering, and correct differential cross sections for πp including the Coulomb-nuclear interference part. The target flasks are being constructed by Bendix, Kansas City, and tests have been conducted of a possible regulator system to use with the targets. The outline of the software for the on-line PDP 11/20 is being completed in cooperation with MP-1. Some details have been worked out concerning the structure of routines, parameter lists, control words, etc.

Pion Form Factor Experiment

A proposal to measure the electromagnetic form factor of the pion was recently submitted to the LAMPF Program Advisory Committee (Proposal No. 114). The differential cross section $d^2\sigma/dtdk^2$ for the reaction $\pi^- p \rightarrow n e^+ e^-$ will be measured at various values of s . By extrapolating the function

$\rho(t) = (t - m_\pi^2)^2 d\sigma/dt$ (at fixed values of s and k^2) to the pion pole at $t = m_\pi^2$, the value of $F_\pi(k^2)$, the pion electromagnetic form factor, will be obtained. Major efforts have been placed on writing a Monte Carlo code for generating events according to a theoretical model suggested by J. S. Ball, 1971. The effects of the pion form factor on various differential cross sections have been studied. The computer program has predicted effects as large as 25% for $F_\pi = (1 - k^2/0.50)^{-1}$ (corresponding to a pion rms radius of $\sim 0.7F$) as compared to $F_\pi = 1$. These effects are enhanced when the electron and positron are each emitted at laboratory angles of $\sim 70^\circ$ from the pion beam, and also when the electron, positron, and incident pion are approximately coplanar.

The problem is to design an experimental setup that incorporates these facts without severely restricting the counting rate. The counting rate predicted by the Monte Carlo program is quite close to that observed in the Russian experiment reported by Yu. Akimov, et al.¹

¹Yu. Akimov et al., Yad. Fiz. 13, 748 (1971) and Sov. J. of Nuc. Phys. 13 425 (1971).

Pion Absorption Experiment

Final analysis of the data continued with the help of Edward Arthur of the University of Virginia, who is on fellowship at LASL. The results should form the basis of his Ph.D. thesis.

The energy calibration of the NaI counter has been redone to include corrections for temperature and position on the crystal face. This was needed to reduce systematic errors which can broaden the energy resolution but more importantly can introduce asymmetries in the Trieman-Yang angular distributions.

M. Salomon, a collaborator from the University of British Columbia, has been studying the $(\pi^+, 2p)$ data from the liquid nitrogen target. He has proposed an explanation for the absence of low-lying states of the recoiling ^{12}C nucleus. This explanation is also consistent with results from experiments on α knockout and pickup in ^{16}O .

Precision Measurement of the Process $\pi^+ \rightarrow \pi^0 + e^+ \nu$ (Proposal No. 32)

Search for (π, p) Reactions with EPICS (Proposal No. 39)

High-Resolution Study of the Boson Mass Region 0 to 490 MeV using the HRS (Proposal No. 59)

Work has been done by LASL and by outside collaborators during the quarter on preparations for these experiments. A thin-walled, gas-ballasted liquid D_2 target for experiment no. 39 is being designed by K. Crowe at the Lawrence Berkeley Laboratory. Temple University collaborators on experiment no. 32 have acquired some lead glass for the γ detectors and are testing a prototype counter. A sample of the new LRS Model 2248 Multi-ADC has been acquired for test and evaluation. Its performance in reading out the pulses from the ^{90}Sr phototubes to be used in experiment 32 will be studied.

Low-Resolution Spectrometer

Preliminary designs have been made of a spectrometer, primarily for experiment no. 99 ($\pi^- p \rightarrow \pi^+ \pi^-$ near threshold) but hopefully for general utility. In an effort to minimize system length and maximize acceptance, consistent with moderate ($\sim 1\%$) resolution, a parametric study of several spectrometer systems, comparing $N = 1/2$, simple edge focusing, and split-pole designs is continuing.

Nucleon-Nucleon Interaction Experiments

A. Neutron-proton charge exchange scattering. Progress continues to be made on checking the analysis of this experiment. (A paper giving a subset of the results was published in Phys. Rev. Letters 23, 542 [1969].) A difficult background subtraction to account for the process $np \rightarrow d\pi^0$ has been solved. The remaining question concerns the absolute normalization of the data.

B. Neutron-proton forward elastic scattering. The data analysis of this experiment is proceeding on schedule at Princeton and Los Alamos. Cross sections are expected by May or June.

C. Neutron-nucleus total cross sections. Final documentation for this experiment has been completed and a paper has been submitted to the Physical Review for publication.

D. Neutron-nucleus bibliography. A complete compilation of high-energy neutron-nucleus total cross sections is being completed and will be published in report form.

E. Screening in Nd total cross sections. A study of the momentum dependence of the screening effect in Nd total cross sections was undertaken. The uncertainties in both experimental data and theoretical treatment were studied. The results were presented at the San Francisco meeting of the American Physical Society.

Neutral Decays of the ω Meson

A paper is being prepared to submit to The Physical Review describing the details of this experiment. (The results were published in Phys. Letters 36B, 607 [1971].)

Theoretical Physics

Theoretical studies of the interactions of pions and kaons with nuclei were continued.

The "local" potential for π -nucleus scattering has been applied to various cases. It assumes a somewhat different form for the off-shell π -nucleon scattering amplitude than that implied by the familiar Kisslinger model, and predicts recent 270 MeV $\pi^+ - {}^{16}\text{O}$ elastic scattering remarkably well. For $\pi^- - {}^{12}\text{C}$ in the 120-280 MeV resonance region, it gives too much large-angle scattering, perhaps because of effects from the large ground-state deformation. A brief paper has been submitted to Phys. Rev. C for publication.

Using both simple classical optics ideas and optical model codes, the substantial model dependence of total and integrated elastic π -nucleus cross sections has been exhibited. A paper emphasizing the need for such data from LAMPF was submitted to Phys. Rev. C for publication.

A final draft of a paper on the use of π^+ elastic scattering to determine neutron distributions is nearing completion.

Work on an improved optical model code, which will be useful in planning and analyzing LAMPF pion-scattering experiments, is being continued.

A recursive scheme for exactly evaluating multiple scattering series without small-angle (Glauber) approximations has been applied to recent CERN π -He data. It gives good predictions of the minima, which the Glauber model fails to do.

Energy level shifts and widths in K-mesic atoms have been related to a unique complex effective potential with an attractive real part. Earlier predictions of repulsion have been shown to be based on incorrect approximations. This work has been published in Phys. Rev. Letters 28, 1061 (April 17, 1971).

A paper on perturbation theory for optical potentials has been submitted to Phys. Rev. C for publication.

General Facilities for Preparation of Experiments

Chamber Construction

A wire-winding machine for fabrication of multi-wire proportional chambers has been tested successfully. The precision and uniformity of wire spacing is very good. The electronic error in wire spacing is negligible, and the measured 10- μ variation is exactly the machining accuracy in the lead screw threads. This winding accuracy will permit proportional chambers of excellent quality and pulse-height resolution. The electronics driving the machine was rebuilt and wiring was greatly simplified to improve the reliability of the system. More experience is required in the art of transferring the wires to the chamber planes. A prototype multi-wire chamber has been built using polyethylene gaskets. Another design is also being tried. Either will be satisfactory with respect to cost and ease of construction.

Readout and Coding Electronics for MWPC

The prototype decoder unit for processing signals from 200 proportional wires was completely checked out and documentation prepared for construction bids. The bids have been requested and received, and we are now in the process of evaluating the potential constructors. It is expected that 42 of these decoders, sufficient to handle 8400 wires, will be completed and tested by the end of the next quarter. By minor changes in the input delay circuit, the time resolution and speed of the decoder system has been substantially improved; a time resolution of better than 2 nsec, with a total conversion time for 200 wires of $< 10 \mu\text{sec}$, can now be measured. Background rejection is improved and data rate capability has been increased. It should be noted that these decoder units are compatible with both on- and off-chamber amplifier systems.

MWPC Amplifiers

The circuit design was exhaustively examined and firmed up this quarter; the physical parameters of the amplifier board were determined along with chamber frame development. Drafting work on the final amplifier card is under way, but the circuit itself is now in final form. These amplifiers will be suitable for mounting in confined spaces right on the chamber frames.

The hybrid circuit, which had appeared promising last quarter, was found by LASL's E Division to be 50% more expensive than originally expected, which almost eliminates it from immediate consideration. In addition, the first prototype which E Division made was found to have unacceptable levels of crosstalk between adjacent channels due to poor layout of input and output leads. A prototype of a new layout version is being built.

Computer Interfaces

The design and construction of a single chassis which will interface up to 40 MWPC decoder units to either the Supernova or the PDP-11 computer, is expected to be completed early next quarter. This unit, at a parts cost of about \$300, represents a substantial savings over a CAMAC interface, which is estimated at about \$400 not including connectors and driver units. The cost of having two separate interfaces was substantially cut by writing the I/O service codes for the PDP-11 and the Supernova to

combine the interface into a single unit. This unit has not been tested and the cables have not yet been built.

Helical MWPC Development

The development of the helical multiwire proportional chambers for use as EPICS detectors was continued with significant progress. Two proportional chambers using delay line readout techniques have been tested and give spatial resolutions of $< 0.33\text{-mm}$ fwhm for minimum ionizing particles. One chamber which uses a bifilar helical delay line is intended for use where high count rate capability is required. The second chamber which uses a single wire helical delay line, can be used where a simple and economical chamber is desired and high count rate capability is not of prime importance. Both chambers incorporate a new design. The delay lines are an integral part of the chamber. Each helix is wound around the chamber frames surrounding the anode wires to form a flattened helix and serves as both the cathodes and the delay lines for the positive-induced pulses.

The bifilar helix is a low impedance (300Ω), small attenuation length (120 nsec) delay line, consisting of two separate helical windings. The first helix was wound at 1-mm spacing and all turns were in electrical contact with a grounded copper bar placed along one edge of the chamber. A thin insulator was placed over the copper bar and a second helix was wound at 1-mm spacing midway between the turns of the first winding. Since the attenuation of the delay line is very large, the dead time of the chamber is shorter than the length of the delay line, and therefore counting rates $< 2 \text{ MHz}$ are possible. Signal taps have been placed every 2.5 cm in order to minimize any effects due to attenuation of the pulses. Extensive tests of the delay line scheme with a collimated ^{90}Sr beta source have shown that the linearity is $< 0.1 \text{ mm}$; the most probable cathode pulse height is $\sim 8 \text{ mV}$, and the coincidence resolving time is $\sim 30 \text{ nsec}$. The observed 0.33-mm spatial resolution includes contributions from multiple scattering and source width (0.25 mm). The actual resolution is expected to be much less than 0.33 mm .

The single wire helix is a high impedance ($2.7 \text{ k}\Omega$), large attenuation length ($\sim 2.5 \mu\text{sec}$)

delay line. It consists of a single helix wound around the chamber frame at a turn-to-turn spacing of 0.5 mm. Capacity-to-ground is supplied by insulated metallic strips laid across the turns. This chamber has not been tested as extensively as the bifilar helix but the tests performed so far have shown that the linearity is < 0.1 mm, the most probable pulse height is < 10 mV, and the count rate capability is $\sim 10^5$ particles/sec. In addition, no taps are used for this chamber, only two amplifiers, one at each end of the delay line. This drastically reduced the cost of readout. The spatial resolution is comparable to the bifilar helix.

Continual testing and development of both these chambers are planned in the future. Development and testing of the readout electronics are in progress, and the chamber design and electronics should be finalized this summer.

Other Facilities

Other preparations for experiments include ordering timing cables with new K-Loc connectors, ordering phototubes, and designing a phototube base-magnetic shield assembly. A box for testing phototubes has been built and a suitable light-emitting diode is being ordered. Two systems for gas mixing and flow control for multiwire chambers are under construction.

IX. PRACTICAL APPLICATIONS OF LAMPF

Biomedical Program: Application of π^- Mesons for Cancer Therapy (Work sponsored by Division of Biology and Medicine.)

Biomedical Pion Channel Design

Studies aimed at optimizing the performance of the biomedical channel are continuing. Two aspects of the problem have received particular attention.

The first is that of designing bending magnet pole edge curvatures such that geometric aberrations in the channel are minimized. Initial studies indicate that beam flux non-uniformities arising from the first-order optical characteristics of the channel and from multiple scattering in the wedge energy degrader at the dispersion plane are far more significant than the effects of second-order aberrations. Little is to be gained by correcting for these aberrations. In order to verify this conclusion, another attempt will be made to further improve the beam flux uniformity with pole edge curvatures using a somewhat different configuration and tuning of the beam-shaping quadrupole magnets at the end of the channel.

The second aspect of the optimization problem which was studied is that of choosing beam-shaping quadrupole lengths, interquad drift distances, and quadrupole tuning modes such that the beam transmission efficiency is maximized. Because the phase space of the beam in this channel is relatively large after the pions pass through the wedge energy degrader, it is especially difficult to contain the beam within quadrupoles of reasonable size. By making the beam slightly diverging at the end of the channel and by using short quadrupoles of bore radius 7 in. and pole length 11 in., it is possible to transport 80% to 90% of the beam which got beyond the last bend to the end of the channel. Making the poles even shorter would have increased the transmission efficiency, but the contribution to the integrated field by harmonics greater than a quadrupole harmonic would become unacceptably large.

Pion-Production Target for the Biomedical Pion Channel

Three target materials were considered: C, Mo and Al_2O_3 . The basis for evaluation were pion yield, e^-/π^- ratio, effect of the target on the incident

proton beam, ease of construction and lifetime.

The result was that carbon is as good as or better than either of the other two in most respects.

Earlier tests at the Electron Prototype Accelerator have shown that a cylinder of carbon, 1.0 cm to 1.5 cm in diameter, 5.0 cm long, and cooled by a jacket of water, has effectively an infinite lifetime in the LAMPF beam.

An Mo target has a shorter lifetime (several hundred hours) and must be a radiation-cooled wheel target. The target mechanism for the wheel targets are larger and would be much harder to fit into the available space than the relatively simple and compact water-cooled targets.

Al_2O_3 has such a low coefficient of heat conductivity that it is questionable whether a usable target can be made in either the water-cooled or the radiation-cooled configuration.

The e^-/π^- ratio is smallest for the C target over most of the pion energy range of interest. In the low-energy region around 50 to 70 MeV, the ratio is only slightly higher (~ 1 to 10% higher) than for Mo and Al_2O_3 .

Although the yield of pions per cm of target length is 50 to 300% higher for Mo than for C, considerably more C than Mo can be put into the proton beam before causing unacceptable degradation of proton beam with the final result being that a more copious flux of pions can be obtained with a C target than with Mo.

Neutron Shielding - Biomedical Target

Neutron shielding has been calculated by several approximate techniques. The one believed to be the most accurate treats the input neutron spectrum as a sum of bins of discrete energy. Each monoenergetic bin is assumed to generate a $1/E$ spectrum cut off at the input energy. The $1/E$ spectrum is input at the entrance to the shield and is normalized so that at an equilibrium distance into the shield the $1/E$ spectrum has attenuated to the same level as found from Monte Carlo calculations.

The steel shielding calculated for the biomedical target ranges in thickness from 6 to 10 ft depending on direction from the target and personnel tolerance levels. The biomedical targets create a potentially large background for the neutrino experimental area; the shielding in the direction of

that area will be a minimum of ~ 10 ft near the target. Secondary sources of scattered neutrons will also be important if the extremely low tolerances in the neutrino area are to be met.

The shielding criteria have been completed, and requirements have been transmitted to Group MP-8 for further design work.

Support Structure for Biomedical Pion Channel and Shielding

Engineering design of the steel structure for supporting the pion channel and the facility shielding is being done. This support structure is a major item in the stubout part of the Biomedical Facility. It must not only provide a rigid, stable foundation on which the beam channel magnets will be mounted and aligned, but it must also support the several hundred tons of steel and concrete shielding to be placed around the pion-production target.

Miscellaneous Items Associated with the Pion Channel

Engineering design of the combination beam stops and phase-space-defining slits for the channel is in progress. These slits will be of depleted uranium and will be moved by computer-controlled stepping motors.

Both the pion-production target and the proton beam-profile monitor must be removable through a common vertical overhead port. Study of the best way to do this is under way.

It will be necessary to monitor the pion-beam profile at the end of the channel. The use of strip ionization chambers is being considered. Initial calculations indicate that this technique will be feasible. With the beam fluxes anticipated, a 1-cm-wide strip in a 10-cm-wide beam will generate a voltage on the strip of $1.3 t$ volts where t is the sampling time in seconds.

Biomedical Channel Control System

Considerable attention has been given to obtaining the optimum computer configuration. The DEC PDP-11/45 system is expected to be delivered at the end of August 1972. A change order on the system is in process, which will obtain the DEC RSX-11B real-time executive software package. This will greatly ease the problems of implementing the required channel control programs while allowing treatment planning and patient record-keeping programs to run

on a time-shared basis. A high-speed paper-tape reader punch is being added to the system in order to support the RSX software package. The 250-k-word fixed-head disc originally ordered is being replaced with a 1.2-M-word moving-head disc pack in order to allow adequate safety margin for program storage space.

A Tektronic R4010 storage display terminal with keyboard has been ordered to provide graphic display. An electrostatic printer-plotter was evaluated for treatment-plan hard-copy output. Other schemes being considered for hard-copy output include a pen plotter, or a facsimile printer operated from the storage scan.

An order was placed for a Kinetic Systems CAMAC interfaced display with light pen for channel listing, menu selection and other alphanumeric applications.

Arrangements are being made with the electronics group at LBL to purchase from them a CAMAC tape drive interface for the two surplus IBM 729IV tape drives which we plan to utilize.

The control console and racks were ordered and were scheduled for shipment in mid-April from St. Louis. Arrangements have been made to set up the control console adjacent to the PDP-11/20 system which is being used to test the CAMAC microprogrammed branch driver. It is planned to interface the console to this computer for testing until the biomedical PDP-11/45 is delivered.

Much of the console and control interface equipment is on order, including the microprogrammed CAMAC branch driver, the CAMAC crate controllers, a variety of CAMAC modules, the console oscilloscope and the video monitors. The computer-interfaced button assemblies and the computer assignable knob and readout assemblies are being fabricated, although some problems on the knob interface remain.

Beam-Monitor Electrometers

Construction on a prototype integrating electrometer for the Biomedical Facility is under way. Preliminary tests indicate that this instrument will be stable at currents far lower than those expected from the biomed transmission ion chambers. Operation at 10^{-11} A is realistic with the current design and efforts will be made to push this lower limit to about 10^{-12} A. With the possibility of wider use

in mind, efforts will also be made to add some extra features such as range switching, etc., that are available on commercial units.

The pair of integrating electrometers used in the Biomedical Facility will be continuously monitored by circuitry designed to detect differences that develop in the two pulse-train outputs. Marked errors in either of the two independent-dose monitoring systems will remove the target when a preset level of "accumulated error" is reached.

Neutron Dose From π^- Stopping in Tissue

An important problem to be considered in pion radiotherapy is the dose to the healthy tissue outside the tumor region due to neutrons produced by the π^- stars. Neutron spectra resulting from π^- capture in various nuclei commonly found in tissue (C, N, O) have been calculated¹ using a Monte Carlo intranuclear cascade model. Using these spectra, assuming a point neutron source, the dose as a function of distance has been calculated for a "tissue-equivalent" material of spherical geometry consisting of C, N, O and H. The code used for this calculation is ANDY - a multigroup, neutron transport code developed at LASL. Since the highest energy group used in ANDY is 15 to 17 MeV, higher energy neutrons must be treated approximately. These high-energy neutrons have simply been included in the highest energy group, an approximation which seems justified by the relatively flat dose curve for neutrons with 10 to 100 MeV energy.² Preliminary results have been obtained and are being checked. Improvements to the code being considered include: 1) distributing the neutron source over a finite volume (e.g., a typical tumor volume); 2) use of more realistic, complex geometries; 3) inclusion of inhomogeneities, such as bone; and 4) possibly treating the higher-energy neutrons using the NMTC computer code.

¹M. P. Guthrie, R. G. Alsmiller, Jr., H. W. Bertini, "Calculation of the Capture of Negative Pions in Light Elements and Comparison with Experiments Pertaining to Cancer Radiotherapy," Oak Ridge report ORNL-TM-2371-R, (August 1, 1968).

²R. H. Thomas, "The Conversion of Particle Fluence to Dose Equivalent," Stanford University report SUHP69-3 (1969). (See Table A6.1.)

In Vivo Tissue Analysis with Mu-Mesic X-Rays

A visit was made to the Colorado Medical Center in order to consult with the staff about possible applications of mu-mesic x-ray tissue analysis. The main areas of interest were: 1) bone studies with respect to Ca metabolism abnormalities; 2) liver studies with respect to Fe metabolism abnormalities; and 3) general metabolism studies.

Radioisotope Production

Another series of experiments was performed at the Space Radiation Effects Laboratory (SREL) during February. These experiments included several monitor foil studies, testing the effect of secondaries on the aluminum monitor as well as comparing results using aluminum, polyethylene and graphite foils. Targets irradiated for cross section studies included Mg, S, Cl, K, Ti, V, Cr, Ni, Zn, Se, Mo, In, Lu, Hf, W and Bi, some of which have been studied in previous SREL experiments. Long exposures, using the internal beam, to build up the activity of long-lived isotopes were made on SiO_2 , Cr, Fe, Zn, As, Mo, Hf, W and Pb targets. In addition, a lengthy irradiation was made of lanthanum slugs to produce ^{127}Xe in order to test chemical procedures to be used in the production of ^{123}I at LAMPF. Three sets of Fe and Cu targets with monitors were irradiated in order to provide interlab comparisons of analysis techniques with Battelle Northwest Laboratory and Aerojet Nuclear Corporation, the object being to eliminate discrepancies among our data.

The cross section results obtained from the several experiments conducted at SREL during the past year have provided empirical input for isotope yield and cost studies that have been made for several isotopes at the request of AEC Headquarters. In March, E. E. Fowler and J. E. Machurek, Division of Applied Technology, visited LASL and toured LAMPF as well as the radiochemistry facilities. Our cost analysis for selected isotopes was reviewed and the funding of the isotope production program discussed. As a result of this meeting, a questionnaire is now being prepared, in collaboration with representatives of the Brookhaven Linac Isotope Producer (BLIP), in order to survey the potential markets for new isotopes as well as determine the priority for these products. It is planned that this questionnaire be distributed in cooperation with the

Society of Nuclear Medicine.

Meson Chemistry

Efforts continue to develop an understanding of the cascade process for a meson in an atom, together with the perturbations due to the physico-chemical environment of the atom. Rather than write our own atomic cascade code, attempts are being made to borrow an existing code which includes both Auger and radiative transitions. The inclusion of perturbations in such a code might also lead to a better understanding of intensity patterns that have been observed by nuclear researchers in mesic-atom experiments.

An atomic cascade code is also useful for calculating population distributions among atomic levels. This information, together with a "library" of empirical spectral lines taken with a Ge(Li) detector using isotopic sources, makes possible the synthesis of a muonic x-ray spectrum for almost any desired material. This problem is of mutual interest to those wishing to use muonic x-rays for *in vivo* tissue analysis. Results of these studies being made in collaboration with R. Hutson and A. Lundy should provide valuable information for planning experiments at LAMPF.

X. LAMPF USERS GROUP

Executive Committee and Technical Advisory Panel (TAP)

The Executive Committee held its first meeting of 1972 during the APS meetings in San Francisco, January 31-February 3, 1972. Newly elected Chairman Kenneth M. Crowe presided over the meeting at which the members heard a report from Lewis Agnew on what progress was being made to provide housing for users in Los Alamos. The treasurer's report showed a balance of \$833.00, most of which came from an AWU grant of \$500.00. Appointments to the TAP for 1972 and 1973 are as follows:

Robert E. Chrien (BNL), High Resolution Spectrometer

Sheldon Kaufman (ANL), Nuclear Chemistry

Peter Nemethy (Yale), Neutrino

James E. Simmons (LASL), Nucleon Physics Laboratory

Robert E. Welsh (College of William & Mary), Muon

C. S. Wu (Columbia), Experimental Facilities
In addition to the new members of the TAP, advisors to the TAP for 1972 were appointed to augment certain areas of expertise when TAP considers questions in these areas. The advisors for 1972 are as follows:

Max L. M. Boone, M. D. (Arizona Medical Center), Biomedical

Roy P. Haddock (UCLA), General Facilities

Frederick A. Kirsten (LBL), Electronics

David A. Lind (Univ. of Colorado), General Facilities

Robert D. Moseley, Jr., M. D. (Univ. of New Mexico School of Medicine) Biomedical

Harry Palevsky (BNL), General Facilities

Gerald C. Phillips (Rice University), General Facilities

Harold Butler (LASL), Computers

Bruce J. Dropesky (LASL), Nuclear Chemistry

H. A. Thiessen (LASL), Spectrometers.

The dates for the spring TAP meeting and next Executive Committee meeting were scheduled at Los Alamos on March 20-21, 1972. The Sixth LAMPF Users Meeting will be November 13-14, 1972. L. Agnew submitted the membership list, which was approved. A draft of the proposed Articles of Incorporation

and By-Laws for the Users Group was adopted after making a few changes. The articles and by-laws will be submitted to the membership along with a letter of explanation. At the close, a joint meeting was held with the members of the TAP, George Rogosa (AEC), and Darragh Nagle (LASL), to discuss the FY-73 budget.

The spring TAP meeting was held on March 20-21, 1972 in Los Alamos. At this time, the TAP heard reports from Louis Rosen on the impact of the FY-73 budget on LAMPF, Donald Hagerman on the status of the accelerator and the anticipated scheduling for the next nine to twelve months, Donald Cochran on cryogenic targets, and the status of the secondary beam lines from Lewis Agnew. In addition, the TAP heard and discussed the recommendations for the Equipment Pool presented by Robert Macek and Richard Mischke. The Equipment Pool Subcommittee submitted a policy statement for inclusion in a LAMPF Users Handbook, which was adopted with a few minor changes. The report of the Separated Isotopes Subcommittee was accepted with a minor change charging LAMPF with the task of record-keeping.

During the Executive Committee Meeting at the close of the TAP meeting, it was decided that users who have complaints and problems should bring them before the Executive Committee. A new Equipment Pool Subcommittee was appointed for the TAP: Robert Chrien (Chairman), Frederick Kirsten, Mark Jakobson, and Robert Welsh. Housing continues to be a concern, and a survey of the users will be made and this information will be presented to LASL and to local realtors. The formation of a new Radiation Damage Working Group received attention. The formation process will proceed and formal recognition will follow. George Igo assumed responsibility for arranging for speakers at the Sixth LAMPF Users Meeting. A Nominating Committee was appointed. Before adjournment, the next Executive Committee Meeting was scheduled for either July 24 or July 31, 1972.

Users Activities

The EPICS Working Group held a meeting in Los Alamos on April 17, 1972. Reports and discussions covered the topics of budget, time schedule for the channel and spectrometer, spectrometer performance, counters, and the particle separator for the channel.

Several areas where help is needed for this summer received attention and help is forthcoming.

The Biomedical Applications Working Group formed the new Subcommittee on Tumor Localization and Simulation. At its January 13-14 meeting the Subcommittee on Physical and Biological Dosimetry covered a large number of topics. The recommendations from this meeting are included in a report being prepared for circulation to the biomedical users. The Subcommittee on Isotopes and Diagnostics Applications, at a meeting on February 25-26, 1972, also made recommendations and began planning for the clinical tests of the isotopes.

Liaison Office

The Proceedings of the Fifth LAMPF Users Meeting have been mailed to the membership, followed closely by Vol. 4, No. 1 of the LAMPF Users Group Newsletter. The proposed Articles of Incorporation and By-Laws are in the final stages of preparation and are being checked for compatibility with AEC and LASL regulations. Work has begun on collecting material for a new LAMPF Users Handbook.

At the San Francisco APS meetings, a meeting was held at the suggestion of G. Victor Beard (AWU) concerning the establishment of an AWU-administered AEC Division of Physical Research fund to pay travel and short-term subsistence for users who can contribute to scheduled experiments at LAMPF. The prospects are good that the funds will be made available.

There is concern about the housing shortage in Los Alamos and its effect on users. Every possibility that appears to have some hope of alleviating the problem is being pursued.

Statistics

As of April 1, 1972, there were 797 members of the LAMPF Users Group, 630 non-LASL and 167 LASL. The following charts give additional statistics of the group.

I. FIELDS OF INTEREST

	<u>Oct. 1969</u>	<u>Oct. 1971</u>	<u>April 1972</u>
Nuclear and particle physics	251	348	484
Nuclear chemistry	46	98	106
Biomedical applications	66	215	248
Not specified (mostly physicists)	43	107	81
Other (including administration, facilities, operations, coordination, and miscellaneous applications)	?	45	90

(These numbers do not add to total membership because of duplication of interests.)

II. INSTITUTIONAL DISTRIBUTION

LASL	167
Other national or government laboratories	104
Universities	335
Industrial	26
Foreign	65
Hospitals and medical centers	<u>100</u>
Total	797

III. REGIONAL BREAKDOWN

East (PA, NJ, DE, DC, MA, NY, CT, VT, RI, NH, ME)	117
Midwest (OH, MO, KS, IN, WI, MI, IL, ND, SD, NB, IA, MN)	95
South (MD, VA, TN, AR, WV, KY, NC, SC, AL, MS, LA, GA, FL)	85
Southwest-Mountain (MT, ID, UT, WY, AZ, CO, NM, OK, TX)	178
Far West (AK, HI, NV, WA, OR, CA)	90
Foreign	65
LASL	<u>167</u>
Total	797

IV. AFFILIATION OF PARTICIPANTS IN LAMPF RESEARCH PROPOSALS

(The 115 proposals received as of April 4, 1972 are included.)

U. S. universities	180
LASL	74
Other national or government laboratories	36
Foreign	14

Research Proposals

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

- 114 "Determination of Electromagnetic Form Factors
Using the Reaction $\pi^- + p \rightarrow e^+ + e^- + n$ "

E. Knapp, Spokesman

J. Helland, E. Knapp, R. Martin, M.

Paciotti (LASL); J. Ball (Univ. of Utah)

- 115 "Radiochemical Study of Stopped Negative Muon-
Induced Fission"

Kurt Wolfsberg, Spokesman

G. P. Ford, A. E. Norris, K. Wolfsberg

(LASL)