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PROGRESS REPORT

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Quarterly Report on the
Medium-Energy Physics Program
for the Period Ending April 30, 1973

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

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

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Progress Report

UC-28

ISSUED: July 1973

**Quarterly Report on the
Medium-Energy Physics Program
for the Period Ending April 30, 1973**

Compiled by

Eleanor Dunn

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MASTER

QUARTERLY REPORT ON THE MEDIUM-ENERGY PHYSICS PROGRAM
FOR THE PERIOD ENDING APRIL 30, 1973

ABSTRACT

Work this quarter has continued on the development of the experimental areas and improving the reliability and reproducibility of accelerator operation. The accelerator was operated continuously for 12 days. The H^- injector was turned on for the first time on March 28, 1973. On April 6, we were successful in simultaneously accelerating H^+ and H^- ions to 100 MeV, with peak currents of 50 μA for H^- and 200 μA for H^+ .

I. SUMMARY

Engineering Support

Effort in support of the secondary beam lines and Area A installation activities has continued unabated this quarter, and allocation of engineering effort for several projects has been delayed until these lines are functional.

Routine maintenance of the rf systems in support of accelerator operation was continued. Some long-range development of maintenance techniques, record-keeping methods, writing of rf-systems manuals, and updating of electrical drawings was accomplished.

Engineering effort to build the biomedical facility is phasing into the procurement and installation stage, with less manpower required for design.

Retrofitting of the magnet power supplies by replacement of the regulators is nearing completion. The new regulator is functioning quite satisfactorily.

Support of users has consisted primarily in the building of light pipes, scintillation counters, and placement of the order for a pion decay vacuum chamber.

Accelerator Systems Development

Successful operation of the H^- injector was achieved for the first time on March 28 and H^- beams have been provided for linac tests during April. Simultaneous acceleration of both H^+ and H^- beams up to 212 MeV has been obtained with no evidence of

deleterious interaction between the beams. The H^- injector has been operated at 3% duty factor at 500- μA peak current for over an hour. Work is continuing to optimize performance of this injector.

The design calculations for the new accelerating column for the H^+ injector are almost complete and engineering drawings are being prepared to fabricate a new set of accelerating column electrodes. This new design employs more electrodes, larger beam apertures, and other changes in electrode configuration which will reduce the voltage between electrodes and increase the conductance of the column. A new column will be assembled, using this design, and installed later this year.

Work was resumed in studying alternative modes of operating the high-intensity beam-transport system in order to provide suitable beams for a beam chopper to be installed on this beam line and to improve the quality of beam delivered to the linac.

Measurements at 100 MeV with 17- μA peak beam current showed the emittance of 99.9% of the beam to be $0.625 \pm \pi$ cm-mr.

The Δt system was brought to its design accuracy and can now be used to verify the 201-MHz phase scan results and provide an absolute starting point at 211 MeV for the switchyard spectrometer. The switchyard spectrometer was used to tune the beam to 500 MeV.

Work continued on development of instrumentation, applications programs, measurement of the computer control system performance, and data bases

for operations and maintenance management. An intensive review of accelerator alignment was initiated.

Electronic Instrumentation and Computer Systems

A beam-diagnostic system for HARPS, based on a satellite PDP-11/20 computer, was assembled and tested successfully. The system, which involved two computers, CAMAC hardware, data links, and supporting software, was put into operation in less than four months from inception.

The H^- injector was operated through the controls in the Injector Control Room, marking the completion of the main elements of this control system.

Practically all of the control wiring for beam lines LB, LC, and EP was scheduled, installed, and terminated. Substantial progress was made in the first phases of the controls checkout for Line B. The regulators on the power supplies in the switchyard were replaced with more stable units. The eight racks which house the controls for the equipment in Area A were wired and installed. Wire schedules for the devices along the primary and secondary beam lines were prepared.

The effort to improve the operating characteristics and software reliability of the control computer continued to show positive results.

The beam-spill radiation-detection system was separated into two systems, one for controlling activation, the other for tuning the accelerator. Progress was made in bringing both these systems into full operation.

A special TV system was assembled to aid in the development of stripper foils.

The sixth computer for the data-acquisition system, a PDP-11/45, was received and installed.

Accelerator Operations

Accelerator operations spanned 138 eight-hour shifts during the period. The beam was on or available 78% of that time, a substantial improvement over the 70% availability reported during the previous quarter.

Several old problems were brought nearer to solutions and a number of significant advances and firsts were recorded.

The first H^- beam was injected into the linac. The first simultaneous H^+ and H^- emittance measurements were made. Beams of H^+ and H^- were

accelerated simultaneously to 212 MeV. For the first time, H^+ beams were transported through the Transition Region Side Track and Side Track emittance measurements were made.

The Δp spectrometry technique for setting cavity phases and amplitudes was employed in increasing beam energies from 212 to 500 MeV. The associated beam-diagnostic gear and control software were improved during the period.

Some progress was made in increasing beam intensities, attaining 59- μA average current at 212 MeV and 5.2- μA average current at 497 MeV.

Eight target-foil irradiations were completed successfully for LASL Group CNC-11; five at 100 MeV in the North Port diagnostic area, one at 302 MeV in Line A, and two at 497 MeV in Line X.

Experimental Area

Due to the tightness of the current operating budget, the level of effort on the Experimental Area was reduced and procurement of some of the hardware was deferred. Revised schedules call for delivery of tune-up beam to Line B shortly after July 9 and delivery of tune-up beam to Line A shortly after July 30. A temporary beam stop will be installed at Target A-3 until Area A-East is ready for beam.

The temporary beam stops that were installed in the switchyard last summer have now been removed in preparation for delivery of beam to the experimental areas. A new beam stop, which can accept beam from Line X when the polarity of one of the magnets is reversed, has been constructed. Preparations have been made for installation of the final quadrupoles and a number of steering magnets needed for fine control of Lines A, B, and C. Wire scanners, harps, and other switchyard instrumentation have been modified and upgraded.

The installation of the beam-line components of Line B is well along. All magnets have been installed, roughly aligned, and plumbed. All power supplies are in place. Good progress has been made with the control systems and cable installation. The shielding near the neutron-production target is partially complete. Beam diagnostics will consist of toroid current monitors, wire scanners, and harps. These devices are under construction and the computer control requirements have been established.

One of the large high resolution proton spectrometer (HRS) magnets has been given its first

operational tests and full field-mapping is starting. The other large spectrometer magnet is being assembled in Area C. The components of the two 57% bending magnets for Line C have been finished and these magnets are being assembled by the vendor. The HRS project has also recorded progress on beam scanners and steering magnets for Line-C diagnostics, machining of the HRS field clamps and nosepieces, and computer controls. The stripper mechanisms to be used in beam-sharing operation with Line B and for Line-C diagnostics have been built and tested. Planning and design effort have been devoted to the time-of-flight detector system, beam-current integrators, taut-wire system, collimators, and shielding.

The support stands and mounting hardware for the low-energy pion channel (LEP) have been installed and aligned. All the quadrupoles and the first two bending magnets have been measured. Final installation can proceed without further alignment. The channel components, controls, and power supplies are all either on hand or nearing completion.

Most of the magnets for the energetic pion channel and spectrometer (EPICS) have now been delivered. Assembly of the separator is under way. The channel support system has been erected. Assembly and testing of slits, collimators, and the beam plug is under way. Initial tests of the magnet field-measuring apparatus and its computer control have been successfully carried out. The computer interface for the bifilar helical chamber was debugged.

All stands and magnets needed for tune-up of the high-energy pion (P^3) channel were installed and aligned. Channel shielding and vacuum plumbing are proceeding. Cooling coils are being added to the yoke pieces of the first quadrupole to prevent overheating due to the charged particle flux generated at the nearby production target.

Essentially all stands for the stopped muon channel (SMC) have been delivered and 11 of the magnets have been installed. Basic alignment procedures have been carried out. All magnets have been tested. Some of the beam-line components have been deferred until next fiscal year. The ac and dc installation is in the final planning stages.

Plans for Line-A diagnostics and tune-up continue. Harps and toroids will be used through CAMAC interfaces to a PDP-11/10 which will be

linked to the main SEL-840 control computer. Refined transport calculations on the Line-A magnets reveal that known aberrations and misalignments are not bothersome. Steering magnets will be employed for fine control. Criteria have been set for collimators to be placed downstream from the production targets. Six of the target-cell triplets have now been completed; more than enough for initial operation of Line A.

The target design for the biomed beam has been finalized and fabrication of the first unit has started. A three-target assembly, one of which is very thin, will be employed. Development work on high-density pyrolytic graphite as a target material continues. Design has started on an Al_2O_3 wheel target for possible use as Target A-1.

Repairs have been made on the motors for fans of the cooling-water pumping systems. Valve-cavities manifolds at Targets A-1 and A-2 are complete, and distribution systems to the secondary lines are being installed. The process water system in Area B is nearly complete. A contract has been let to install the water-cooling for the Area A power supplies.

The calibration of magnet-measurement apparatus has been carefully studied. As a result, the various quadrupole measuring coils agree to $\pm 0.3\%$ and absolute values of $\int B \cdot dl$ to $\pm 0.05\%$ can be achieved for bending magnets.

The mechanical components and the computer controls for the H^- strippers have been perfected, and studies are continuing on the graphite foils. Failures due to thermal stress were observed in some tests; this problem has apparently been solved by a redesigned foil clamp. The foils are expected to function satisfactorily at 800 MeV.

The full mechanism for remote drive and installation of Target A-1 is on hand except for the vacuum enclosure which is due by June 1. Delays in the Target A-2 mechanism are being encountered, but will not hold up beam in Line A. A temporary foil in target will be used at A-2 until the final unit is ready.

Bulk steel shielding for Target Cell A-2 has been completed to the 9-ft level, as planned for 1- μA operation. Stacking at A-1 has started. A new wall has been stacked in Tunnel B and the shield needed at the neutron production and nuclear

chemistry stations in Area B is being stacked. The stacking crews work a two-shifts-per-day schedule. About 5200 tons of shielding were installed during the quarter. Additional steel has been ordered and about 2000 tons of concrete are being obtained from the disposition of the Carnegie-Mellon University cyclotron.

Research

Preparations continued for the tuning of the low-energy pion channel. Tuning will be done with a multiwire proportional counter (MWPC) system on-line to a PDP-11/45 computer.

An MP-designed MWPC amplifier has been adopted for the first group of experiments. Components for the first 2000 channels are on hand; 1000 channels are being constructed by a local electronics shop. The development of a commercial hybrid-chip amplifier is in abeyance because of the vendor's refusal to make delivery commitments.

The MWPC shop and the scintillator shop have produced a number of counters for various experiments and for beam tune-up and monitoring.

Substantial progress was made in obtaining consistent calibrations for the coils used in the magnet-field-measuring program. The new calibrations have been applied to beam switchyard magnets and to experimental area magnets.

Hardware and software development was continued in preparation for the first round of experiments.

Practical Applications of LAMPF

[Summarizes work being performed under auspices of USAEC Division of Physical Research, USAEC Division of Biomedical and Environmental Research, National Cancer Institute, and USAEC Division of Military Application.]

During this last quarter, work has continued on the construction of the biomedical facility. The schedule seems to be paced by the installation of the beam line to the final beam stop, and no problem is foreseen in having the biomedical beam line complete prior to the completion of the main beam line to the final stop. Mechanical assembly of the channel components is progressing with no problems being encountered, which would have delayed the channel construction appreciably. Work on the tuning procedures has continued. During this

quarter, the control computer for the biomedical facility was moved to the stubout and into its final location. It is now operating satisfactorily in this location. Several peripherals for this system are soon to be ordered, essentially completing the hardware acquisition for this system. Additional shielding calculations have been made for the facility after it was discovered that even a minimal beam spill in the region just upstream or downstream of the target cell might cause excessive background radiation in the treatment room with the target retracted. A steel liner on the walls of the treatment room has been considered, and can be installed if necessary, after testing of the system and experimental determination of the background levels in the treatment room. Work has continued on the fast-acting range shifter for varying stopping depth of the pions, and a hydraulic system has been chosen.

Because the primary beam line appears to be coming on somewhat later than anticipated, a proposal is being prepared for preliminary biomedical experiments to be undertaken on the low-energy pion line which are to run in a position behind a primary experiment. Thus, a start can be made on some of the preliminary work necessary to characterize the beam, and get some base points on the cell-survival curves with specific cell cultures.

Work has continued on the localized rf heating of tumors in collaboration with the University of New Mexico School of Medicine. Calculations are continuing on the capture of negative mesons in matter.

Research to be Mounted at LAMPF

The date of the next meeting of the Program Advisory Committee has been set for September 19-21, 1973. All proposals received up to July 31, 1973 will be considered at that meeting. To date, a total of 90 proposals have been approved for beam time, with 9 proposals recommended for resubmission.

LAMPF Users Group

A meeting of the Board of Directors was held at LAMPF on February 25-26. The housing situation at Los Alamos was explored in detail. A presentation of LAMPF users' needs was made to the University of California Board of Regents at their meeting at LASL on April 12 by Chairman of the LAMPF Users Group, Mark Jakobson and Louis Rosen, Director of LAMPF.

Membership of the Technical Advisory Panel (TAP) to the LAMPF Users Group for 1973-74 is as follows:

T. H. Blewitt, ANL
R. E. Chrien, BNL
R. A. Eisenstein, Carnegie-Mellon University
E. E. Gross, GRNL
D. C. Hagerman, LASL
W. R. Hendee, University of Colorado Medical Center
S. Kaufman, ANL
W. K. McFarlane, Temple University
P. Nemethy, Yale University
J. E. Simmons, LASL
R. E. Welsh, College of William and Mary
C. S. Wu, Columbia University
M. M. Kligerman, M. D., University of New Mexico School of Medicine and M. L. M. Boone, M. D., University of Arizona Medical Center, have been appointed as advisors to the TAP in the field of biomedical applications of LAMPF.

A subcommittee consisting of M. J. Jakobson, D. E. Nagle, and S. E. Sobottka, was appointed to study the function of the TAP and to explore its role and new functions brought about by the actual operation of LAMPF.

The Nominating Committee for 1973 was selected and consists of the following:

H. Palevsky, BNL, Chairman
H. Feshback, MIT
M. M. Kligerman, M. D., University of New Mexico School of Medicine
D. E. Nagle, LASL
A. L. Turkevich, University of Chicago

Meetings of the EPICS and HRS Working Groups were held at LASL on April 3, 1973, and at Washington on April 22, 1973. A meeting of the EPICS/HRS Working Groups has been scheduled for July 30-August 2, 1973, to be held at Los Alamos.

Publications

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J. S. O'Connell, "Neutrino Disintegration of the Deuteron at LAMPF Energies," Los Alamos Scientific Laboratory report LA-5175-MS (March 1973).

D. M. Lee, S. E. Sobottka, and H. A. Thiessen, "Proportional Chambers with Monofilar Helical Cathodes for High Spatial Resolution," Los Alamos Scientific Laboratory report LA-5195-MS (March 1973).

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R. E. Mischke, "LAMPF Electronics and Equipment Pool," Los Alamos Scientific Laboratory report LA-5190-C, 27-30 (1973).

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L. Rosen, "Some Medical Applications of Accelerators," IEEE Trans. on Nucl. Sci. NS-20, No. 1, 10-23 (1973). Presented at Nucl. Sci. Symposium and Nucl. Power Symposium, Miami, FL, December 6-8, 1972.

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L. Bidwell, D. Machen, J. Potter, R. Rajala, and R. Thomas, "A Long Distance CAMAC Branch Via Data-Link and Microprogrammed Branch Driver," *ibid*, 675-679.

N. Tanaka, LASL, M. M. Castro, R. H. Milburn, W. B. Richards, et al., Tufts University, "Recoil-Proton Polarization in Neutral-Pion Photoproduction between 900-1800 MeV," Phys. Rev. D, 1.

L. Rosen, "The Clinton P. Anderson Meson Physics Facility (LAMPF)," Proc. Nat. Acad. Sci. USA, 70 No. 2, 603-610 (1973).

K. Halbach, "Some Eddy Current Effects in Solid Core Magnets," Nucl. Instr. and Methods, 107, 529-540 (1973).

G. J. Igo, N. Tanaka, and H. A. Thiessen, "High Resolution Proton Spectrometer (HRS) at LAMPF," Proc. of the 4th Intern. Conf. on High Energy Phys. and Nucl. Struc., Dubna, USSR, 624-31 (1971).

Papers Prepared for Publication; Papers Submitted at Conferences

A. S. Goldhaber and M. M. Nieto, "The Mass of the Graviton," submitted for publication in Phys. Rev. D.

B. L. Hartway, J. Bergstein, and C. M. Plopper, "The Central Control Room Man-Machine Interface at the Clinton P. Anderson Meson Physics Facility (LAMPF)," to be published in the Proc. of the 1973 Part. Accel. Conf. on Accel. Eng. and Tech., San Francisco, CA, March 1973.

D. C. Hagerman, "Operating Results on the 800-MeV Proton Linac at the Los Alamos Scientific Laboratory," presented at the 1973 Part. Accel. Conf., San Francisco, CA, March 1973.

D. R. Machen, "Digital Filter Design for Accelerator Data and Control Systems," prepared for publication in the Proc. of the 1973 IEEE Part. Accel. Conf., San Francisco, CA, March 5-7, 1973.

B. L. Hartway, "Compact Programmable Control Panel for Computer Control Systems," prepared for presentation at and publication in the Proc. of the 1973 IEEE Part. Accel. Conf., San Francisco, CA, March 5-7, 1973.

B. L. Hartway, J. Bergstein, and C. M. Plopper, "The Man-Machine Interface at the Clinton P. Anderson Meson Physics Facility (LAMPF)," prepared for publication in the Proc. of the 1973 IEEE Part. Accel. Conf., San Francisco, CA, March 5-7, 1973.

R. A. Gore and D. R. Machen, "Minicomputer Applications at LAMPF," prepared for presentation at and publication in the Proc. of the 1973 IEEE Regional Conference on Minicomputers, Honolulu, Hawaii, May 2-4, 1973.

II. ENGINEERING SUPPORT

LAMPF Accelerator

Accelerator Structures

New designed rf drive loops have been installed in Tanks 2, 3, and 4; a similar loop replacement is planned for Tank 1. Rexolite windows, $1\frac{1}{2}$ -in. thick, are being fabricated for Tanks 2, 3, and 4. This new design has a convoluted cross-section and is expected to reduce the probability of window-arcing.

Sensing heads for the residual gas analyzer have been received and will be permanently mounted in the spare tuning slug ports of the four 201-MHz tanks.

A continual surveillance of the vacuum in those modules having a higher than normal pressure has been maintained. Several small leaks were found and, in most cases, the escalating pressure of these modules indicates that the ion pumps will soon need reconditioning.

Ten standard 3-in. linear actuators were assembled using the small HS25 stepping motor. Thirty additional actuators, having the larger M063 motors, will be ready for final assembly and testing as soon as the dropping resistors are mounted.

Alignment checks of the 805-MHz quadrupole doublet magnets from module 20 through module 34 and module 9 through module 48 were completed; approximately 42 of the 805-MHz modules were checked for levelness. Data points obtained from these checks are being programmed for computer analysis.

RF Power Systems

Considerable effort was expended this past quarter to improve the efficiency of rf maintenance methods. Maintenance facilities were completed, procedures were defined and computerized record-keeping techniques expanded, resulting in an overall improvement of 201-MHz system reliability. Emphasis is being placed on the upgrading of tank resonance controllers and a computer model was developed for these devices so that a study of control philosophy could be made. Techniques learned from this study were used to control resonance of Tank 3, with good results. New resonance controllers utilizing these features will be installed as soon as they are available.

201 RF System

Each of the four stands logged 1000 h of high-voltage time during this report period.

A 4664 tube failed in service at 1200 h of high-voltage time due to an attempted turn-on at 9% duty factor; a loss of emission resulted because of cathode damage. The filament current was increased and the tube operated satisfactorily for another 250 h before a control grid-to-screen grid short developed, thereby completely disabling the tube. The spare 4664 tube was found to be defective upon installation; a 2771 tube was used, which had to be operated at low duty, until a new 4664 tube was received from RCA. This new tube has been received and is functioning satisfactorily.

Two IPA modulator filament transformers were purchased for evaluation. The first transformer failed after 1500 h of operation and was returned to the vendor for examination. The second transformer is now in use.

The new 4616 tubes have had a relatively high rate of turn-on failure, which prompted the testing of five spares that were on hand. Four of the tubes operated satisfactorily, but the fifth displayed a grid-cathode short when the filament was hot.

A total of 4300 h of high-voltage operation time was logged on an RCA 7835 tube in module 3 before failure, which is the first in-service failure with this type of tube. The mode of failure was the tube's inability to hold off high voltage, believed to be caused by the plate breaking down to the grid-support structure. This tube is being returned to RCA for evaluation and rebuild.

Work has continued on the development of an experimental 201-MHz klystron. An experimental output cavity is being constructed in order that loop and window geometry and output impedance-matching studies may be made.

805-MHz RF Systems

The 25 Litton L-5120s have passed acceptance tests and 10 of them have seen service on the accelerator.

The VA-862A klystrons have accumulated more than 152,000 filament hours, with four failures. The LPT-44 modulator triodes have operated for 164,000 filament hours, with two failures.

A VA-862A klystron (SN-203) was rebuilt this past quarter and passed acceptance tests at 6% duty factor. The tube was operated at high voltage for 221 h and then installed in Sector C of the accelerator. After 75 h of high-voltage operation, the modulator failed due to breakage of an internal connection which caused the klystron to run CW at low-beam current and full-beam voltage. The resultant dc beam melted the input coupling loop and the drift tubes. An attempt to again rebuild this klystron is under way.

A program is under way to provide a graphical output of rf maintenance which will display curves of faults, costs, accelerator downtime, and man-hours required for repairing a given unit.

The first draft of the 805-MHz rf systems description manual was written and the master source description manual was completed. Several procedures were written to assist the operations crew in performing first-echelon maintenance.

Magnet Power Supplies

Now that the acceleration of H^- particles is a reality, all of the transition region (201-MHz to 805-MHz) side-track magnets were connected in series and driven with one power supply at 2700 A and 54 V. Original plans were to utilize two power supplies in series to power these magnets. The single power supply scheme functions much better for several reasons, one of which is the near optimal conduction angle that the power supply presents to the 480-V, 3- ϕ house power at the operating load.

Thirty-one of the 38 new power supply regulators have been installed on the supplies required for the magnets in the switchyard and Lines B, EPB, and C. The problem of limited range of operation encountered with the original regulators, as previously reported, has been eliminated with the new design.

The 56 Acme power supplies have been modified to accept the new regulator.

Six of the 28 Ling power supplies were received and one is presently powering its magnet satisfactorily.

Experimental Area

A file has been established for all LAMPF experimental area magnets. This file contains pertinent magnet information and is available to all

LAMPF and user personnel.

The design of a modular deionized cooling-water system is under way. Each of these systems has an output of 300 gpm at 300 psi with a capacity of ~ 1 MW. The intended use of these systems is to cool magnets that are not subjected to high levels of radiation.

Cold traps, mechanical refrigerators, vacuum gauges, and ion-pump gauges have been ordered for Lines A, B, C, and the secondary beam lines. All of the pneumatically operated vacuum isolation valves for the secondary beam lines now under construction have been ordered.

Because of the diminishing space available, the magnet tooling dock activities will move to the Equipment Testing Laboratory as soon as the alignment-fixturing work on the two magnets presently in the dock is completed.

Switchyard

Three beam-diagnostic harps were installed in the switchyard as replacements for the ISICS Systems. The harps were tested and read via a new minicomputer system which successfully displayed information on the SEL-840. This new system will read a 40-wire harp in 4 msec.

Six harp boards were fabricated by the winding technique rather than the individual wire placement method, producing a more uniform wire spacing. A uniplane harp was successfully fabricated using 0.002-in. carbon monofilament rather than the 0.0008-in. gold-plated tungsten wire. Both types of wire yield the same signal but the carbon wire should last much longer due to the reduced energy absorption and improved thermal emissivity.

A vacuum-manifold and valve system has been designed and built for Group CNC-11's thin target to be located at the entrance of Area A.

Due to the outgas characteristics of the target cell A-1 and its collimator, additional pumping will be required between the switchyard and cell A-1 if the pressure in Lines B and C are to be maintained at 10^{-7} torr. A turbomolecular pump having a capacity of ~ 350 liter/sec has been ordered and will be located near cell A-1 along with conductance-limiting devices.

Realignment of LX-BM-03 and its associated beam stop was completed.

Line A

Two 4-way matrix-switched multiplexers have been ordered for the Line A beam-diagnostic harps. The Line A current monitors have been redesigned in such a way as to eliminate the long lead time required for procurement and the expensive ceramic insulators.

A rail system for the installation and removal of the 12-in. Line A vacuum tubulation has been designed and is being fabricated. Vacuum joints in this line will be of the single-convolution bellows type, and will be welded at assembly, similar to the types employed on the 805-MHz vacuum manifolds. Bellows made from 0.032-in.-thick material have successfully withstood an axial load of 525 lb.

Tests of materials for the thin-vacuum target-cell windows have continued. Havar appears to be the only material that will meet our requirements. Brazing tests are under way to determine window-assembly fabrication techniques.

Line B

All magnets and major associated hardware have been installed and rough-aligned. Fabrication and installation of master monument-alignment stations has started for the external proton beam (45°). These monuments, which are located both inside and outside of the building, will provide reference points external to Line A.

Vacuum beam pipe has been fabricated and is being installed. The pneumatic actuator for the four-inch, fast-acting valve has been machined and is ready for testing and adjusting.

The magnet support structure for BM-06 and -07 was installed and check-out is ~ 75% complete.

A new four-inch-aperture current monitor and preamplifier system was designed, fabricated, and tested. This design is at least ten times less sensitive to mechanical vibration and stray magnet fields when compared to the older design.

Line C

Magnet stands for the 57° bending magnets have been received. Base support structures for the twister magnets and installation of three bending magnets and one quadrupole magnet was completed. Measurements and fixturing work was performed on the high-resolution proton spectrometer (HRS) magnet-measuring cart.

Installation drawings for the beam stop are complete and materials for fabrication are on order.

The prototype scintillator actuator has passed all tests; beam boxes for these actuators have been designed and detailed. Design of proton degraders is complete and design drawings are being made.

Tests of one of the three 2400-liters/sec ion pumps are still in progress. Pumping speed for N_2 has been confirmed at 2400 liters/sec. Helium pumping tests are in progress.

Line D (Weapons Neutron Research Facility)

Initial beam-line layouts for this line were started in order that monuments in the switchyard area may be located.

Parameters for the 16 bending magnets were released early in this quarter and the engineering design is now complete. Copper conductor material and steel core material are on order. Drawings have been sent to coil builders and machine shops for fabrication quotations.

Engineering design of the other magnets and components for this line will continue as firm parameters are released.

Low-Energy Pion (LEP)

Final installation and alignment of the four LEP bending magnets is complete. Magnets BM-02 and -03 have been fixtured in the tooling dock on their alignment base (Fig. 1). Assembly and fixturing of the last quadrupole doublet is being performed in the tooling dock.

Pion and Particle Physics (P^3) Channel and Stopped Muon Channel (SMC)

Final alignment of the first three bending magnets in both of these lines is complete. Beam plugs and proton absorbers along with their vacuum chambers are in the process of being fabricated.

Energetic Pion Channel and Spectrometer (EPICS)

Slits 01 and 02 have been received and are being assembled; delivery of slits 03 and 04 is expected in May.

Design of the turbomolecular pumping package, consisting of two pumps, was completed and assembly is in process.

Biomedical Beam Line

Fabrication and erection of the Biomedical Beam Line support structure is complete. Figures 2-4 show some of the steps taken of the erection process.

Fig. 1. Tooling-dock fixturing of LEP bending magnet (BM-02).

Fig. 3. Installation of biomedical beam line support structure.

Fig. 2. Installation of biomedical beam line support structure.

Alignment mounts for RT-QM-01, -02, -03, RT-BM-01, -02, and RT-BM-03 magnets are complete and on hand. Design of the alignment mounts for RT-QM-04 through -08 is ~ 80% complete.

An order has been placed for a portable weather cover which will be used over the line stubout.

Fabrication of parts for the neutron pipe and top plates for the notch shield is complete and an order for installation is being processed. Installation of the bulk steel shielding in the stubout notch was completed.

The basic core assemblies for quadrupole triplet magnets (RT-QM-01, -02, -03) were received and accepted; preparation of the mineral-insulated conductor is now in progress. The core and coils for the rad-hard bending magnets (RT-BM-01 and -02) are on site and the assembly of the manifolds and electrical hardware is nearing completion. The core for the third bending magnet (RT-BM-03) is on hand.

The first shipment of magnet conductor from the supplier to the coil vendor for the last five

III. ACCELERATOR SYSTEMS DEVELOPMENT

Accelerator Beam Performance

Injector Beams

The major accomplishment of the quarter was the commissioning of the H^- injector system and the successful first simultaneous acceleration of positive and negative hydrogen ions ever achieved.

The H^- injector was turned on four days ahead of schedule on March 28, and 52 μA of 750-keV H^- beam was successfully obtained. Beam tests have continued during April and the intermediate-design H^- ion source has met or exceeded almost all its design goals. This source has been operated at 3% duty factor at 500- μA peak current for over an hour. The operation of the injector has been relatively trouble free although a number of details remain to be completed. Work is continuing in optimizing the performance of the ion source.

On April 6, 1973, the first simultaneous acceleration was obtained to 100 MeV. Acceleration to 211 MeV has now been achieved at low average intensity. Nominal H^- accelerated currents of 150- to 200- μA peak have been accelerated with H^+ currents up to 10-mA peak, with no evidence of any deleterious interaction between the beams. Investigation of the required tuning strategies and settings for simultaneous beams has begun. The MESA program was used to study the sensitivity of the H^+ beam to transport magnet settings which have been commonly used. Further work will be done on the individual and simultaneous beams as optimum settings are worked out. Additional scrapers are also being considered.

A new H^+ beam configuration involving a size constraint in one plane at the location of a slow-wave deflecting structure has been studied as part of the requirements for the proposed Weapons Neutron Research (WNR) facility. These initial studies, both with the TRACE program and experimentally, show feasibility, and the next step involves further sensitivity analysis using the MESA program.

An experimental ion source with a smaller aperture was installed on the H^+ injector and smaller-diameter, smaller-current beams were provided for several weeks of operation this quarter. With the transport system operated in the same manner as with the larger-diameter beams, the beams then obtained

Fig. 4. Installation of biomedical beam line support structure.

quadrupole magnets (RT-QM-03 through -08) was damaged in transit and replacements are being fabricated.

Shielding layout drawings to define cutting and stacking activities are being made. Approximately 50% of the 2000 tons of shielding steel required is on order.

at the linac entrance had the same phase-space orientation as the large-diameter beams, but with smaller emittance. Thus, the experimental ion source may be interchanged with the regular ion source without having to change the beam transport conditions.

Additional detail is included in the section on injector programs below.

201.25-MHz Linac Beams

Module-to-Module Field Adjustment. The energy of the beam at the exit of Tank 4 can now be accurately checked (to ± 0.01 MeV) using the Δt measurement, thus allowing the calibration of the absorber-collector rf phase scan. The phase-scan program has been modified to take advantage of the new circuitry that was installed to control the absorbers and collectors. In particular, it now:

- 1) provides computer control of the insertion and retraction of the absorber and collector plates of the ends of Tanks 2, 3, and 4;
- 2) takes simultaneous absorber and collector data;
- 3) outputs the design values as well as the present values of the full width at half maximum and displacement center from left edge; and
- 4) analyzes the present results, recommends new settings for the amplitude set point and phase-shifter quantity.

With these changes, the 201-MHz phase scans can be run completely from CCR. On completion of the phase-scan process certain data can be punched on cards and processed for an up-to-date summary of phase-scan results for use in long-term stability analysis. Shifts occasionally occur in these settings. With the present evolution of consistent and easily usable phase-scan technique and Δt techniques to set the rf parameters, it should be easier to determine the origin of the remaining drifts and changes from the nominal settings.

Horizontal Oscillation. The Fast Fourier Transform algorithm was used in conjunction with accelerometers and pressure transducers to search for the driving forces causing the horizontal beam-position oscillation previously reported. Although the spectrum of vibrations could be successfully analyzed by this technique, a conclusive solution has not been found so far. Further work is in the planning stages, with contemplation of both surge suppression and mechanical stiffening.

Transition Region

A great deal of effort was put into the transition region (TR) apparatus, measurement devices, and associated software in preparation for the simultaneous H^- and H^+ beams.

The emittance measuring system in the transition region serves a dual purpose, beam and linac studies and TR tune-up. While jaws upstream can be positioned to form an artificial aperture, the collector assemblies downstream yield pulse-to-pulse position and profile information. Since the same equipment services both the main line and side track it has been incorporated into the TR tune-up algorithm for both H^+ and H^- beams. Figure 5 is a display of the measured emittance at 100 MeV and 17-mA peak current showing an area of 0.625π cm-mr. (Estimates of slit width effects which may reduce this figure somewhat are now being made.) This is in reasonable agreement with the design goal of 0.5π cm-mr. These measurements will be used in the near future to study the feasibility of scraping off the undesirable low-density beam halo at 40 and 70 MeV.

A new algorithm was prepared for setting the beam precisely on the magnetic axis of the transition region by minimizing the steering effects of changes in the focusing field strengths. The MESA program was also used to give preliminary information about the sensitivity to the various parameters.

Fig. 5. Vertical emittance at 100 MeV and 17-mA peak current.

805-MHz Linac Beams

General. The switchyard spectrometer became available as a relative-energy-measurement instrument during the quarter, and was used for tuning to 500 MeV as described below. Later in the quarter, extensive modifications were made in the switchyard, adding an extra beam dump and upgrading both the beam instrumentation and its associated data-collection equipment. Investigation of the absolute accuracy of the spectrometer continues. Initial test runs were also made to explore the use of the long insertable-strip ion chambers (ISICs) for investigation of low-intensity beams and the low-momentum tail of higher intensity beams.

Using a combination of beam-loading rf phase-scan, Δt , relative spectrometer measurements, and beam spill minimization, the beam was run at 500 MeV with average currents to $\sim 5 \mu\text{A}$ and an estimated rms emittance of $0.06 \pi \text{ m}\cdot\text{cm}$ at 4-nA peak current. An average current of $60 \mu\text{A}$ was accelerated to 211 MeV, with spill estimated at below 3.5 nA. Considerable periods of time were spent at average currents above $1 \mu\text{A}$ at various energies, and it is believed that the goal of achieving reliable operation for initial tune-up of the experimental area has been achieved.

Module-to-Module Field Adjustment. The Δt measurement yielded its remaining sources of error to intensive investigation during the quarter, and it has now been shown that the measurement is accurate to within $\pm 1^\circ$ (corresponding to approximately plus or minus one part in 10^4 energy) overall phasing conditions of the beam-induced input signals. The major problems were found to be incorrect monitoring of the electronic phase-shifter-control voltage, rf leakage from the rf amplifiers through the power supply, ac-filament voltages on the rf amplifiers, and a matrix switch which had deteriorated in insertion loss and VSWR characteristics and had developed sticking contacts with use. This equipment will now be rebuilt using the fast electronic version exclusively, and incorporating the various improvements and checking features into an operational version. The speed with which the measurements can be made is a major advantage: a check of the eight modules was made via operator interaction with the programs in eight minutes. Work will begin on automation of this tune-up.

Using the energy determined by Δt at 211 MeV and beam loading to $\sim 300 \text{ MeV}$ as a starting point, the accelerator was tuned to 500 MeV using a combination of beam loading and the switchyard spectrometer. The rf amplitude of each module was adjusted until the offset in energy at the rf phase setting giving maximum beam loading was correct, and then the rf phase was adjusted to give the design energy. This procedure was straightforward once the beam was positioned on the axis.

An attempt is being made to derive as much information as possible from beam-independent measurements of module field amplitude and module-to-module phasing to establish baselines for comparison of the results of beam-dependent tuning techniques, many of which exhibit a random walk characteristic in phase. Amplitude is inferred from measurements of the power delivered to the module and uncertain experimental data on shunt impedance. Module-to-module phasing was set using a null technique between magnetic field probes in adjacent modules. The effective phase length of these probes is not uniform, exhibiting a random scatter averaging $\pm 7^\circ$ with peak differences to 30° over those checked. Comparison to settings from actual tune-ups with beam and other techniques allow the resolution of 180° ambiguities from various sources. In spite of such random errors, it is hoped that useful baselines will result. Programs for convenient comparison of current tuning settings to the baselines have been written.

Alignment. Work continued on the question of alignment of the linac. It is highly desirable to know with some accuracy the inherent misalignments and their stability. They can then either be corrected, or the steering algorithms can systematically take them into account. A resurvey of the 805-MHz linac established that the alignments are not within the specified tolerances, but failed to provide a baseline for definition of the misalignments or reproducibility checks.

In the present alignment technique, the limited range for high accuracy with the laser requires that the displacement of each doublet in a two-module interval be measured relative to a reference line established in the previous module. Because a new reference line is established at each module, redundant measurements are made to insure continuity. A measuring procedure has been

established which allows automatic data reduction and which can be repeated for reproducibility checks.

Since the reference line is discontinuous, a computer code has been written to transform each measurement to a displacement relative to a straight line. A second line is fit to this data, using a least squares technique, to establish the linac axis for the purpose of finding steering solutions. Efforts must now be made to improve the basic accuracy of the alignment measurements, especially in the vertical plane. At least one complete resurvey is scheduled for the next quarter. Concurrent studies are in progress to use the beam itself to help understand the magnetic axis; this work should be facilitated when beam position monitors become available. Thorough understanding in this area will be necessary to achieve full intensity. It is encouraging to note, however, that the present very preliminary experience with simultaneous H^+ and H^- beams, at low intensities, has produced reasonably satisfactory beams with very little steering.

Repositioning checks were made on a number of wire scanners, showing them to be reproducible to within 0.001 in.

Accelerator Systems Development

Operations Support Development

The accumulation of information for the general background data base for installed equipment through the end of the linac continued. Most equipment, with the exception of the injector, has been numerically labeled according to a unit scheme where common elements are given the same number. Detailed questionnaires were prepared to gather information on each unit and a great many were completed and entered, and required spare parts and material have been identified.

The operations and maintenance action reporting system was used during the quarter. Programs were written for the PDP-11 computer in the Central Control Room (CCR) which provide a quick turn-around, daily report of equipment problems. This report is furnished each morning. The daily reports are then entered into a data base for development of records. Work started on summaries which can be generated by item or system over any desired time periods, and programs are being prepared for bar-chart plotting.

A generalized sorting capability was added by C-Division to the Generalized Information Retrieval-LASL System (GIRLS) program which forms the basis of the data-base system. This added a great deal to the ease of formatting retrieved data and makes use of the data base for capital equipment practical for the first time. The data base for intergroup job requests and accelerator scheduling was reviewed and the retrieval summaries were restructured to take advantage of the sorting capability.

The various additions and improvements to GIRLS resulted in a new system version, and all of the data bases and associated programs were reprogrammed as required to transfer them to the new version.

Manuals

The preparation of technical reports and the accumulation of information for drafting and wiring record updating are being continued.

Stability Studies

New studies added to the system for obtaining long-term-stability data included the transition-region magnets, switchyard vacuum, beam-spill monitor parameters, and the analog data system gains and offsets. A program was also written which should provide a reasonably accurate summary of the average and peak intensities, energy, and duty factor parameters of beams delivered to various areas. Programming problems and problems with the integrity of long-term data storage in the control computer system limited the useful output during this quarter. It is believed that these problems are now solved.

The accelerator vacuum study continues to be a useful preventive maintenance tool. In about half of the cases where vacuum deterioration is noted, leaks have been located and repaired on scheduled maintenance before downtime faults occurred. In the other cases it is believed that the results of pump aging are becoming apparent, because most of the cases of high-current readings are occurring in the modules with the longest in-service time. If this proves to be a proper assumption, the records will be used to dictate pump replacement requirements.

Data obtained from the klystron rf drive amplifiers in Sector B indicates that their gain has not yet deteriorated.

The change of plasma aperture in the H^+ injector at the beginning of the quarter established baselines

for new aperture behavior. The change from the replaced aperture (0.034-in. diam) to the new one (0.024-in. diam) was clearly reflected in a factor of 2.8 drop in the hydrogen flow rate traces at the same chamber pressure. The ratio of hydrogen flow rate to chamber pressure (a measure of the conductance of the orifice) dropped from 0.015 to 0.005. It is this ratio in particular that will be watched in the future for indications of orifice enlargement.

A bothersome residual chamber pressure, after the palladium heater current is turned off, can also be followed in the records. Water vapor, indicated by mass spectrometer studies, seems to collect on the ion source side of the palladium leak when the injector is running. It also appears that the records, with the addition of pulse arc voltage and arc current, may become useful as an indicator of average cathode condition and help establish a cathode replacement schedule.

Control Computer Programming and Development

Applications Programs. A disk file has been established containing selected accelerator parameters and selected alignment and calibration data. The file is organized as 20 columns of 50 numbers each, where the N^{th} number in each column corresponds to the N^{th} module of the linac portion of LAMPF. The columns contain proton energy at the end of the module, best estimate of power required, module length, quadrupole strengths, phase shifts offset and calibration, and eight columns of quadrupole alignment data. Programs to use these data have also been prepared. One program presents the ratio of the actual forward power to the estimate of power required from the table. The program also presents module-to-module phase shifts derived from the actual phase setpoints and the offset and calibrations data from the file.

Another program calculates and plots the transverse beam oscillations based on the conditions of the beam at the entrance to module 5, the quadrupole misalignments from the file, and the actual horizontal and vertical steering excitations. The program allows the steering excitations within the program to be adjusted for simulations of other steering excitations. Eventually, this effort could lead to an automatic steering algorithm which would provide optimum steering for each beam energy.

Numerous programs were modified to handle operation with H^- or simultaneous beams, and work continues in this area.

A comprehensive wire-scan program was written to run approximately 20 wire scanners in the switchyard area, optimizing actuator movement and data taking through the four modules. It allows any five wire scanners to be run in any order, then calculates the critical path in time for the linear actuator drives and minimizes the number of data takes. Gains and strokes of the scanners are individually variable. The problem actually consists of seven individual programs, divided by function, which communicate with each other via transfers through a common system. One of these programs contains the 17 physical constants, channel numbers, etc., associated with each scanner on a single card to allow adaptability in cable swapping, etc. Other routines perform the functions of actuator motion, data taking, plotting, and testing. This group of programs is noteworthy in that it represents an attempt to deal, in a general way, with the gathering of data from channels which are not modular in their grouping or nomenclature.

System Performance Studies. The study of computer system measurements to determine utilization and efficiency continues. Programs have been written which measure the number of time-slices given to each program that is running or measure the amount of core memory being held for long periods of time by any program running. Preliminary results from these measurements indicate that a few programs are holding significant amounts of core with very little computing activity. Changes to improve the efficiency of these programs are indicated.

A program was written which sees what programs use a file-definition look-up when calling other programs. The results from this study have already been used to improve the efficiency of certain scheduling programs. Currently, less than one percent of all program starts require a file-definition look-up.

A study of the dynamic characteristics of core allocation has been initiated. It is expected that the study will indicate how the demand for core fluctuates with time (e.g., are there sharp peaks in demand?), and will indicate whether it would be

worthwhile to move small blocks of core around to free larger blocks for future allocation.

A program is being developed which permits measurement of response time for various central control console functions. The interval from the time when a button is pushed, for example, to the time when some indication of response is returned to the operator can be analyzed. Variation of response time with system load may be studied.

To aid FORTRAN programmers a list of quirks of the FORTRAN compiler was prepared.

Dialogues with the central control system programmers led to several improvements in timed data collection, tweak knob response and other areas of the interface between the computer and the control system user.

Radiation Monitor Experiment

The programs prepared for testing the consistency of the radiation monitor system were used to verify that the KR settings (KR is the ratio of beam-spill pulse current to wire-scanner pulse current) for all 805-MHz modules through module 12 had remained stable. The check was made against a similar run six weeks earlier and showed relatively little change. Information at higher energies was obtained during the 500-MeV tests. The data showed the expected increase in sensitivity between modules 13 and 30 and then relatively constant sensitivity throughout the rest of the machine with increased scatter at the end of the machine. The KR values up to module 12 were the same as before. The test showed roughly a 75% increase in KR for a 150% increase in energy between 211 and 500 MeV. The scatter in the data is partly attributable to the precision with which the beam is steered since this produces background effects on the monitors.

The servo program is written so it can store away sufficient data each time it is run to keep an automatic monthly log as part of the stability program.

RF System

Checkout and scaling performance, of the feed-forward control system with peak current, was accomplished.

Long-term stability studies of the master reference system indicated the need for additional cooling and temperature control in the screen room;

procurement of air-conditioning equipment was initiated.

Diagnostic Equipment Development

Emittance Measurement. The emittance-measuring system has been expanded and improved during this quarter to include emittance measurements of the H^- beam in the low-energy transport region and of the H^- or H^+ beam at 100 MeV. The program is set up to accommodate the measurement at a total of eight locations: EM1, EM2 and EM3 being the original locations in the H^+ transport line, EM4 and EM5 being new locations in the H^- transport line, EM6 being reserved for a measurement in the polarized H^- transport line, and EM7 and EM8 being new locations at 100 MeV corresponding to mainline and sidetrack lines respectively.

The physical dimensions of the emittance gear at each location have been entered into the program, allowing the measurements to be expressed in units of centimeters and milliradians. A provision has been made to allow a meaningful measurement of emittance even in the case where there are quadrupole lenses or bending magnets between the slit and collector array. An emittance distribution graph has been added to the graphical output. This allows one to judge the portion of the total emittance related to the low-density halo regions, as opposed to the higher density core regions of the beam's phase space.

A new chassis of sample-and-hold circuits, having a sensitivity (20- μ A full-scale) 10 times greater than previously available, has been built and checked out. These new electronics are being used to study the details of the H^- beam emittance, and will be useful in studying the time-structured features of signals from instrumentation in the switchyard. Final installation and checkout of switching hardware and cabling for the multiple-station emittance-measurement system are scheduled for a shutdown period during the next quarter.

Instrumentation. Continued progress was made on procurement and assembly of a system of harps. A modified prototype of a shortened linear actuator for use in close quarters was tested with good results.

Circuitry for the beam-position monitor circuit was finalized and procurement initiated. It

still appears that each unit will have to be tuned with its particular loop assembly removed from the beam line and then re-installed; extra quality will thus be built into the electronics to minimize gain and offset drifts.

The 805-MHz beam-current monitor circuits were also studied to increase their gain and reduce noise. The reworked circuits can be fabricated on the same boards with the beam-position monitor, at little additional cost.

A beam-current calibration circuit was designed and successfully tested. The calibration windings on all of the beam-current transformers along the machine were connected in series in order to allow a consistent, instantaneous, and simultaneous calibration on all modules.

Injector Programs

The High-Intensity Injector Program

Accelerating Column Improvements. A fast-protect system to limit beam impingement on the electrodes of the accelerating column has been implemented and is now operational. This system interrupts the beam-gate pulse to the ion source if the beam current to the column electrodes exceeds a given threshold after an initial time delay which has been set to eliminate a turn-on transient. Initial difficulties with component failures from arc downs were solved, and the system has been operated for several weeks without any failures. The wiring and software required to incorporate this system into the central computer fast-protect display program is now being implemented.

The preliminary design of the titanium electrodes for a new accelerating tube has been completed. Final calculations to determine the maximum electric field gradients produced at the electrodes are in progress. Compared to the present design, the new design has twice the beam aperture (4.0-cm diam instead of 2.0-cm diam) after the first two electrodes to reduce beam impingement which causes arc down. The maximum voltage between electrodes has been reduced from 108 keV to 54 kV by using 16 electrodes instead of the 10 electrodes in the present design. This design should reduce ion-exchange loading which depends on the total voltage between electrodes rather than the voltage gradient. The new design will also have larger pump-out apertures which should reduce pressure bursts during arc down.

The concept of providing larger clearance between the beam and electrode apertures was tested by installing an experimental ion source in which the Pierce anode aperture was reduced from 1.4-cm diam to 0.8-cm diam. When this source was run at the same current density as the regular ion source, a proton current of 13 mA was obtained. Under these conditions a significant reduction in arc-down rate was observed at the full 6% duty factor operation. The major improvement was in the ease and speed of going directly from an off condition to full 6% duty factor operation both in reduced sensitivity to initial tuning and in snap-on recovery. There also appeared to be an improvement in the rate of arc downs occurring after the operating level had stabilized, but this has not been fully assessed. An overall arc-down rate of 2 arcs/h at 6% duty factor was obtained during extended high-power tests with this source.

During the last quarter, extraneous current pulses to the accelerating tube electrodes were observed both during and between beam pulses. If these pulses are caused by small discharges in the accelerating tube, they should be detectable with suitable photo-detection equipment. A photomultiplier detector was built and these discharges were looked for but no flashes of light were observed nor were there any observable current pulses to the electrodes. This test will be repeated again.

The prototype capacitive pickup plate to monitor high-voltage transients in the H^+ injector has been replaced with a permanent design. A photograph showing this device, now installed on the wall of the Faraday cage of the H^+ injector, is shown in Fig. 6. The monitoring and control circuitry is now being built. This system will seek to use precursor information from these transients to improve the arc-down performance of this injector.

Ion Source Operation. The hydrogen flow from the regular ion source was greatly reduced when the old plasma aperture was replaced. This aperture had been in service for almost 18 months and had enlarged to over 0.034-in. diam. A new aperture of 0.024-in. diam was installed and the hydrogen flow rate required to maintain a chamber pressure of 200m torr was reduced from 3 to 0.8 atm cc/min. Tests were also conducted which verified that the lapped anode aperture insert design did not contribute

Fig. 6. Capacitive pickup electrode mounted on the wall of the H^+ Faraday cage. The outer square plate defines the circular capacitor area and acts as a protective spark shield.

Fig. 7. Horizontal phase-space distribution for a 10-mA proton beam at EM3 produced from the experimental 0.8-cm aperture ion source.

significant hydrogen leakage. A new filament was also installed in the ion source which permitted stable operation of the arc at a lower chamber pressure. Both of these factors have reduced the hydrogen flow required and are expected to quadruple the lifetime of the hydrogen ion pumping elements.

An experimental ion source employing a smaller Pierce anode was built and installed on the H^+ injector for several weeks of operation this quarter. This source was designed to produce a 0.8-cm-diam beam with a 16-mA-peak ion current at design operating conditions. This design was realized with an 80% proton fraction yielding a proton beam of 13 mA. This beam was transported to the linac with over 90% transmission efficiency using the same beam-transport conditions as are used with the regular source. Typical emittance patterns for a 12-mA beam at the entrance of the linac are shown in Figs. 7 and 8. The phase-space orientation of these patterns is the same as those obtained with the regular ion source at its design current. The beam size and emittance at the linac is smaller with the experimental ion source owing to the lower-current operation.

Fig. 8. Vertical phase-space distribution for a 10-mA proton beam at EM3 produced from the experimental 0.8-cm aperture ion source.

Beam Transport Studies. Work has been resumed this quarter in studying alternative modes of operating the high-intensity beam-transport system in an attempt to improve the quality and stability of the beam delivered to the linac and reduce the excitation of some of the focusing magnets in this beam line. The transport system was operated to

produce more symmetrical beam envelopes and a smaller beam in the parallel section of the TD beam lines (Figs. 9 and 10). Initial tests indicate that an additional beam scraper in the middle of this portion of the beam line would permit more effective scraping of the halo beam.

Study on the transport conditions is being continued to obtain alternative modes of operation which are more compatible with the operation of a beam chopper that is being designed. For effective operation of such a chopper, it is desirable to form a ribbon beam to minimize the voltage required to deflect the beam off a chopping aperture. The required beam-transport conditions have been calculated

Fig. 9. Beam cross section at TDVS01 just in front of the prebuncher for a 22-mA proton beam being transported with more symmetrical transverse beam envelopes. The graticule spacing is 1.0 cm.

Fig. 10. Beam cross section at TDVS02 halfway down the parallel section of the TD beam line for a 22-mA proton beam being transported with more symmetrical transverse beam envelopes. The graticule spacing is 1.0 cm.

and tested on the high-intensity beam-transport system, producing a 4- by 1-cm ribbon beam at the chopper location. The beam was then refocused to obtain the required phase-space distribution to match the admittance at the entrance of the linac. Studies are continuing to optimize this solution.

Alternate 45° Beam Line. An alternate 45° beam line has been installed on the high-intensity beam-transport system and has been used to provide high duty factor beams for graphite stripper foil tests. This beam line has the advantage of permitting

installation and testing of experimental equipment and targets on an off-line basis while the high-intensity beam line is in operation and has proved to be a useful adjunct to the H^+ injector system.

The H^- Injector Program

H^- Source. The H^- ion source was reinstalled after the accelerating column was put on the equipment dome and no problems have been encountered in its operation. Replacement of an aluminum electrode in the column with a similar unit made of titanium was successful in eliminating severe sparking problems. The first operation of this injector was successfully carried out on March 28, and its performance was essentially identical to that previously reported for the 30-keV H^- beams without the column. The H^- beams were transported to the linac without difficulty.

In beam tests so far conducted, up to 600 μA have been obtained at the first Faraday cup and 380 μA of H^- beam has been delivered to the linac. The injector has been operated for about an hour at 500 μsec , 60 Hz, and 500- μA peak current without difficulty. Some Cockcroft-Walton (C-W) sparking has occurred but most of this sparking was traced to an electronic fault in the slow stabilizer of the C-W. The beam emittance at 750 keV was 4π cm-mr measured by pepper-pot measurements and $\sim 2\pi$ as measured by electronic emittance scanners at the EM3 location. Further measurements will be made with improved scanning sensitivity. The capture efficiency of H^- beam in the linac is over 50%, close to that expected for single-buncher operation.

One unexpected result in the initial H^- operation was the observation of four distinct beam components. The predominance of H^- ions produced from H_2^+ ions over those produced from H^+ ions was observed in early test stand results, but H^- ions produced from H_3^+ ions were not expected nor observed in the test stand experiments. This result was probably due to the low resolving power of the test stand analyzing magnet.

The two 45° bending magnets in the H^- beam-transport line have a quadrupole triplet between them which allows ordinary operation of the 90° bend in an achromatic mode, but the triplet can also be operated to make this 90° bend dispersive. When this mode of operation was effected, a four-component

energy spectrum of the beam was observed (Fig. 11). By varying the C-W energy and the charge-exchange canal voltage (which was nominally 20 kV) the beam components could be identified as:

- (1) 20 keV H^+ $\rightarrow$ 20 keV H^- $V_{H^-} = 760$ keV
- (2) 20 keV H_2^+ $\rightarrow$ 10 keV H^- $V_{H^-} = 750$ keV
- (3) 20 keV H_3^+ $\rightarrow$ 6.67 keV H^- $V_{H^-} = 746.7$ keV
- (4) 0 keV H^0 $\rightarrow$ 0 keV H^- $V_{H^-} = 730$ keV

The intensity distribution of this energy spectrum is dependent on many parameters. For the case of a 136- μ A beam, the percentages were 4, 37, 58, and 1, respectively, for the H^+ , H_2^+ , H_3^+ , and H^0 parent ions. The energy deviation in the first and fourth components is sufficient to preclude substantial linac capture, but their contribution appears to be low at almost all values of normal operating conditions, partly because of the 4-mm aperture plate at the column entrance. This aperture permits only ions with the correct energy to be focused and hence transmitted to the column. The first component (H^- ions of H^+ parentage) may be enhanced by changing the gap lens focusing but this condition results in a large reduction in total H^- current. The predominance of H^- ions produced from H_2^+ and H_3^+ ions in the initial beam evidently occurs because of

Fig. 11. Energy spectrum of the H^- beam observed by operating the H^- beam transport system in a dispersive mode.

the large cross sections for charge exchange in the high-pressure region (20 μ) of the expansion cup. The suspected processes are:

There is no evident reason why multiple energy beams cannot be injected into the linac, and in fact the initial tests indicate that this has been done with good results, although there is still an unresolved question as to why optimum capture occurs for C-W voltage some 6 keV lower than expected.

Investigation of the x-ray production by this injector showed a bremsstrahlung spectrum expected of 750-keV electrons. It was found that 35% of this bremsstrahlung was produced by secondary electron emission from the 4-mm aperture at the column entrance. A small bias voltage was sufficient to eliminate these electrons. About 60% of the bremsstrahlung was caused by electrons produced in the high-potential charge-exchange region. A crossed-field filter with permanent magnets is being designed to suppress these electrons. The remaining 5% appears to occur from ionization in the column. With the planned suppression, the anticipated radiation level at full design operation of this injector (6% duty at 2-mA peak) will be 500 mR in the exit cone of the column. Since the radiation is strongest in the gaps of the first quadrupole quadruplet yoke, it is anticipated that a substantial reduction in radiation can be achieved with minimal local shielding in these gaps. Shielding of the beam-transport region can be accomplished without difficulty.

Future plans include a systematic study of ion source parameters including several canal dimension changes, installation of different exit apertures, testing of electron cross-field suppression, and operation of the source at full 6% duty factor.

The H^- Cockcroft-Walton Generator. Measurements were made of the voltage division ratio of the compensated resistance divider strings on both the H^+ and H^- 750-kV C-W generators to determine the origin of sparks which occur at the low-voltage control circuits during arc down. A tunable oscillator was used to drive the C-W equipment dome and the voltage division was measured directly as a function

of frequency. Impedance measurements were then made on the resistance dividers as a function of frequency, and the division ratio was calculated from these measurements. Both measurements on both dividers showed that the division ratio (Figs. 12 and 13) dropped from its low frequency value of 500:1 to very low values beyond 1 MHz. A very poor response in the H^- C-W was traced to a wiring error and was corrected. A low-pass filter will be installed on both generators to attenuate frequencies greater than 1 MHz and thus protect the stabilization circuit components from damage on arc down.

The H^- C-W was operated extensively for the first time and several wiring errors and faulty components were found and corrected. One problem was a

Fig. 12. Voltage division ratio of H^- C-W compensated divider vs frequency.

Fig. 13. Division ratio for H^+ .

nonlinear voltage reading, which resulted in the beam energy used in the initial H^- linac tests being some 30 keV low. There are no remaining problems in the C-W operation although the lack of arc downs in the operation of this injector has not yet been adequately explained.

The H^- Accelerating Column. The H^- accelerating column was assembled and installed in the H^- injector this quarter. The assembly of the accelerating tube on top of the double-cone assembly is shown in Fig. 14. The extractor network at the base of the column is identical to that used in the H^+ column since all parts of this column (except the titanium electrodes) are to be exact replacements in case of any emergency with the H^+ column. The extractor network couples a variable voltage power supply to the first electrode of the column, provides a means to read the voltage and current to this electrode and protects the power supply from column arc downs. Biasing tests on this electrode have provided information as to the origin and energy of the two groups of electrons from the ion source which accounts for 95% of the x-ray production from this injector.

A different procedure was used in cleaning the ceramic insulators on this accelerating tube than was used in cleaning those on the H^+ tube. None of the titanium feedthrough washers were masked when the ceramic was cleaned by blasting with 240-grit alumina. This procedure provided better cleaning right up to the ceramic-metal interface. The titanium stress-relief flanges were masked as on the cleaning of the H^+ tube.

The design of the titanium electrodes for the H^- accelerating tube differs from that used in the H^+ column in the following respects:

- (1) Flat plate rather than Pierce geometry electrodes have been used because of the low beam current.
- (2) The electrodes are attached to each feedthrough washer so that the maximum voltage between electrodes is only 52 kV rather than 108 kV in the H^+ column.
- (3) The buttons used to attach electrodes to the washers have been eliminated, since arc tracks were observed to be concentrated near these buttons on the ceramic walls of the H^+ tube.

Fig. 14. H^- accelerating tube mounted on double-cone assembly.

- (4) Better conductance has been provided to the tube interior to minimize pressure bursts in the tube during sparking.

After the insertion of the double cone and accelerating tube inside the acrylic jacket, the accelerating column module was positioned between the equipment dome and the Faraday cage wall as shown in Fig. 15. Voltage conditioning of the column was accomplished quickly and required only a few hours to reach 800 keV. The maximum voltage that the column has reached is 847 kV with 5 psig pressure of SF_6 in the acrylic jacket. Since the equipment dome normally operates at 720 keV, there have been few high-voltage problems during initial beam tests. The present column design is much less prone to arc down and appears to be able to sustain sparking between electrodes without arc down of the injector.

The maximum voltage obtainable is directly related to the SF_6 pressure inside the acrylic jacket indicating that the voltage limitation is outside

Fig. 15. H^- accelerating column.

the accelerating tube but inside the acrylic jacket. Photographs taken through the transparent acrylic jacket show that sparking occurs consistently across the third ceramic from the ground end of the tube when the SF_6 pressure is reduced to 1 psig. The upper voltage limit was increased from 810 to 847 keV after some work on the spider assemblies, which can be removed through the removable portholes on the acrylic jacket, as shown in Fig. 15.

The H^- Beam-Transport System. The construction of the H^- beam-transport line was completed this quarter and this system was used to transport H^- beams to the linac for initial accelerator tests. A photograph showing the dual beam-transport system is shown in Fig. 16. The main transport elements are now operational but work is still in progress to complete installation of the beam-current transformer amplifiers and beam-position monitors. An emittance scanner is also being installed on the first section.

The initial operation and tune-up was effected using viewing screens, beam-current transformers, and Faraday cups; over 95% transmission to the linac was achieved on the first beam tests. A photograph showing the H^- beam spot observed in the initial straight-out portion is shown in Fig. 17. More detailed beam-transport studies will be carried out as soon as measurements specifying the beam at the column exit are completed.

Fig. 16. Dual beam-transport system in the injector complex of LAMPF. The alternate 45° beam line can be seen in the lower portion.

Fig. 17. Beam cross section of the unfocused H^- beam at the first viewing screen on the H^- beam line. The graticule spacing is 1 cm. The inner spot is H^- beam produced from H_2^+ ions while the outer spot is H^- beam produced from H_3^+ ions.

Pepper-pot emittance measurements have also been carried out at the end of the straight-out section. A photograph of the pepper-pot data is shown in Fig. 18. There is no evidence of the satellite ring structures in the H^- beam that are observed in the H^+ beam. The determination of emittance from these photographs is complicated by the fact that the different energy components of the H^- beams have different phase-space distributions at the exit of the accelerating column and thus have different focal properties in the beam line. The data observed in these pepper-pot measurements indicate that the total emittance of all components in the H^- beam is about 4π cm-mr. More precise measurements will be made when the electronic emittance scanner has been installed.

Detailed emittance measurements (shown in Figs. 19 and 20) have been carried out at the final emittance-measuring station (EM3) at the entrance to the linac. The emittances observed here, however, were only 2π cm-mr. The discrepancy in the measurements is presumably due to the difficulty in interpreting the pepper-pot data.

The H^- Beam Chopper. Work continued on the design of the H^- beam chopper. Engineering drawings have been completed and fabrication is expected to

Fig. 18. Pepper-pot emittance pattern of H^- beam at the end of the straight-out portion of the H^- beam line. The emittance of all components of H^- beam is 4π cm-mr.

Fig. 19. Horizontal phase-space distribution for a 380- μ A H^- beam at the EM3 emittance-measuring station. The small, more diverging component is believed to be the H^- ions produced from H^+ ions in the ion source.

Fig. 20. Vertical phase-space distribution for a 380- A H^- beam at the EM3 emittance-measuring station. The small, more diverging component is believed to be the H^- ions produced from H^+ ions in the ion source.

start this next quarter for an experimental chopper that will be mounted on the parallel section of the TB beam line. This unit will ultimately provide single micropulses of H^- beam at a 12-MHz repetition rate.

IV. ELECTRONIC INSTRUMENTATION AND COMPUTER SYSTEMS

The activities reported in this section relate to the computer control system for the LAMPF accelerator and experimental areas and to the computerized data-acquisition systems being developed to support the program of experimental physics.

Injector Control System

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

The major accomplishment this quarter was the operation of the H^- injector through the controls in the Injector Control Room (ICR). This operation marked the completion of the main elements of the H^- injector control system. During the next quarter, the controls will be made operational through to CCR. Because of the low level of the signals associated with the H^- injector, most of them will have to be amplified. All of the signals have yet to be calibrated. The run-permit, transport-ready, and high-voltage interlock chains have to be completed. Programs to automatically sequence the H^- injector from CCR have to be developed.

Improvement and maintenance of the H^+ injector systems continued this quarter. The C-W high-voltage readout from the digital voltmeter (DVM) was connected to the accelerator data-acquisition system so that accurate dome voltage measurements are available in CCR. Two arcdown sensing channels, one for ultraviolet radiation, the other for gamma rays, were installed and tested. The new beam-current monitoring system for the H^+ injector was put into operation. Tests established that the drift was in the range of $\pm 0.5\%$. The staircase calibrate signal was changed to be a rectangular pulse which can be switched to different amplitudes at each monitor.

A discrete Fast Fourier Transform code was adapted to the ICR-Nova computer to aid in the search for the source of mechanical motion causing the position of the beam to vary during its transit through the 201-MHz linac. Spectral analyses of

accelerometer and pressure transducer signals from the 201-MHz structure were made using the data terminal and display scope interfaced to the Nova.

Switchyard Control System

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

The major activity in the switchyard was the replacement of regulators on the magnet power supplies. The original regulators could not be adjusted for stable operation over the entire range of energies from 200-800 MeV. The new regulators which exhibit the desired stability characteristics were installed, tested, and calibrated. As an adjunct to this effort, calibrations were redone for the magnet bypass shunts and the magnet power supply outputs.

The controls for the flip coil used in measuring the magnet fields in beam lines A and X were modified to eliminate a timing problem that caused erroneous results in some of the measurements.

A new beam stop was added along Line X to trap H^+ or H^- particles, depending on the mode of operation of Areas B-C. Instrumentation and controls for several new devices were installed along the line leading to the stop, including a magnet current-reversing switch, a current monitor, and a wire scanner. The run-permit system was modified to take account of the new modes of operation made possible by the stop.

Experimental Area A Control Systems

The Experimental Area A control systems encompass the instrumentation and controls for the primary H^+ beam line through Area A and the four secondary beam lines.

All of the controls for the primary beam line equipment are contained in a set of eight racks. These racks were set on a special platform at mezzanine level along the south wall of Area A. All of the interrack wiring was completed. The electrical contractor started on the ac power wiring to the racks and on the installation of cable conduit to the cable tray. The installation of the bridge cable tray and duct system awaits the delivery of hardware.

With the release of a drawing specifying locations for the devices, cable ducts, conduits, power supplies, etc., in and around the primary line

shielding, it was possible to make up the wiring lists for connecting all this equipment. Wire schedules were completed for the target controls, beam-steering system, data-acquisition and control terminal, video system, and flow switches. The cabling for the beam-diagnostic system involves 800 runs of RG-174 coax totaling 100,000 ft. The power supply controls require another 800 conductors. The electrical contractor will begin work on this wiring in May.

The final design of the rack assembly for the P^3 controls was finished. The assembly is under construction and scheduled for delivery in May. Included in that design is the layout and interface for the CAMAC system. Wire schedules are being prepared for the device-to-rack wiring. Since that is the first instance of scheduling wires to CAMAC crates, considerable time had to be spent to develop a standard for coding the wires and numbering the paths. The cables between the power supplies and their regulators are in fabrication.

The set of racks housing the controls for the low-energy pion (LEP) line was sent to a vendor for assembly and interrack wiring. The finished product is due back in May. The job of scheduling the wiring between these racks and the beam line devices is in progress. The power supply-to-regulator cables were ordered.

A preliminary design for the controls for the stopped muon channel (SMC) line was completed. Work will start soon on the final design. The rack housing the regulators and interlocks for the four power supplies on this line was delivered. It will be added to the other two to three racks housing different control functions. The cables for the power supplies will be ordered when the location for this rack complex is fixed.

About 1-1/2 man-months were expended on the magnet-mapping equipment for the energetic pion channel and spectrometer (EPICS) magnets. It is expected that this equipment will become a portion of the final EPICS control system.

Experimental Area B and C Control Systems

The instrumentation and controls in the nucleon-nucleon area, (B), and the high-resolution proton spectrometer (HRS), (C), plus the beam lines leading to these areas, (LB, LC, and EP), comprise the Area B-C control systems.

During the past quarter, practically all of the control wiring was scheduled, installed, and terminated for beam lines LB, LC, and EP. The control wiring was also scheduled for the HRS but not installed. Substantial progress was made in the first phases of the controls checkout (both local and computer) for the devices along Line B. This work should be completed in mid-May. Then the effort will be shifted to devices in the other beam lines.

The digital voltmeter (DVM) for measuring magnet fields and currents was received from the vendor along with a 32-channel multiplexer, manual controller, and interconnecting cables. The installation and checkout of this device are scheduled for next quarter.

The fabrication of 17 dynamic magnet shunts for Area B-C and the LEP channel is now 80% complete. Procurement problems with the power resistors slowed progress. If projected shipping dates are met, the units will be completed by mid-May.

Bipolar power supplies will be used to energize 36 magnet windings in Area C and 58 windings elsewhere in the LAMPF experimental area. These power supplies will range in current output from ± 20 A to ± 250 A. The regulators for these supplies are housed in six racks, of which one is totally finished and three others are 75% complete. Checkout will start when the first unregulated power supply is delivered by the vendor.

A magnet position-sensing system based on a taut-wire is being developed. The necessary operational amplifiers, multiplex switches, and address decoders were received. Final design of the master oscillator and taut-wire current drivers is under way.

Steady progress was made on the HRS controls and instrumentation. The rapid mapper is nearing completion. The position control system was operated successfully. The NMR gaussmeter with probe and preamplifier was received. A prototype of the processor to be used with this gaussmeter was tested. All control and interlock electronics for the HT power supply were completed. The main power supply controls were modified to be compatible with operation from CCR.

Experimental Area Beam-Diagnostic System

The new beam-diagnostic system for HARPS based on a satellite PDP-11/10 computer was operated

successfully, just 3-1/2 months from inception. The system was designed to collect large amounts of data from the HARPS and funnel it to the control computer in CCR. A PDP-11/10 controls the acquisition of data from up to four HARPS through a multiplexer interfaced to the computer with CAMAC modules. This computer, in turn, responds to requests for HARP data sent by the SEL-840MP control computer over a CAMAC data link. Beam profiles at selected points in the switchyard and experimental areas are thereby made available to the operators in CCR.

The two PDP-11/10 computers ordered for the system were received and accepted after a design flaw uncovered in the central processor was diagnosed and corrected. One of these computers, along with a powered CAMAC crate, a CAMAC/Unibus controller, and a pair of data-link modules, was assembled in CCR. Programs were developed for the PDP-11/10 to acquire data from the HARPS and to answer requests over the data link. The multiplexer was bench tested and then attached to the CAMAC crate on the PDP-11/10. All necessary CAMAC modules were received and plugged in the crate. A program was written to display the beam-profile data in CCR and to calculate the first and second moments of the beam. A full system test without beam was successfully completed at the end of the quarter. Tests with a proton beam are scheduled for early May. The system will be expanded to include additional HARPS and multiplexers next quarter.

Central Control Room (CCR) Systems

Accelerator operations are conducted from the CCR. Two consoles provide operators with all essential data and controls.

Since all of the major developments scheduled for the consoles and their associated computer interfaces (CIU) were complete, it was possible to begin work on the next level of improvements. A third storage scope was installed on each console. Panel lights with associated logic circuits were added to both consoles to indicate fast-protect faults and computer stalls. An improvement in the trackball response was made by revising the software.

Design work was started on a solid-state matrix switch to control the CCTV system in CCR. If this device works satisfactorily, it could also be utilized in the CCR video system. The facilities monitor alarm panel was redesigned to eliminate spurious

alarms triggered by electrical noise. A design study was initiated on a scheme to consolidate the Tektronix hardcopy unit into the solid-state matrix now controlling the storage scopes. Other aspects of this study include a consideration of hardware generation of vectors and characters and an interactive mode for the storage scopes.

LAMPF Control Computer

The LAMPF control system is organized about an on-line digital computer. Two minor modifications were made in the control processor during the quarter. The enable/disable logic for the memory-protect violation was placed under program control. An extra delay was inserted in the stall alarm counter to provide more time before the associated interrupt is activated. Both changes help protect the system from illegal operations and contributed to the reliability of the software.

Two peripheral devices were purchased as back-up equipment. A card reader capable of 500 cards/min operation was ordered to replace the present 200 cards/min unit, which will be retained as a spare. Both readers are electrically compatible. A third disk storage unit was obtained as insurance against a failure in the other two. Both of the peripheral devices were purchased in a used state at a considerable saving even when the reconditioning expense was considered.

Programming

A major effort was mounted this quarter to improve the reliability of the system software on the control computer. This problem is manifested by an unacceptably high frequency of computer "crashes," i.e., the computer fails to respond to operator commands and the programming system has to be reloaded. An analysis program written last quarter was used to diagnose the main sources of these crashes and efforts were concentrated in these areas.

The Executive Scan program was rewritten. This program decides which task the computer is to do next. A number of design criteria have changed since the program was first written and the new version is better adapted to the present operating environment. It also is more resistant to failures in those situations in which a given resource is not available, e.g., a new program is requested when core memory is already full of programs.

The memory protection software was completed and installed in the system. It makes use of hardware that can detect when a program is trying to store information outside its boundaries, thereby inducing a system crash. In such a situation the memory protection software purges the offending program and types a message on the teletype about the error.

The largest single cause of computer crashes was the alphanumeric display scopes. These devices exhibit a tendency to hang up under heavy usage, forcing a computer restart. The original software did not have adequate recovery capabilities for this problem. A package of subroutines was developed that handles all the functions of the character scope and is tolerant of transient failures in the hardware. This package is in the final stages of debugging and will be installed next quarter. Several new programs were written to incorporate these subroutines into the format input/output software. These programs will also go on-line next quarter.

The work on software reliability is already beginning to yield benefits. Statistics recorded by the computer about its own performance show a significant decrease in the average number of crashes per day. This work will continue until the effective availability of the computer is in the range of 99%.

Several improvements were made in the operational software to satisfy new requirements or correct deficiencies. The software which services the knobs on the operators' consoles was revised to be more efficient and provide better response. The Data Scan programs used in accelerator stability studies were changed to record data on delayed rf signals and to record the same signal at several different time intervals. The software which handles several of the peripheral devices was modified to make use of the on-line/off-line switches which allow a broken unit to be removed during test or repair operations.

The supervisor program which has been so useful in the preparation of programs was further expanded to perform assemblies from card or tape and to do program updates on the disk. These changes have further improved the through-put of the computer for program development.

Distributed Operational Systems

The systems described below are distributed along the length of the accelerator and are being extended into the experimental area.

Timing Systems

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

The repetition rate of the rf system was changed several times during the quarter by minor alterations in the master timer.

The major cable runs were specified for the extension of the timing system into the experimental areas.

Fast-Protect (FP) System

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

Three new signals were added to the FP system in the H^+ injector. These signals come from the dome voltage, extractor current, and electron trap. The FP chassis for the H^- injector is ready for installation. Almost all of the rack wiring for the chassis was completed.

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 run-permissive systems.

Most of the devices for the personnel safety system in Area B were mounted and wired into the control NIM bin. The remaining devices will be installed as soon as the shielding for the target area is in place.

The wire schedules and drawings were completed for the Area C personnel safety system. All of the wire and devices are on site and ready for installation.

A final design was completed for the Area A personnel safety system. The system schematics are ready for drafting. Procurement of devices is under way.

Radiation Safety System

The radiation safety system protects both personnel and equipment against a radiation accident. Personnel protection is provided primarily by area

monitors, while fast-acting beam-spill radiation monitors protect the accelerator.

The reconditioning of 10 surplus area monitors was completed. The leaky valves on the ion chambers were replaced with standard gas valves. Each chamber was evacuated and baked at 100°C, then filled to two atmospheres with dry nitrogen. These units are now ready for installation. All are scheduled to go into Area A but a few will be diverted temporarily into Area B until new units are delivered.

The final design of the area monitor system for Areas B and C was completed. Wire schedules were prepared and the wiring books were compiled. Wire installation is in progress and should be finished early in May.

The evolution of the beam-spill monitoring system into two distinct systems - one for control and the other for monitoring - became a fact last quarter. The precision resistors ordered for the beam-spill control system were received and installed in all station units along the accelerator and in the switchyard. Calibration checks were then made on all 72 units. Since these units are no longer required to supply an instantaneous signal, it was possible to simplify the electronics for the beam-spill control system. It proved to be cheaper to design a new pc board than to modify the existing boards. A prototype board was fabricated. The testing of this board and the replacing of all boards will occur next quarter.

Because the primary purpose of the beam-spill control system is the control of activation, which is proportional to the radiation produced by a beam spill, and because the production of radiation is energy dependent, it is necessary to calibrate the system as a function of energy. This is done at each station by measuring the current induced on a wire scanner and comparing this with the radiation produced, all at known energy. The relation is defined in terms of a sensitivity coefficient, K_R , which must be correlated with activation buildup. Preliminary measurements of K_R were made last quarter through the control computer. These measurements will be related to experimental data on activation next quarter to produce a system calibration.

Wire lists for the beam-spill control system in Areas B and C were completed and the installation of cable was started, with completion expected by mid-May.

The new beam-spill monitor system was designed to allow operators to visually observe the beam spill while making accelerator adjustments. The system to be employed is shown in Fig. 21. A detector will be located on the beam-channel wall opposite the quadrupole magnet between each module. The sensitivity of all detectors within a sector will be controlled from CCR by driving a rheostat with a stepper motor. Variations in the sensitivity of detector photomultiplier tubes within a group can be compensated for by individual resistor dividers.

A three-station prototype of the system was constructed and mounted in Sector H along with detectors at the ends of modules 46, 47, and 48. Tests with this prototype established all the design criteria for the system and it was possible to begin fabrication of all the units required for the facility. Wire schedules for the system were completed and the installation of cables was started. Control modules for each sector were built and installed. The system is expected to be operational next quarter.

The stack effluent from the exhaust stack in the experimental area has to be held within OSHA requirements. A velocity monitor was installed in the stack. The mount for this monitor is designed so that the detector can be positioned anywhere along the stack diameter. The output from this monitor will be remoted to CCR. Work was started on a system that uses signals generated by the gaseous and particulate activity monitors to control the stack effluent.

Communications System

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

The public address (PA) systems for Areas A, B, and C were put into operation. Because of the high noise level in Area A, additional speakers will have to be added. The interphone system in Areas B and C was made operational. Because of the expected heavy interaction between these two areas, the local channels were made common to both areas. The PA system for the Nuclear Chemistry Building was brought into operation, and the one for the Equipment Test Laboratory (ETL) should be working early in May. Some wiring remains to be done on the PA and interphone systems in the Operations Building.

The LAMPF communications system is finding applications in other divisions of LASL. A portable version of the system was put together for one group. An effort is being made to update the documentation and drawings for the system as a means for handling the many requests for information.

TV System

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

Stripper foils are under development for use in the H^- beam line where they are employed to strip the two electrons from the H^- to form protons. In connection with the testing of these foils, data were needed on the time dependence of the heating of the foils and on the break-up phenomena. The special television system shown in Fig. 22 was assembled to provide this data. The integrating effect of a standard TV system was overcome by establishing a "time window," τ_3 , of any desired width between 10 and 500 μsec , with a planar image intensifier. The position of the time window could be controlled relative to the beam pulse by the delayed pulse generator 2. The brightness profile was obtained by selecting a scan line and displaying it as a signal on an oscilloscope screen so that the vertical displacement corresponded to brightness and the horizontal displacement to the image points along the line. The decay of the image with time was avoided by synchronizing the beam pulse with delay generator 1 so that it occurred during the time the TV beam was passing through the image. The assembly of the system involved the fabrication of mounts for the image intensifiers and the 300-mm focal-length lens, and a special optical bench for holding the TV camera, image intensifier, and lens as a unit that could be positioned with a standard pan-and-tilt camera tripod head.

Fig. 21. Beam-Spill Monitor System

Fig. 22. Television System

The design of the TV system for Areas B and C was completed. Wire schedules were prepared and the installation of cables was started.

Data-Acquisition System

The LAMPF data-acquisition system includes computers, software, CAMAC modules and interfaces, data links, and an equipment pool for the purpose of acquiring and reducing data from nuclear physics experiments.

Experimental Area Computers

The sixth PDP-11 computer for the LAMPF data-acquisition system, a Model 45, was received and installed in the LEP counting house. Several peripheral devices have yet to be attached to it. These include a display scope, a magnetic tape controller and drive, and a CAMAC MBD-II. These devices will be connected next quarter and the system will be turned over to one of the experimental groups.

The first of the IBM-729/IV magnetic tape controllers packaged in CAMAC was received. Two more units are on order. Work was started on the software to drive the tapes. FORTRAN subroutines to

read, write, and rewind the tapes were written. This work was facilitated by the existence of standard input/output subroutines for the microprogrammed branch driver (MBD), to which the tape is connected.

An expansion box and 8k of memory (for a total of 16k) were added to one of the Super Nova computers being utilized in the data-acquisition system. After final tests next quarter, the system will be assigned to the neutrino area.

The design of a software package for storing and analyzing experimental data as histograms was completed and program development was started. The first version is due in late May. A standard set of FORTRAN subroutines for bit manipulation was added to the library. Some special software for processing data stored on magnetic tapes was developed to aid in the reduction of magnet-measuring data.

Microprogrammed Branch Driver (MBD)

Major portions of the experiments at LAMPF will be interfaced to the data-acquisition computers through CAMAC hardware. The key element of the interface is the MBD which can multiplex data from up to eight concurrent processes into or out of the computer. The final three MBD-II's (making six) were tested and released for assignment to computers. No further units are scheduled for production at this time.

Work continued on a set of standard subroutines which will allow an experimenter to use the MBD without having to understand the intricacies of the device. A set of diagnostic programs have been developed to aid in the detection of failures.

CAMAC Hardware

Power turn-on resets were added to the CAMAC modules for motor control and binary commands.

The design of a serial CAMAC system standard continued. LAMPF personnel participated in working group meetings in the USA and at the ESONE meeting in Paris, France.

LAMPF Electronics Equipment Pool (LEEP)

Every experiment will require a gate generator and certain synchronizing signals to control the acquisition of experimental data. A prototype LAMPF gate-generator chassis was fabricated and checked out. Care was taken during the checkout to document wiring modifications so that the automatic wiring program for the production units could be updated.

Most of the hardware for 10 units is on hand. The front panels were punched and silkscreened. The chassis were submitted to the shop for machining. When adequate experience has been gained from using the prototype, an order will be placed for production units.

In order to achieve compatibility between NIM and TTL logic, a level converter package (NIM-TTL and TTL-NIM) is being designed to mount in either a NIM or a CAMAC module. This device will become a standard LEEP item.

Bifilar Helical Chamber Electronics

The checkout of the interface electronics for the helical proportional chamber readout system was completed. The entire system, including the two CAMAC modules, was integrated with an MBD and a PDP-11/45 for the final test. A report was prepared to describe the operation of the electronics, including several pages of timing analysis.

V. ACCELERATOR OPERATIONS

Accelerator operations spanned 138 eight-hour shifts during the period. The beam was on or available 78% of that time, a substantial improvement over the 70% availability reported during the previous quarter.

Several old problems were brought nearer to solutions and a number of significant advances and firsts were recorded.

A horizontal transverse beam oscillation was reduced to acceptable levels by adjustment of drift-tube cooling-water flow rates. Installation of a new 7835 amplifier tube in module 3 permitted acceleration of 17-mA peak beam currents to 212 MeV for the first time. A 4-deg systematic error in the Δt measurement system became much worse and was traced to a faulty remote matrix switch system. A change in optimum tank-to-tank phasing in the drift-tube linac developed late and was unexplained at the end of the report period.

The first H^- beam was injected into the linac. The first simultaneous H^+ and H^- emittance measurements were made. Beams of H^+ and H^- were accelerated simultaneously to 212 MeV. Peak H^- beam current was 200 μA and the simultaneous acceleration was accomplished with both small- and large-peak H^+ currents. For the first time, H^+ beams were transported through the transition region side track, and side track emittance measurements were made.

The Δp spectrometry technique for setting cavity phases and amplitudes was employed in increasing beam energies from 212 to 500 MeV. The associated beam-diagnostic gear and control software were improved during the period.

Some progress was made in increasing beam intensities. Best results obtained were as follows:

59- μA average current at 212 MeV

5.2- μA average current at 497 MeV

Eight CNC-11 target foil irradiations were completed successfully: five at 100 MeV in the North Port diagnostic area, one at 302 MeV in Line A, and two at 497 MeV in Line X.

One staff member, one accelerator operator, and two maintenance technicians were added to the operations staff.

VI. EXPERIMENTAL AREA

Experimental Area Coordination and Facility Planning

The level of activity on the Experimental Area was reduced substantially during this quarter after the cost accounting figures for January, February, and March operations showed spending rates that could not be maintained for the balance of the fiscal year. The use of overtime was discontinued and the manpower level of LASL support departments was cut back. All active purchase orders and local fabrication orders were reviewed with the result that many of them were deferred until the beginning of next fiscal year. The consequences of these actions are that progress was slowed on all but the first-priority projects. Skillful management will be required later to fold the deferred hardware into the final installation schedules.

Schedules for delivery of beam to the experimental areas have been revised. It is now planned to deliver first beam to Area B sometime during the two-week accelerator operating cycle starting July 9. Similarly, it is planned to deliver first beam to Area A sometime during the two-week accelerator operating cycle starting July 30. First beams, which will be low in average current, will be used for tuning the main lines before production targets are inserted for secondary beams. In the case of Line A, a temporary stop capable of handling up to 10 μ A of 800-MeV protons will be installed at target A-3 for use until Area A-East is ready to accept beam.

Tight coordination of the manpower and resources available for installation of the Experimental Area facilities continues. The progress of a number of these coordinated activities related to beam-line installation are shown in Figs. 23-28.

The Isotope Production Facility contractual construction is completed except for minor items such as painting. Design of stacked shielding near the beam stop is completed up to beam elevation, and the shielding is being fabricated. The lower shield is to be installed before the south stringer housing for isotope production is set so that an adequate assessment of ground shifts can be made.

The Radiobiology and Therapy Research Facility construction has started. Numerous meetings have been held to establish shielding needs in the beam line and target areas.

PRE-INSTALLATION TESTING

Fig. 23. Progress on preinstallation testing of magnets.

M.I. MAGNET PREPARATION & TESTING

Fig. 24. Progress on preparation and testing of m.i. magnets.

Fig. 25. Progress on magnet measuring

Fig. 26. Progress on tooling-dock operation of attaching magnet alignment referencing fixtures.

Fig. 27. Progress on magnet installation.

Fig. 28. Progress on shielding fabrication and installation.

Design of the Merrimac doors above the biomed target has been completed. Cost estimates have been made and fabrication of the shield boxes has been started.

Meetings have been held with the Engineering Department to establish shield block sizes for the neutrino experiments. Design of a standard beam-type block that can serve as a floor is now under way.

The review of final design drawings and specifications for the weapons neutron research (WNR) facility has been completed and suggestions have been given to the architect-engineer.

Switchyard (BSY)

The switchyard is being prepared for delivery of beam to Areas A and B. The temporary beam stops in Line A and Line X have been removed. A new shield wall has been built at the end of Line X. Shielding has been added between the thin-target area and the first target station in Area A. Preparations are being made for the installation of LA-QD-03 and -04. A scattering chamber for the thin-target area has been designed and the drafting is being checked; delivery after July 1 is expected.

The new beam stop in Line X, which was described in the previous quarter's report, has been fabricated and installed. The shutter and the nuclear chemistry target channel are complete. One of the $11\text{-}1/4^\circ$ bending magnets (LX-BM-03) was modified with new side yokes with holes for beam passage. When the magnet field is reversed (opposite polarity from LX-BM-01 and -02), an exit path for transporting the beam to the new beam stop is provided.

Several steering magnets are also required in the switchyard for fine control of Lines A, B, C, and the external proton beam. An air-cooled design is used, with polyimide-insulated magnet wire windings.

The positions of the steering magnets in the switchyard part of Line A are:

- (1) an x,y steerer downstream of LA-QD-04 and
- (2) a y steerer downstream of LA-QD-02.

This placement allows for independent steering for the thin-target (TTA) station and Target A-1. In addition, this positioning decouples the effects of tuning for spot sizes from the problem of steering. The maximum angular deflection will be ± 1.7 mrad which is $\pm 1/2$ -in. at Target A-1.

The Line X spectrometer will be used to test the harps and proposed Line A instrumentation readout system.

A quick look at the effects of multiple scattering at the TTA station on the tune of Line A confirms the previous limits placed on the allowable target thicknesses at TTA. The target thickness should be held at or below 10^{-4} radiation lengths.

The vacuum boxes for the Line A and X beam plugs are being fabricated and the shield plugs are ready. The actuator mechanism has been designed and is in drafting. The air cylinders and valves are on order.

A number of modifications and improvements in the switchyard instrumentation have been made.

The Line-A ZnS screen has been removed. The recent 500-MeV run in Line A-south has produced a burn on the screen of ~ 1.3 -cm diam with an offset of ~ 0.3 cm from beam centerline.

In early February two additional wire scanners were installed at the original locations of LX-CN-01X and LA-CN-02X.

Two failures of wire scanners occurred during this report period. The wires which failed were 0.001-in.-diam Cu-plated tungsten. The first was a ductile-tension failure at the center of the span. A small spring is used to maintain tension on the wires. Evidence that the wires were at high temperature is the fact that, in each case, no Cu plating remained on the wire. In the second failure, the solder joint at one end of the wire appeared to have melted. The joint is 8 cm from beam centerline.

The wire scanner frame and mounting structure have been redesigned as a modular prealigned unit to facilitate repair and calibration. Twenty assemblies are being fabricated for replacement in the switchyard when servicing of the wire scanner is required. Five wire scanners for Line B are being built with this new design.

The harps have also been redesigned, and three of the new units have been fabricated. A glass seal is now used on the m.i. cable for the signal/feed-through leads. Resistance to ground of these leads is from 100 to 1000 G Ω with an average value of 300 G Ω .

The present harp grids are 40 by 40 with 1.0-mm wire spacing, mounted on plug-in printed circuit boards to allow prealignment, calibration, and quick replacement. Harp grids have been prepared with 0.0008- and 0.002-in.-diam tungsten wire and 0.002-in.-diam carbon filament.

Beam Area B - Nucleon Physics Laboratory (NPL)

Many of the components for Lines B and EP in Area B have been installed. All magnets have been installed, rough aligned, plumbed, and several have been wired to their power supplies. All power supplies are in place and are being wired. Good progress has been made with the installation of the control electronics. Most of the beam vacuum pipes have been fabricated, and the chamber for the LD₂

target is under construction. Several shield walls around the LD₂ cave have been stacked, allowing conduits and water piping to the cave to be installed. The beam stop water tank has been modified, and equipment for its installation is being prepared.

The assembly of the beam diagnostic equipment is under way. Toroid current monitors, wire scanners, and harps will be used. The electronics for these devices are in construction and will be ready for installation in May 1973.

In joint discussions between the beam line designers and the CCR programmers, the computer software requirements needed for LB and EP tuning have been formulated. Most of the building block sub-routines appear to be in fairly good shape and no unforeseen delay is anticipated.

Considerable effort was directed towards the study of hysteresis characteristics of the Line B bending magnets. A very specific field-cycling procedure must be followed to assure the magnetic field setting based upon its current. Small variations of magnet current ($\sim 1\%$) about a given set point can change the magnetic field at a given final current by 0.1%. In order to facilitate beam tuning at a later date, the B vs I characteristics of the bending magnets were carefully established using the cycling procedure.

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

Since the last report, reasonable progress has been made with the strippers and their associated electronics, the beam scanners and electronics, steering magnets, machining of the HRS field clamps, and nosepieces, as well as certain aspects of the computer control of the beam line and diagnostic equipment. Some progress has also been made on the time-of-flight system, beam-current integration, shielding layouts, collimators, taut-wire system, and the analysis of certain of the magnetic field data.

Final design of the steering magnets was completed (Fig. 29) and the engineering drawings were finished for the two steering magnets at the end of Line X. These magnets have four independent coils which will be excited using a single raw power supply with four independent regulators. Design calculations indicate a field homogeneity for the dipole

Fig. 29. Field contour of the octupole steering magnet as calculated by the code POISSON.

field better than $\pm 10^{-4}$ over the central 1/4 gap. This field can be rotated through 360° . The same magnet should also provide a pure quadrupole field to $\pm 2.5 \times 10^{-3}$ over the same spatial region. This field can also be rotated through 360° . The first two of these steering magnets are now being fabricated and should be finished early next quarter at which time test runs with the power supply will be made. This will be followed by more extensive field measurements to check the magnet performance, with July as target date for installation.

One of the large spectrometer magnets, HS-BM-02, has been completed and the first operating test was performed. The magnet was turned on to full power for 20-30 min. A rough measurement of the magnetization curve was made by using a Hall probe. This magnetization curve is shown in Fig. 30. At present, the apparatus needed to make complete measurements of the magnetic field is being worked on. Meanwhile, eight point coils were wound and they are being calibrated by using one of the 1° bending magnets. A NMR probe and a gaussmeter were received and they are being tested inside HS-BM-02. As soon as this test is completed, the NMR probe will be mounted inside the linear actuator and will be used for the H_t -winding study for the HS-BM-02. Codings for the PDP-9 for motions of the magnetic-field measuring device and mapping data are near completion. Before any mapping data can be taken, interfacing of all these programs must be completed. A procedure for studying H_t winding was worked out and the programming for controlling the H_t -winding currents is being carried out. The PDP-9, which is conveniently located near Area C, will be used initially for the H_t -winding optimization program. Ultimately, when

Fig. 30. Magnetization curve for one of the two large HRS magnets.

the spectrometer is in operation, the H_t -winding optimization program will run on CCR.

All peices of the second HRS magnet have been received; assembly will take about four months.

The machining of the first 57° bending magnet, LC-BM-04, was finished in mid-April and the steel assembly was sent to the coil vendor for installation of the H_t windings, main coil, vacuum chamber, plumbing fixtures, and electrical connections. Due to the amount of work remaining to complete this magnet, delivery is not expected until June 1973. The machining of the second magnet steel assembly is proceeding smoothly and will be completed by the end of April.

The first leg of the Line C, from the stripper to the first 57° bending magnet, is being installed. Cabling for the various instruments in Line C and for some of the magnet power has been pulled from the equipment building to the tunnel and Area C.

The ac for all the power supplies for the Line C magnets has been connected. The two spectrometer power supplies are temporarily located on the floor

of Area C where they are being used for the magnet measurements. They will not be installed in the equipment building until magnet measurements for the two spectrometer magnets and the two 57° magnets are complete.

Analysis of some of the magnetic field measurements on beam line elements has been done for use in complete ray-tracing of the beam line with MOTOR. Analysis of the data to go into the magnet tables for the beam line has also begun. A magnet-setting program has been developed and tested with several different options associated with cycling, setting a number of magnets simultaneously as well as giving graphic displays of the magnets, current changes, etc. Also, an on-line optimization procedure has been programmed and partially tested for use in the tune-up and alignment.

A computer program has been finished which can simulate the beam line for collimator design studies of Line C. The objective is to achieve a design for a collimated beam in the different variables at the target with a minimal amount of charged-particle and neutron contamination.

The first beam scanner, a prototype, has been built and is now under tests. Significant reductions in cost were made by standardizing to basic stroke length (6 in. and 12 in.). In the latest test, which was carried out over a period of about 10 days, the total system was run some 200 traverses of 6000 steps each without losing any pulses and with a maximum observed absolute positional error of ± 0.0001 in. (step size = 0.0005 in.). Depending on the progress of the programming of the interface PDP-11, it should be possible to run the first few of these scanners in July.

A layout of the taut-wire system at the beginning of the beam line exists. A detailed design taking into account the beam line components and the various fixtures which will be required is being carried out.

The secondary emission monitor (SEM) for beam-current integration has been built and leak tested.

The development of the wire chamber detectors at BNL is proceeding. At the present time, the detector planes which will be installed on the spectrometer are being wound. All the electronics were ordered. It is expected that the completed detector system will be tested sometime this summer, in the pion beam of AGS.

The time-of-flight system for the HRS has been laid out and the electronics ordered. A threshold Cherenkov counter has been sent out for bids, and scintillator specifications are in preparation. The Brookhaven group is looking into the design of the support structure for housing the time-of-flight system in conjunction with the detector box.

The vacuum enclosure for the scattering chamber was fabricated and delivered. Tests of the sliding seal for the scattering chamber will be done as soon as manpower permits.

Low-Energy Pion Channel (LEP)

Ceramic insulators and seals have been installed and have been measured on the last two quadrupoles of the LEP channel. The field clamps have been positioned and the fields mapped in the first two bending magnets.

The support stands and mounting hardware for all the magnets have been aligned and, as the magnets are measured and completed, they can be put in place in the channel without further alignment. The support for the center vacuum tank has been installed and aligned.

Collimators, beam plug, momentum slit, and proton absorber have all been fabricated and wired.

Racks for the channel controls are being wired at an outside contractor. All the magnet power supplies have been modified and the ac power distribution has been designed. The PDP-11/45 computer for the LEP channel has been installed in the counting room.

Energetic Pion Channel and Spectrometers (EPICS)

Several of the magnets for the EPICS system were delivered this quarter. The present status of the magnet procurement is shown in Table I.

TABLE I: Status of Magnet Procurement for EPICS

	<u>Status</u>	<u>Delivery</u>
Channel Magnets:		
EB01 and EB04	complete	
EB02 and EB03	50% complete	July 1
Spectrometer Magnets:		
Quadrupoles	complete	
Bend Coil	complete	
Bend Yokes	complete	
Bend Poles	50% complete	July 1
Bend Vacuum Chamber		June 1
Separator Bend	complete	

Some problems with magnets were encountered which require minor rework. The field clamp brackets on the quadrupoles broke loose during shipment, damaging two of the coils. These are being repaired by the vendor. A machining error in the EB01 inner yoke was discovered after delivery. A solution to this problem has not yet been found.

Many of the EPICS separator components are on hand and assembly of this device is under way. A high-voltage test will be attempted about July 1. The separator is being assembled in the injector building under the guidance of people experienced with the C-W high-voltage supplies for the injectors for the LAMPF accelerator. The flux box has arrived. The magnet has been completed and delivery is expected soon.

The magnet power supply and most of the fabricated high-voltage parts for the separator have been installed in the test area. The segmented insulators were received this quarter. The due date for completion of the open-loop electronics is July 1. The high-pressure, high-voltage line was recently designed and put under fabrication. Tests of the voltage divider await fabrication of a high-voltage test fixture.

The erection of the channel support system for EPICS has been completed. This stand uses the required shielding as a structural member, and was considerably cheaper than the separated function systems presently installed elsewhere in the experimental area. Most of the components for the slits, collimators, and beam plug have been delivered. These are being assembled and tested.

The system for measuring the field of the EPICS magnets was assembled and operated under computer control. This was a test to ascertain that all parts operate properly. The system was then torn down for re-assembly, with careful alignment. The computer will be moved to the EPICS counting building so that field mapping can be done in Area A. Work on final installation of the counting building was started, and completion is expected in time to measure EB01 approximately June 1.

The computer interface for the bifilar helical chambers for EPICS was debugged. Work is now beginning on a version to be used with the single-wire helix, and several copies will be available in time for check-out of the channel.

High-Energy Pion Channel (P^3)

All stands and magnets were installed and aligned from the target cell through the third bend; BM-03 has since been removed because a second field map was required. Figure 31 shows BM-02, BM-03, and their adjacent quadrupole doublets. Most of the voids around and under the stands have been filled with shielding. Approximately 25% of the vacuum plumbing is fabricated.

Based on calculations made by P. A. Thompson on secondary particle heating, the decision was made to water-cool the iron in the first quad-doublet (QM-01 and QM-02) and the tungsten jaws of the first slit (MS-01). The design work was completed on this slit and the modifications are being made. In the case of the quad-doublet, copper cooling coils are being attached to the side plates using a heliarc torch and a high temperature brazing alloy as the filler rod. It was not possible to use commercially available heat-transfer plates such as "Platecoil" because of the rad-hard requirement of this quad.

Stopped Muon Channel (SMC)

During this quarter, 11 of the SMC magnets have been installed on their support stands and rough-aligned. The final alignment of three bending magnets has been completed; these bending magnets will be used as monuments to final-align the quadrupole magnets on the line. All magnet stand hardware has been delivered except the base support for the six 12Q15 magnets of the decay section, which is to be delivered in June 1973.

Fig. 31. View of P^3 Channel.

All of the magnets are on hand and the pre-installation testing of these magnets had been completed. The fabrication of the beam plug, beam jaws, proton absorber, and some of the beam-pipe components has been delayed until next fiscal year for economy. The installation of the ac and dc power is now in the final planning stages.

Primary and Secondary Beam Transport

Beam Line A

Collimators will be placed on Beam Line A beyond the production targets to protect the downstream target cell triplet (TCT) from reaction products and scattered beam. The design criteria for these collimators are:

- (1) low carbon steel material,
- (2) opening half-angle is 30 mrad (as seen from target),
- (3) inner walls will have baffles, and
- (4) the collimators will be water-cooled.

The diameter of the collimator is based on the maximum acceptance of the TCTs and the baffle dimensions are chosen so that the typical angle subtended by the next baffle is substantially larger than the mean projected angle from multiple Coulomb scattering in the collimator material.

The preliminary software requirements for Line A diagnostics and instrumentation readout consist of:

- (1) a data-acquisition package for a PDP-11/10 to acquire the raw data through CAMAC interfaces from the harps and toroids,
- (2) a data link communications package between the PDP-11/10 and SEL 840 control computer,
- (3) a control, analysis, and display package for the SEL 840, and
- (4) in the future, an analysis program will be included in the PDP-11/10.

A test of the preliminary version of this system will be made on Line X in the early part of May. Monofilament carbon wires will be tested in the harps. The carbon wires hopefully will reduce the problem of short harp lifetime due to heating.

Refined transport calculations for Line A using TRNSPTJ revealed that known misalignment and sextupole components in the target cell triplets do not contribute large or bothersome second-order effects. The steering magnets planned in Area A and Area A-East will compensate for the steering effects due to misalignment. Further transport calculations were

made to study the feasibility of placing target cell triplets at the mass-separator facility during initial operation.

Six of the target cell triplet quadrupoles (8QN16M/7, 11QN32M/9, 11QN15M/9) have now been completed. Since only four are required for initial 1- μ A operation (one being shortened to an 11-in. doublet), this meets the requirement for Beam Line A for the present. Although remote handling will not be used in initial operation, the necessary remote connectors are being installed, and the positioning fixtures will ensure reproducible replacement of these magnets on their bases. Figure 32 shows one of the triplets being set up for test.

A number of x- and y-steering magnets (mineral-insulated and air-cooled) will be installed in the target cells. Parts for these are on order.

Secondary Beam Lines

All of the mineral-insulated¹ secondary beam-line magnets for LEP, P³, and Line B have now been completed and measured with the exception of field maps on two LEP bending magnets. Installation of these magnets is proceeding on schedule. Some values of quadrupole harmonics in percent of $n = 2$ at 400A, i.e., about 1/2-rated pole-tip field, are shown in Table II.

TABLE II

	Internal			Integral		
	n = 3	n = 6	n = 10	n = 3	n = 6	n = 10
8QN16M/7	0.03	0.433	0.090	0.001	0.15	0.26
11QN22M/9 (original pole tip)	0.023	0.162	0.001	0.005	0.22	0.15
11QN22M/9 (revised pole tip)	0.013	0.022	0.143	0.05	0.18	0.05

All of these magnets have chamfered pole ends to reduce the duodecapole ($n = 6$) component in the integral field.

Test Channel

The collimating beam tube is in Area A and is ready to be installed. An alignment stand has been designed for the bending magnet using existing components and a piece of a 12-in.-thick counterweight. Delivery of the quads is now scheduled for mid-May.

Fig. 32. A target cell triplet being readied for tests prior to installation in Line A.

Experimental Area Equipment and Experimental Area Support

Target Development

The biomed target design was modified and finalized. A schematic drawing of the three-target assembly is shown in Fig. 33. The top target is a calibration target of six 0.003-in.-thick disks to be used for producing a low-intensity pion beam needed during channel tune-ups. The average density of this target is 0.01 gm/cm³. It dissipates the beam heat by thermal radiation. The middle target is ATJ graphite of density 1.73 gm/cm³. It is water-cooled and housed in a hard copper jacket. This target is similar to one which showed no deterioration in EPA tests for 100 hours at LAMPF conditions. The lower target is ZTA graphite of density 1.92 gm/cm³. It will produce 11% more pions than ATJ graphite. It is water-cooled and housed in an experimental water jacket of high tensile strength Monel.

A second target assembly will have the middle target of ATJ graphite in a 316 SS, copper-coated jacket. This target was also used successfully in the electron prototype accelerator. The lower target of the second assembly will be ZTA in a hard beryllium-copper jacket. If beryllium copper proves to be a reliable jacket material, it will be used as a jacket for a pyrolytic graphite target. Pyrolytic graphite has a density of 2.20 gm/cm³ and will increase pion production by 27% over ATJ.

Fabrication work is about 50% complete on the first target assembly. Calculations have begun on a

BIOMED TARGET ASSEMBLY

Fig. 33. Schematic drawing of the three-target assembly being built for the biomed beam.

higher density water-cooled target. Some promising materials are diamond-beryllium composite, TiC, and copper.

A North Port Faraday cup calibration test was run. This low-accuracy test showed the Faraday cup to be reading between 0 and +3% high. The necessary electronic circuits are being modified to achieve an accuracy of $\pm 0.1\%$.

Design and drafting work were completed on an Al_2O_3 wheel target for 800-MeV beams of $<300\text{-}\mu A$ average current. The target is primarily for experiments on the Low-Energy Pion Channel at Station A-1. It is 1-cm thick and 12-in.-diam; it is composed of eight segments which are held together by two niobium wires around the outside diameter. Each segment is supported by a TZM molybdenum spoke.

Radiation thermocouples were designed and fabricated for measuring the temperature of the wheel targets at A-1 and A-2.

Water Systems

Motors from the X03, X05, X06, and X07 pumping systems were sent to the vendor to be degreased under warranty. The field windings on these motors had become saturated with oil which had leaked from the thrust bearing oil reservoirs. These motors have been reinstalled and are back in operation. It

was necessary to provide air vents on the reservoirs and to seal the top end caps on the motors to prevent a recurrence of the leakage problem.

The installation of the valve cave manifolds at Targets A-1 and A-2 is complete. Installation of the distribution systems from these caves to the target cells and to the secondary beam lines is continuing. Several of these installations are nearing completion. Many of these caves are currently being used to provide cooling-water for magnet-measuring work in the experimental area.

The X07-X08 process water system became fully operational during this report period. Initially, this system was used to provide cooling-water for measuring the first HRS magnet in Experimental Area C. Currently this system is being used for the simultaneous testing of power supplies and magnets in Beam Line B.

All but one of the process water manifolds has been installed in Beam Line B. This manifold will be completed after the stacking of the new shield wall in Beam Line B is finished.

Stubouts have been provided for cooling-water and service-air to the new beam stop in Line X.

A contract has been awarded for the Area-A power-supply water system. This work will begin as soon as the drawings are revised to show the power supplies in their new locations. The drawings for the hot and warm process water valve cave for Target A-5 are complete. These drawings along with the power-supply cooling-water manifolds for the Biomed Facility will go out for bid as a package.

Magnet Measurement

A great deal of effort this quarter has gone into calibration and reconciliation of the magnet-measurement apparatus. The various quadrupole measuring coils have been compared and their constants adjusted so that data from them all agrees to $\pm 0.3\%$. Similarly, all bending magnet $/B \cdot dL$ coils have been recalibrated (including a calibration at SLAC, through the cooperation of the magnet-measurement group there) so that absolute values of $/B \cdot dL$ to $\pm 0.05\%$ can be achieved. Studies to ensure that rapid-mapper field maps agree with $/B \cdot dL$ measurements are still in progress.

H⁻ Beam Strippers

Work on the stripper mechanisms and controls is essentially complete. They have been leak tested,

wired, and fully tested mechanically via the computer. The associated electronics have been built and tested and the computer control programs are written and tested; there are a total of $\sim 72k$ pulses to make one full traverse. The programs are able to center an arbitrary foil on any stripper mechanism to within ~ 0.002 in. in 90 sec or less when the accelerator is running in all cases tested.

Full power tests were made on the graphite stripper foils using the 750-keV proton beam. The average heat load (84 W/cm^2) was the same as a previous successful foil test using a cw infrared laser. However, due to pulsed operation, the peak power densities were much greater (1.4 kW/cm^2) and this imposed temperature rates of $0.5 \times 10^6 \text{ }^\circ\text{C/sec}$ on the foils with resulting severe thermal stresses. Several failures occurred while using a peripheral clamp to enhance heat conduction. After a nonres-training edge clamp was adopted, the foils performed successfully although they depended almost entirely on radiation cooling.

A diagram of the electronic apparatus used to measure the transient response of the foils is shown in Fig. 34. The image-intensifier diode provides a narrow optical gate, adjustable from $10 \mu\text{sec}$ to $500 \mu\text{sec}$, through which the image of the hot spot on the foil can pass to the vidicon. Furthermore, by means of pulse-delay electronics, this gate can be swept across the length of the beam pulse and between beam

Fig. 34. Schematic drawing of setup for observing the transient response of graphite stripper foils.

pulses. The image amplitude is a rough measure of the temperature of the foils, which can be plotted against time as shown in Fig. 35. The apparatus also provides the ability to move a selected scan line through the beam-spot image. At each line position an intensity profile is obtained from which an image contour map can be constructed as shown in Fig. 36.

Fig. 35. Approximate temperature response of graphite stripper foils when pulsed at high power using the 750-keV injector proton beam.

Fig. 36. Contour map of relative intensities of spot on stripper foil.

At the power densities used in these tests, the foils glow red-to-white hot and the image field probably exceeds the actual size of the beam. The problem of determining actual beam profile from the image with this technique is very difficult. These foils are made of 1 mg/cm^2 pyro-graphite and introduce an insignificant amount of multiple scattering at 800 MeV.

Other than the failures due to thermal stresses, which appear to have been solved by the use of non-restraining clamps, the only other failure is attributed to differential dE/dx heating on one foil which, nevertheless, did not rupture during a 5-h test. The edge of the beam spot on this foil is shown in Fig. 37, which shows serious ablation and delamination. The upstream surface was completely untouched. Ablation is suspected since the foils cool predominantly by radiation, and their average temperature at 84 W/cm^2 is $\sim 2200^\circ\text{K}$. The peak temperature near the end of each pulse is even higher, especially on the downstream surface, so that evaporation thinning at a rate of almost 10%/h is possible. This effect was seen as a gradual increase in transmission current during the run. The differential dE/dx problem will not be present at 800 MeV, where the foils are expected to function satisfactorily if they are properly mounted.

— 1 MM —

Fig. 37. Magnified view of graphite stripper foils following test runs. Delamination and ablation of downstream surface of 1 mg/cm^2 pyrolytic graphite foil is observed after 5 hours in 750-keV pulsed-proton beam. Average power = 84 W/cm^2 , peak power = 1.4 kW/cm^2 . The arrows point to two 0.1-mm holes (intentionally drilled).

Equipment

The acquisition of a number of draftsmen, on a temporary basis, has aided considerably in the completion of badly needed design drawings. The design and procurement status of the various major components is as listed below:

Target A-1

Target changer: on hand
Shielding and drive shafts: on hand
Vacuum box: delivery before June 1
Drive package: on hand
Shield cask: in design

Target A-2

Target changer: in fabrication
Shielding and drive shafts: out for bid
Vacuum box: in fabrication
Drive package: fabrication complete, not assembled
Shield cask: in design

Biomed Target

Target plug: out for bid
Profile monitor plug: out for bid
Vacuum chambers: in design
Shield cask: in design
Target water system: in design

Target A-1, A-2 Profile Monitors

Plug and vacuum box: in fabrication
Beamline vacuum box: on bid
Shield cask: not started.

Due to expected late delivery of the Target A-2 equipment, a piece of beam pipe will be put in place of this equipment to permit beam passage to a temporary stop at A-3. The substitute pipe will have a simple flip-in target that is cooled only by conduction through its drive to produce pions and muons for the P^3 and SMC.

Initial difficulties must be expected with the wheel target drive systems as bearings, gears, and flexible joints are being used in vacuum, high temperature, and radiation environments. The shortage of draftsmen did not permit hardware to be fabricated in time for the desired prototype work.

Steering magnets have been designed for the 12-3/4-in. o.d. beam pipe along Line A. The magnets are designed to be remotely removed by Merrimac. All components except the pole iron are being fabricated in-house.

The shield doors at Target A-1 have been slightly revised due to a shift in location of the target-cell triplet. The door splits are now at 6-ft 3-in. and 18-ft 0-in. from the west wall. The total door slot length is 63-ft 2-in. and the total weight of the movable door is 2600 tons. Target-cell-triplet shifts at A-2 required major revision of the doors there. The doors now roll at an angle of 41.3° to Line A.

Shielding

Major shield-installation work was concentrated on Target Station A-2. Mass steel shielding for this target station has been completed to the 9-ft level. Mass shield stacking at Target A-1 has been started. Concrete block stacking in Area A is held up until further secondary line installation work is completed.

Two shifts have been working throughout the quarter on shield stacking. A graveyard shift was activated for one week in April to push the shielding work in the switchyard.

In the switchyard the temporary beam stops and their mass shielding were removed from Line A and Line X. A semipermanent stacked shield wall about 10-ft thick has been installed in the Line B channel to isolate Areas B and C from Line A operation.

A beam stop off Line X has been installed and shielded. Additional steel shielding around the liquid deuterium target and the radiochemistry target in Area B has been installed.

During the quarter about 5200 tons of shielding were installed. Some 2250 tons of additional steel have been purchased for delivery next month. Just over 2000 tons of concrete shield blocks are being obtained from the disposition of the Carnegie-Mellon University cyclotron.

VII. RESEARCH

Preparation for Beam Tuning and Experiments

The apparatus for tuning the low-energy pion (LEP) beam channel is almost completely constructed. Assembly and testing has progressed very well. Two multiwire proportional chambers (MWPC) and associated electronics have been mounted and operated. A new gas circulation system has been built.

Testing is complete for the MP-designed MWPC amplifier.

Fabrication of 1000 channels has been ordered, and components are on hand for a second thousand which will be built by July 15. Parts are on order for 4000 more channels to satisfy the needs of the first experiments. The project for a hybrid chip amplifier has vendor difficulty, and we will rely on the local design.

Scintillation Counter Shop

Production of scintillation counters for various experiments and for beam monitors is proceeding. Thirty-five counters have been completed; orders for about 35 more have been received. The production of Pilot scintillator material has been transferred to Nuclear Enterprises.

Magnet Measuring

The absolute calibration of all the integral flip coils has been determined to the 0.05% level. Corrected numbers for magnetization curves of the beam switchyard magnets are now being determined from the corrected coil constants.

The 10-ft rapid mapper has been used extensively. Approximately 15 maps have already been made on two of the LEP bending magnets in order to specify modifications of the field-clamp configuration. The average step size has been measured as 1.00357 ± 0.00013 in. Agreement between the rapid mapper and the integral coils is at the 0.1% level.

7p Elastic-Scattering Experiment (LAMPF Proposal No. 96)

The MWPC chambers have been modified to accept the new amplifiers. A frame to hold the chambers has been constructed. The liquid hydrogen target is being constructed; the refrigerator has been tested and a first flask has been built.

Two prototype scintillation counters have been fabricated out of Pilot B material, for use as dE/dX counters. The dimensions are 26.7 mm by 26.7 mm by

¹A. Harvey, "Radiation-Hardened Magnets Using Mineral-Insulated Conductors," Proc. of Fourth Intern. Conf. on Magnet Technology, September 19-22, 1972, BNL, Upton, L.I., N.Y., CONF-720908.

1.6 mm. Preliminary tests shown ~ 30% pulse-height variation over the nominal sensitive area, with an efficiency of 98%. A light pipe for a total energy counter has also been constructed.

Considerable programming for the FDP 11/20 has been completed. These include system routines for disc bookkeeping and microprogrammed branch driver (MBD) checkout, a code for data acquisition from CAMAC and MWPC, data display routines, and experiment control routines. The software for both the LEP tune-up and Experiment No. 96 are in reasonable shape.

Parity Violation in p-p Scattering

Considerable progress has been made in understanding sources of systematic error in this experiment. Phosphorescence of scintillators and radioactive decays gave rise to signals which affected the frequency response of the detector. A new detector was constructed using liquid scintillator and a gold beam stop, which performed somewhat better, but instrumental drifts and unwanted beam-parameter modulations from the Lamb shift source still limit the sensitivity. An upper limit to the parity-violating contribution at 10^{-4} of the total cross section can be obtained, which is a limit three orders of magnitude smaller than has been published. What little theory exists would predict a parity-violating effect of 10^{-6} to 10^{-7} .

Helical Multiwire Proportional Chambers

Investigations of longer (65 cm) monofilar helical chambers were done this quarter. These chambers exhibited some mechanical and electrostatic problems, similar to the problems of long Charpak chambers. Some of the electrostatic problems have been eliminated and some of the mechanical problems solved. In bench tests the chamber behaved similar to previous helical chambers. The attenuation was reasonably small ($<1/3$), and the pulses were sufficiently large (~30mV). Present plans are to improve the performance by decreasing the attenuation (increase anode to cathode gap) and increasing the pulse height (increasing the anode wire spacing from 2.5 to 3.0 mm).

Some further investigations have been done with the modified helical chamber used at the Van de Graff. The active area has been increased and a thin nonhelical proportional counter has been

inserted in front of the existing helical chamber so that a coincidence can be required. This will eliminate background from neutrons and gammas.

Experiment 32

The prototype MWPC for Experiment 32 was installed in its rf shielding box, with 40 channels of the old design discrete amplifiers; checkout is to begin soon. Plateau tests have been started.

Personnel associated with Experiment 32 have cooperated in development of a new MWPC amplifier (based on Texas Instruments 810 voltage comparators) by testing that amplifier and comparing it with the Fairchild and LRS hybrids. An amplifier test stand to be used for the alignment of the production amplifiers was also produced. Since this experiment's MWPC design will use short twisted-wire pairs to connect the chamber and amplifiers, that connection method was tested with the new amplifier, with satisfactory results. Experiment 32's amplifier requirements are included in the initial production of new amplifiers.

A bid for fabrication of the decay chamber was accepted, with delivery in the next fiscal year.

At Temple University, both shower counters have been built, studies of ion chambers for beam monitoring are continuing, scintillation counters have been delivered (phototubes and bases were already on hand), and design of the support structures has been started.

VIII. PRACTICAL APPLICATIONS OF LAMPF

[Summarizes work being performed under auspices of USAEC Division of Physical Research, USAEC Division of Biomedical and Environmental Research, National Cancer Institute, and USAEC Division of Military Application.]

Biomedical Pion Channel

Although a water-cooled carbon target will be used for pion production initially, there is the intention of upgrading the target design from the standpoint of increasing reliability, increasing pion yield, and decreasing electron contamination of the pion beam. As an initial step in this upgrading program, a list of 16 possible target materials was compiled. Detailed study of these materials will begin shortly.

Wire orbit measurements were made of the fields in a stopped muon channel bending magnet. This experience will be valuable in expediting the progress of similar measurements on the biomedical pion channel magnets.

Engineering design of the first set of adjustable slits along the channel was completed and design of the second set of slits and the wedge-energy-degrader mechanism was started.

It was decided to use a range-measurement technique for determining pion momenta during tune-up. Consideration is being given to install a temporary vacuum system in the first half of the channel so that alpha particles can be used for initial studies. Indications are that there is neither manpower nor money to undertake this extra effort. However, no final decision has been made.

Control Computer

The biomed control computer and console were moved from the laboratory in the Lab-Office Building to its permanent home in the biomed stubout. This move was made in mid-March and the computer was down for only three days. Unfortunately, the stubout structure has been plagued by a number of problems and about seven manweeks of effort have gone into dustproofing and floodproofing the structure and straightening out various problems ranging from door locks to fire sprinkler systems.

At present, all of the control room racks and console sections have been installed including ac

power and wireways to them. The CAMAC interface rack has all the equipment installed and 85% of the wiring is done. Very little progress was made on completing the console panels and interfacing, but all of the hardware is now on site. The conduits and wireways from the control room to the equipment room which will house the magnet power supplies and to the treatment room have been installed and cable installation should get under way early next quarter. The magnet interlock system and temperature monitoring system design has been finished and an order for fabrication has been placed.

The two IBM-729 IV magnetic tape drives, acquired surplus from LASL's C-Division, have been installed, powered up, and the drives themselves tested. A CAMAC interface for these drives was purchased from the Lawrence Berkeley Laboratory and this has been received and installed but not yet tested. Software drivers for this system should be completed during the next quarter.

Also during this quarter, a second 1.2-million-word disc drive was purchased, installed, and was satisfactorily checked out on the PDP-11/45 control computer. An order for an additional 16k of core memory was placed and delivery is expected within the next two weeks. This will bring the total system memory to 40k words. An order for a new real-time system executive (RSX-11D) software package is expected to be placed within the next week as well as an order for an electrostatic printer-plotter unit. Delivery of both items is expected about June 1.

Additional time was spent early this quarter doing a detailed review of the facility building plan. Essentially all conduits and wireways required for the installation of the simulator, the treatment planning computer interface and the 250 kV-peak x-ray unit for radiobiology reference studies were specified and have been included in the building contract. With Group MP-8, the utilities requirements and control cable wireways for the upper levels of the stubout structure were specified and submitted to the LASL Engineering Department.

Specifications for an automatic isodose plotter were worked out with personnel from H-Division and the UNM Medical School. Comments were solicited from others on the LASL staff and discussions were held with manufacturers of such units. It appears that a suitable commercial unit can be obtained and quotations will be requested within the next two weeks.

An abstract of a paper entitled "A Method of Achieving Clinically Useful Pion Dose Distributions" by A. S. Luncy, J. A. Helland, R. L. Hutson, D. J. Liska, J. D. Wallace, and E. Rodgers was submitted for the annual meeting of the Association of University Radiologists in Vancouver, Canada, on May 9-12. The paper has been accepted and will be given by Lundy.

Shielding

Shielding against small average beam loss is being planned to permit a total spill about 0.2% of full proton beam, distributed from roughly 20 ft upstream of the biomed stubout to 10 ft downstream of the stubout. This amount of loss will then be tolerable for people who are working in the treatment room while the beam is passing through the area and the biomed target is retracted.

The steel required to shield against a total of 0.2% spill in the biomed vicinity is divided into two distinct parts. First, steel will be placed in the proton tunnels both east and west of the biomed stubout extending to the beam stop to the east and to the A4 stubout to the west. It is accepted that we will have only one chance to place this steel; the tunnel is the only area where there is strictly no overhead access and where "hands on" maintenance is not required, i.e., where induced activity is not controlled. In addition, the tunnel east of the stubout will be inaccessible from the west because of biomed and from the east because of the beam stop. The second category of steel is the wall "liner" that covers the north wall of the stubout with steel (from elevation 6953 ft to 6968 ft) and, partially, the east and west walls of the stubout over the same elevations. This steel is to be stacked against the concrete walls on the second and third levels of the support structure. Cost and practicality have combined to dictate that this steel be placed in small, hand-stackable pieces. This steel is the last phase of the shielding and can be installed as needed. If the cost is determined to be excessive, the shielding can be postponed with the understanding that persons do not stay in the treatment room for extended periods while the proton beam is on.

Biomedical Channel Range Shifter

Some progress was made this quarter on the design of the variable thickness energy degrader. It

was decided to build two prototypes, one based on the original high-flow, low-pressure concept and the other a precise direct-drive hydraulic servomechanism. The former is almost complete and will be used to gain operating experience. The latter is presently conceived to be the final form of the system. It is shown in Figs. 38 and 39. The design criteria used are 1) minimize depth along the beam line to provide more room for technicians and patient, 2) provide fast response to match the high-harmonic sweep curve required for uniform dose. The means of achieving 1) is to utilize a metal bellows, 9.5 in. i.d. with 6 in. stroke and capable of 10^7 full-stroke cycles. The plastic window attached to the bellows is driven by three hydraulic actuators immersed in the fluid. The use of hydraulics and high performance servovalves makes 2) easier to achieve. The system operates at atmospheric pressure and is a closed system with actuation energy provided by a constant pressure gas-charged accumulator and refill provided by a pump acting off the vented reservoir.

Biomedical Channel Electrometers

The two integrating electrometers for the biomed channel have undergone extensive reliability testing and are entering a phase of testing for temperature drift effects. The NIM bin which houses these modules is ready for use. The error-sensing module is currently under test. Conceptual design for a quadrant ion chamber electrometer system has begun.

Fig. 38. Schematic of automatic controlled-energy degrader.

Fig. 39. Schematic of energy degrader hydraulic servomechanism.

Biomedical Channel Pion Beam Tuning

Three multiwire proportional counters are being tested using the old LAMPF (Martin on-chamber) amplifiers. The purpose of these tests is not to check out the chambers or amplifiers, since they are essentially obsolete, but rather to develop the related software and hardware for the MWPC system. The decision has been made to replace the Martin (on-chamber) amplifiers, of which only 20 boards exist, with a modified LBL design. Tests are under way on one of these amplifier boards and approximately 20 more will be received around July 1. At that time the MWPCs will be rebuilt to accommodate the new amplifier boards. In the interim, numerous bugs in the MWPC system are being eliminated. The latest addition to the system is a graphic display unit for the visualization of particle distributions, histograms, trajectories, etc. Extensive software along these lines is being developed.

Radioisotopes

Many of the results obtained in the series of experiments conducted at the Space Radiation Effects Laboratory are being published. A paper on half-life measurements on ^{172}Hf and ^{194}Hg is being published by Inorganic and Nuclear Chemistry Letters. The results of the interlab comparison of analysis techniques with Battelle Northwest Laboratory and Aerojet Nuclear Corporation using irradiated Fe and Cu targets have been written up in a paper now ready for submittal to Physical Review. A paper is now in preparation describing the results of the V, Co, As, Nb, Ta, and Bi irradiations, including comparisons with theoretical results obtained with the

Brookhaven and Oak Ridge intra-nuclear cascade and evaporation codes.

Results of the Society of Nuclear Medicine questionnaire regarding the anticipated use of ^{123}I , ^{127}Se , ^{67}Ga , ^{111}In , ^{52}Fe , and ^{48}Co have been compiled. Generally speaking, there were no surprises; the anticipated demands for each product being equal to or greater than our previous estimates. A letter describing the results will be sent to all members of the Society that responded to the questionnaire.

Theoretical Studies for Hospital Accelerator

Calculations are in progress to determine the optimum proton energy for producing negative pions in the 70- to 90-MeV range at moderate lab angles (45° - 90°). The theory being used to treat the fundamental particle-particle interaction is the one-pion-exchange isobar model. These results will be used as input for the code¹ treating nuclear effects. Problems dealing with unitarity corrections, absorption effects, and form factor dependence are also being considered. Theoretical predictions should provide a guide for preliminary experiments being planned in connection with the development of a hospital-scale accelerator for negative-pion radiotherapy.

Three-Dimensional Dose-Distribution Calculations

Collaboration continued with ORNL personnel who are doing Monte Carlo calculations of pion dose. Results of a calculation of the effect on the dose distribution of a slab of bone imbedded in soft tissue were received from ORNL and were evaluated.

A proposed scheme for calculating dose distributions in a patient using realistic beam and collimator configurations was outlined at the flow-diagram level.

Efforts were initiated to study the feasibility and advisability of developing the capability of doing calculations, at LASL, similar to those done at ORNL.

Technology Transfer

Radio-frequency Tissue-Heating Studies. - (The basis for this work was outlined in the previous quarterly report, LA-5262-PR.) Two primary goals in this effort are to:

- 1) Improve the methods of localizing heat in spontaneous animal tumors. A referral service has been set up at the UNM School of Medicine for the treatment of such tumors.

2) .Test the response of normal tissue to different dose levels. This is also being done at the UNM School of Medicine.

Four dogs have had spontaneous tumors treated. Although three of these animals are considered terminal cases, initial results have been encouraging. Differential response to the treatment between normal and cancerous tissue has been seen on at least one animal.

Negative Meson Capture In Matter

Calculations are continuing on the capture of negative mesons in matter.

We consider the life of the mesic atom in three stages: (1) Initial Capture, (2) Deexcitation through the Electron Cloud, and (3) Deexcitation below the Electron Cloud. (1) and (2) are handled using the Fermi-Teller Model while (3) is described quantum-mechanically. Some supposed discrepancies with the work of Fermi and Teller which affect (1) and (2), have now been resolved, and, further, the role of an electronic energy gap has been formulated. Computer programs had been developed for each of the stages and have now been put together in a single program which predicts the intensities of the observable x-ray lines. It has been found that the change in shape of the λ -distribution in stage (2) is so slight as to be negligible. We have also found that changing the atomic potential (from Thomas-Fermi to Dirac-Hartree-Fock) affects the x-ray intensities only a minor amount (a few percent or less).

In order to test our model, we want to compare our predictions with experimental absolute x-ray yields (using relative yields is a much less stringent test of our understanding of the atomic physics), and since the most extensive data are for K^- capture we have been concentrating on these. Comparing with Weigand's 1969 data over a large range of atomic number Z we note that (a) the agreement is surprisingly good, considering that we are using an *ab initio* calculation with no adjustable parameters; (b) the observed large (and non-monotonic) variation in Z of the maximum line intensities is not reproduced.

In regard to (b), we note that some Z variation is present which comes from the influence of detailed atomic structure (as opposed to the structureless Thomas-Fermi atom) in stage (3). This leads us to

suspect that including the effects of detailed atomic structure in stage (1) might produce the observed variation; this inclusion means replacing the Fermi-Teller Model by a more general one, the "Fuzzy Fermi-Teller" Model, which we have been developing.

A report of this work was made (jointly with R. Seki, who has been collaborating on this problem) at the Washington A.P.S. Meeting (April), and another will be contributed at the Fifth International Conference on High Energy Physics and Nuclear Structure, Uppsala, Sweden (June 1973).

Biomedical Low-Energy Pion (LEP) Proposal

Work on a research proposal for the "Study of the Radiobiological Properties of Negative Pions" is in progress. The physics portion of the proposal is complete and the biomedical section is nearing completion. The proposed program is to be carried out at the LEP channel prior to the completion of the biomedical channel. A dose rate of ~ 2 rads/min can be obtained at the LEP channel, assuming a $10\text{-}\mu\text{A}$ proton beam, a 3-cm Al_2O_3 target, maximum available solid angle and momentum bite, and a pion path length of ~ 18 m. The pion beam will be transported through the equipment of Exp. 96 and focused on our apparatus using the spare proton doublet quadrupole. With this dose rate, it will be possible to make the early RBE measurements that are crucial for subsequent pre-clinical and clinical radiobiology experiments.

In Vivo Tissue Analysis with Mu-Mesic X-Rays (Experiment 100)

Cooperation with Group VC-11 in planning for Exp. 100 has continued. Plans are progressing to obtain an intrinsic Ge detector of moderate volume in order to make possible high-resolution measurements with good counting efficiency.

The list of possible applications of mesic x-ray tissue analysis is being expanded with the help of personnel at the University of Arizona Medical School.

¹ M. M. Sternheim and R. R. Silbar, Phys. Rev. D 6, 3117 (1972).

IX. RESEARCH TO BE MOUNTED AT LAMPF

Program Advisory Committee

The next meeting of the Program Advisory Committee has been set for September 19-21, 1973, to be held at LAMPF. At that time, all new, revised and resubmitted proposals for LAMPF, received through July 31, will be considered.

Engineering Review Committee

Comprehensive engineering reviews of approved experiments were initiated during this quarter.

Research Proposals

During this quarter, the following new research proposals have been received:

141 "Search for a Light Scalar Boson"

C. K. Hargrove, Spokesman

C. K. Hargrove, R. J. McKee, H. Mes (National Research Council of Canada); D. Kessler, R. W. Morrison, J. Walters (Carleton Univ.); E. P. Hincks (National Research Council of Canada and Carleton Univ.)

142 "Negative Muon-Induced Fission in the Actinide Elements"

John R. Huizenga, Spokesman

J. R. Huizenga, C. Kalbach-Cline (Univ. of Rochester); Z. Sujkowski (Inst. for Nuclear Research, Warsaw, Poland); J. P. Unik (ANL)

X. LAMPF USERS GROUP

Users Activities

An EPICS Working Group meeting was held in Los Alamos on April 3, 1973, with Stanley E. Sobottka (Univ. of Virginia) chairing the meeting. H. A. Thiessen (LASL representative) gave a status report on the EPICS channel and discussed recent action of the Program Advisory Committee, summer plans, and the procedures for tune-up of the channel. There were also reports on detectors, the scattering chamber, measurements, data-acquisition programming, and controls programming. R. J. Peterson (Univ. of Colorado), Secretary of the EPICS Working Group, prepared a report on the meeting, which was sent to all members of the EPICS Working Group by the Liaison Office. A combination EPICS and HRS Working Group meeting is scheduled for July 30-August 2, 1973 in Los Alamos. Letters of invitation to all members will be mailed out in the near future.

A meeting of the HRS Working Group was held on April 22 in Washington, DC. The meeting was chaired by Harry Palevsky of BNL. The agenda included: 1) present status of magnet construction, assembly, and testing; 2) ray-tracing measurements; 3) multiwire proportional counter (MWPC) detectors; 4) status of proposed experiments; and 5) plans for machine start-up and early scheduling.

Board of Directors and Technical Advisory Panel

The Board of Directors of the LAMPF Users Group, Inc. met February 25-26, 1973 in Los Alamos. The first order of business was a discussion of the housing situation for LAMPF Users in Los Alamos. The Board looked at preliminary plans for a proposed user's housing complex to be located in Los Alamos. Various sites were discussed. The Board felt that a presentation should be made to the Univ. of California Regents at their April meeting in Los Alamos. The Board took action in requesting that LASL provide dormitory sleeping trailers at the LAMPF site for this summer.

Louis Rosen discussed with the Board the impact of the FY-74 budget. The main impact will be the operation of 11 shifts/week, rather than the originally planned 15 shifts/week.

In other business, Lewis Agnew was reappointed Secretary/Treasurer for the LAMPF Users Group, Inc. for 1973. The Board was apprised of the list of 973

members of the LAMPF Users Group. The Treasurer's report showed that as of January 1, 1973, there was a balance of \$1,654.84 in the bank account. The Board requested that a letter be written to G. Victor Beard of Associated Western Universities (AWU), requesting further financial support from AWU during FY-74. The Board also requested that a summary of the minutes of the Board of Directors meetings and the TAP meetings be included in the newsletters in the future and that copies of the newsletters be distributed to the LAMPF Policy Board and the Program Advisory Committee. The LAMPF Users Group, Inc. will bear the initial expense of having telephones installed in the 25 LASL-administered apartments for LAMPF users, and the users will be billed for the basic service plus \$2.00/month.

The Board of Directors appointed TAP members for 1973-1974, following the recommendations of the Working Groups. New appointees are as follows:

- T. H. Blewitt (ANL)
Radiation Damage
- R. Eisenstein (Carnegie-Mellon Univ.)
EPICS
- E. E. Gross (ORNL)
LEP
- D. C. Hagerman (LASL)
General Development of LAMPF
- R. Hendee (Univ. of Colorado Medical Center)
Biomedical Facility
- W. McFarlane (Temple Univ.)
P³

TAP members serving the second year of their two-year terms are:

- E. Chrien (BNL)
HRS
- S. Kaufman (ANL)
Nuclear Chemistry
- P. Nemethy (Yale Univ.)
Neutrino Facilities
- J. E. Simmons (LASL)
Nucleon Physics Laboratory
- R. E. Welsh (Coll. of Wm. & Mary)
Muon Channel
- C. S. Wu (Columbia Univ.)
Experimental Facilities

M. M. Kligerman, M.D. (Univ. of New Mexico School of Medicine) and M.L.M. Boone, M.D. (Univ. of Arizona Medical Center) have been appointed as advisors to the TAP in the field of biomedical applications of LAMPF.

The Board of Directors also appointed a subcommittee to study the function of the TAP and to

explore its role and the new functions brought about by the actual operation of LAMPF. The members are Mark Jakobson, Darragh Nagle, and Stanley Sobottka.

The Nominating Committee for 1973 was selected and consists of the following:

- Harry Palevsky (BNL), Chairman
- Herman Feshback (MIT)
- M. M. Kligerman, M.D. (UNM School of Medicine)
- D. E. Nagle (LASL)
- A. L. Turkevich (Univ. of Chicago)

In action taken since the meeting, Chairman Mark Jakobson gave a presentation of the housing problem for LAMPF Users to the Board of Regents, outlining the type and number of units needed.

Liaison Office

Minutes of the February 25-26 Board of Directors meeting were prepared and copies sent to all members of the Board. A letter dated February 22, 1973, from W. K. McFarlane, TAP Representative for P³, giving an informal report on the November TAP meeting was mailed to all Working Group members in February. Letters of invitation to the EPICS Working Group meeting were sent to all members of that group. Letters of invitation were also mailed to the HRS Working Group announcing the HRS meeting in Washington on April 22. The final portion of the recommendations of the subcommittees of the LAMPF Biomedical Users Steering Committee entitled "Recommendations for Implementing Radiotherapy with Negative Pions at LAMPF" was mailed to people interested in the biomedical applications of LAMPF.

Other documents prepared and distributed to all members of the LAMPF Users Group, Inc. by the Liaison Office are the April 1973 Newsletter and LA-5190-C, "The Proceedings of the Sixth LAMPF Users Meeting". The Quarterly Report on the Medium-Energy Physics Program for the Period Ending October 31, 1972, and a letter from Louis Rosen to the LAMPF Users dated February 7, 1973, reporting on LAMPF developments since the last Users meeting, were also mailed to the entire membership and including an invitation to LAMPF Users to participate in the Practical Applications of LAMPF.

In addition to the LASL-administered apartments (20 kitchenettes, 2 one-bedroom and 2 two-bedroom apartments) that have been assigned LAMPF Users for the summer, about 30 Users have been assisted with finding outside housing.

Work is still in progress in arranging for telephones to be placed in the LASL-administered apartments for Users and arranging for transportation for Users. A new LAMPF Users Handbook is in the process of being prepared at this time.

The following Tables give some of the statistics of the Users Group membership:

TABLE I. FIELDS OF INTEREST

Nuclear & Particle Physics	675
Nuclear Chemistry	157
Biomedical Applications	348
Not Specified	19
Other (including administration, facilities, operations, coordination, and miscellaneous applications)	383
Isotope Production	84
Radiation Damage	116

(Note: These numbers do not add to total membership because there are duplicate interests.)

TABLE III. REGIONAL BREAKDOWN

EAST (PA, NJ, DE, DC, MA, NY, CT, VT, RI, NH, ME)	156
MIDWEST (OH, MO, KS, IN, WI, MI, IL, ND, SD, NB, IA, MN)	102
SOUTH (MD, VA, TN, AR, WV, KY, NC, SC, AL, MS, LA, GA, FL)	84
SOUTHWEST-MOUNTAIN (MT, ID, UT, WY, AZ, CO, NM, OK, TX)	202
FAR WEST (AK, HI, NV, WA, OR, CA)	113
FOREIGN	100
LASL	178
TOTAL	935

TABLE II. INSTITUTIONAL DISTRIBUTION OF USERS GROUP MEMBERS

LASL	178
Other National or Government Laboratories	121
Universities	394
Industrial	32
Hospitals & Medical Centers	110
Foreign	100
Total	935

TABLE IV. AFFILIATION OF PARTICIPANTS IN LAMPF RESEARCH PROPOSALS

U. S. Universities	216
LASL	92
Other National or Government Laboratories	39
Foreign	16
Total	363