50
- 2

LA-4850-PR

A PROGRESS REPORT

2032

MASTER

Quarterly Status Report on the
Medium-Energy Physics Program
for the Period Ending October 31, 1971

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

↓ ↓

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

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

LA-4639-MS

LA-4692-MS

LA-4571-MS

LA-4753-MS

In the interest of prompt distribution, this report, like other special-purpose documents, has not been edited for accuracy.

Printed in the United States of America. Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.95

LA-4850-PR
A Progress Report
UC-28

ISSUED: December 1971

Quarterly Status Report on the
Medium-Energy Physics Program
for the Period Ending October 31, 1971

Compiled by

Eleanor D. Dunn

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

I. SUMMARY

Accelerator Structures

The major progress reported in this quarter is the attainment of 211-MeV beam through module 12 of LAMPF. This was achieved on August 27, some 35 days ahead of schedule.

Fabrication of the side-coupled linac is progressing satisfactorily with 77% of the tank sections complete. Work on the magnets for the transition region has continued and installation is scheduled for December 1971. Several changes in tuning procedure for the 805-MHz structures have been required in order to eliminate large field excursions which appear to be caused by the "septum pulling" tuning technique employed heretofore.

RF Power Systems

A gratifying result of the past quarter was the successful operation of the accelerator at an energy of 211 MeV. Although much must be learned before beam loss is reduced to an acceptable level, the simultaneous and apparently satisfactory operation of nearly all the different types of subsystems in the accelerator was most pleasing.

The production and testing of klystrons and modulators continues on schedule. Some difficulties have been experienced with the initial klystron production at Litton; as yet, these difficulties appear tractable.

Installation of the rf system continues on schedule.

The design of the electronics controlling phase and amplitude pressed toward optimization, particularly in the 201.25-MHz systems. Control of the field to better than 1% in amplitude and 1 deg in phase over the entire beam pulse, including the beam-induced transient, has been routinely demonstrated.

The study of the integrated 805 accelerator system continues to receive substantial attention. This is a very complicated system and in many respects is not completely understood. Again, the major difficulty is related to the tuning of the accelerator sections. The problem is primarily a combination of lack of optimum tuning procedure and an adequate determination of the maximum allowable errors in the structure. It appears this may well

be the pacing item for completion of the accelerator.

Support engineering continues on magnet power supplies, beam separators, window coating, etc.

Accelerator Control and Instrumentation

The control system performed successfully during the 211-MeV beam test. The control computer was used to change the energy of the protons and to phase the beam for maximum transmission. Since then, the console in the Central Control Room has been the center of operations several nights a week.

The programming effort was divided evenly between systems and applications programs. The systems programming was concentrated on an effort to have the control computer operational 24 h/day by January. Applications programs were written to aid the 211-MeV test, to automate the turn-on and operation of the 805-MHz linac, and to monitor the status of the accelerator.

A major effort went into compiling and updating the wiring records, drawings, and manuals for the Injector A control systems. These systems are now considered complete except for a modest program of improvements. Substantial progress was made on the wiring for Injector B.

The control system for the drift-tube linac remained essentially unchanged. It was in operation almost daily throughout the quarter. Prior to the 211-MeV test, the work of wiring and device installation was concentrated in modules 5-12. Since then, work on the remainder of the accelerator has progressed in a systematic manner. Installation of the control systems for the Transition Region was started.

A preliminary channel list was generated for the local and computer controls in the beam switchyard. A tentative assignment was made of the space in the 20 racks allocated to Beam Lines A and X. The first order for radiation-resistant wire was released for bids. The control philosophy for the Biomedical Facility was developed.

Accelerator Physics

The H^+ injector system (Injector A) has been operated extensively during this period. Operating time scheduled was 663 h, 75% of which time the injector delivered beam. Ion source lifetime has improved. Two critical parts of the ion source assembly, the cathode and the extractor aperture, have operated 600 h without failure.

Considerable effort has gone into experiments to understand the properties of the dc accelerating column. The column is expected to give the best emittance and overall good performance when operated at the design (Pierce) value of the current, since space charge effects are incorporated into the design. Measurements show an interesting correlation between the total beam current and the x-ray output, and the current at the electron trap electrode: These quantities have a broad minimum near the design current and rise steeply on either side. It appears that the rate of column arc-down is also correlated with the high radiation level. This indicates the desirability of operating the column at the design instantaneous current. If the average beam current is to be varied, varying the rep rate and the pulse length is preferable to dropping the injector current, although the duty factor suffers. However, physics experimenters will demand varying current at constant duty factor. A possible avenue to resolve this problem is being studied, namely collimation in the transport line.

A rather detailed study has been carried out of the beam transverse emittance patterns along the transport line between column and linac. A tune-up procedure has been developed which permits 16 mA of beam to be accelerated out of 23 mA-input. A considerable amount of comparison of calculations with experiment has been done. However, further studies of the performance of the column are indicated and are scheduled for next quarter.

The H^- Cockcroft-Walton has been installed in its bay. The new H^- ion source is being fabricated. The testing and development of H^- sources continues. The fabrication of the accelerating column system is well along. The bending magnets and power supplies for the H^- transport line have been received, and the quads should be delivered in November. Design and fabrication of beam-line hardware is on schedule.

The Electron Prototype Accelerator (EPA) was operated with high reliability during the quarter. The proton-Compton-effect experiment, the e-e' experiment, the photofission experiments, and the activation analysis experiments were completed as scheduled. The target tests are nearing completion. Beam time was available for 802.75 h and was used for 701.25 h. Some work is being done in preparation for shut-down of the EPA by 31 December 1971.

The drift-tube linac operated for 218 h during the quarter. The side-coupled cavity logged 5 h of operation, during which time the 211-MeV milestone was achieved. Further operation of the side-coupled linac was postponed until completion of the temporary shield at module 15.

Experimental Area

The layout for the beam lines in Area A has been slightly modified for more efficient use of the floor space. This area is presently being used as a staging area. Beneficial occupancy of the switchyard has been obtained. Areas B and C are in an advanced stage of construction, and the Area A East/Beam Stop A construction package is in progress. Funds have been received for the beam line components for the biomedical pion channel.

All magnets for the Area B beam lines are either on hand or on order. Plans have been made for a beam test of the prototype liquid deuterium target.

All magnet and power supply components of Beam Line C and the High Resolution Proton Spectrometer are either on hand or proceeding according to schedule, except for two bending magnets that were delayed for redesign. Plans for slits, steering magnets, diagnostic devices, and beam monitoring apparatus are being drawn up. A prototype scattering chamber is being designed.

A final optics design for the EPICS Channel has been reached. Partial orders for the four bending magnets have already been placed. The optics design of the EPICS spectrometer is in its final stages and engineering design will start soon. Progress is being made on the conceptual design of the support structure for the channel and separator. A change in the production angle will yield an improvement in pion flux.

The Low-Energy Pion Channel now has all magnets either on order or on hand. Engineering for the support structures and the other channel components is in progress. Preliminary plans have been made for shielding enclosures and counting areas.

The magnets and power supplies for the P^3 Channel are all on hand or on delivery. Preliminary shielding and support system designs have been made. The locations of the P^3 Channel and the Stopped Muon Channel have been exchanged to better use the floor space in Area A. Many of the Stopped Muon Channel magnets and power supplies have already been

delivered. Still pending is fabrication of the three cement-insulated magnets at the beginning of the channel. Shielding calculations have been carried out and preliminary design of the muon caves have been made. A parasite beam with a flux of $\sim 10^5 \mu\text{+}/\text{cm}^2 \text{ sec}$ can be obtained with no difficulty.

Optical design of the Biomedical Pion Channel is continuing and initial engineering studies have begun. Monte Carlo calculations of the neutrons streaming down the channel and penetrating the shielding are being carried out. Other areas where effort is being placed are channel maintenance requirements, design of the pion production target, beam diagnostics, and computer control philosophy. It is expected that a PDP-11/20 or a PDP-11/45 computer will be acquired for the biomed channel.

The mineral-insulated bending magnets for the switchyard are well in hand, with two lots already received and measured, and the third lot ready for inspection at the vendor's plant. The harmonic content of the 8-in.-narrow quadrupole has been measured and the effects of chamfering the pole ends are under study.

Radiation damage tests have been carried out to over 10^{10} rads of fission flux in the Omega West Reactor for epoxy-fiberglass insulation for magnet coils. The initial result is encouraging. Tests of mineral-insulated conductors are in preparation.

The magnet measuring apparatus has been upgraded with the acquisition of a new magnetic tape unit for data storage, further progress on the rapid-mapper, and the construction of several new coils designed for special purposes.

Testing of water-cooled graphite targets at the EPA has come to a successful conclusion. On the basis of results at the EPA, a ZTA graphite target in a copper jacket with nickel coating has been chosen for testing in the LAMPF 100-MeV beam. Testing of wheel targets made of molybdenum and graphite has begun.

Calculations have been made on a water beam stop for the main LAMPF 800-MeV beam.

Fabrication of the magnet stands for the switchyard is under way. Installation drawings for the magnets, power supplies, and cable runs in the switchyard have been completed.

Delivery of the pump-heat exchanger water systems will begin soon. Fabrication of the components

of the ion exchanger and filter systems is under way. The permanent Area A cooling-water distribution systems are being designed.

The Beam Profile Monitor (nonintercepting) has had its first successful test. The beam centroid was resolved to within 0.01 in., and better spatial resolution is expected as the result of the changes in progress. Good sensitivity was observed. Work is continuing on several other monitoring devices.

Preliminary planning for the LAMPF Equipment Pool has begun with surveys of the requirements of approved experiments.

Assembly of Merrimac is under way. The wheels are being attached to the gantry frame, including the wheel drive and steering mechanisms. The shield box is being completed. Essentially all design and installation drawings for Merrimac have been finished. Difficulties have been experienced in disassembling lead-glass windows obtained as surplus items, and new handling techniques are being developed. A number of high-quality surplus manipulators are enroute to Los Alamos from the Nevada Test Site. The main Merrimac access doors for the target stations in Area A have been conceptually designed.

Detailed shielding studies are under way using the ORNL transport code NMTC. Runs have been made for protons incident in carbon and for pions of several energies incident in concrete. These studies have shown the need for re-entrant holes for pion beam stops to reduce the backward neutron escape route. Techniques for obtaining reliable statistics with some economy in computing time are being developed. Considerable information on the flux and the angular and energy distributions of neutrons and charged particles that escape from beam stops of various geometries or materials can be gleaned from the calculations.

Overall stacked shielding requirements have been estimated for the beam stops and for Area A. Design of the main shield mass in Area A has begun.

Analysis of the radioisotope production data continues. Discrepancies with other published data are noted, and results do not agree with calculated predictions in a number of cases.

LAMPF Scheduling and Facility Construction

A one-month strike of the Zia Co. plumbers and pipefitters, with picket lines honored by all other crafts, ended at the outset of this report period.

Extensive reviews of activity sequences and durations have been conducted from which it has been concluded that recovery of the lost construction time will not be feasible.

Physics Research

Pion-Absorption Experiment

Two papers on the (π, p) and $(\pi^+, 2p)$ experiments were prepared for presentation at the IVth Intl. Conf. on High Energy Physics and Nuclear Structure held at Dubna, USSR, and at the Intl. Seminary on π -Meson Nucleus Interactions held at Strasbourg, France.

Meson Chemistry

In order to understand the relationship between the high-energy-level perturbations that occur in chemical systems and the shifts in intensities of low-level transitions that are observed in muonic x-ray spectra, a thorough understanding of the cascade process in these sometimes complicated systems is required. Theoretical studies are under way to delineate the influences of the various interactions such as radiative vs Auger processes, Stark-mixing, etc.

Medical Applications of Muonic X-Rays

Studies are being continued of the possibilities of utilizing the characteristic pi- and mu-mesic x-rays, resulting when stopped pions and muons are captured in given elements in tissue, as a tool for tumor localization or for in vivo tissue analysis.

One hundred hours of beam time were approved by the LAMPF Program Advisory Committee for performing preliminary mesic x-ray studies using mammalian tissue as the muon stopping material.

Proton-Compton-Effect Experiment

Work was continued on the experiment to measure the low-energy proton-Compton-effect cross section using the 27-MeV beam from EPA. Data were taken for a total of ~ 100 h. Since the data were taken in large time blocks, this was an excellent test of computer-based data-acquisition systems. After the major data runs were complete, an effort was made to replace the custom-built interface with CAMAC units which were purchased for evaluation on this experiment. After several weeks of effort, a short data background run was successfully taken using the CAMAC system. The data from these runs are now being evaluated.

Multiwire Proportional Counter (MWPC) Development

Studies of applications of multiwire proportional counters in experiments have been continued. Construction has been started of a wire winder for large wire chambers, based on the design used at NAL. It is expected that this machine will be operational during the next quarter, and then large chambers can be wound at LAMPF.

An effort has been started to standardize on MWPC interfaces at LAMPF, based on LASL's original design. This standard interface will be submitted to various manufacturers of CAMAC units for bids. Construction is nearly complete of one prototype interface unit.

LAMPF Users Group

About 100 participants heard 40 presentations at the 1971 LAMPF Summer Study Sessions on position-sensitive detectors and beam measurements and monitors held on 9-13 August 1971. The proceedings have been compiled and will soon be distributed to all members of the LAMPF Users Group.

The annual election of officers for the Users Group was conducted by mail ballot during October. The 1972 slate of officers will be:

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

Preparations were completed for the Fifth LAMPF Users Meeting to be held at Los Alamos 8-9 November 1971.

Thirteen new or modified research proposals were received since the previous quarterly report. The Program Advisory Committee met in Los Alamos on 21-23 October 1971 to hear presentations on about 25 research proposals that had not been reviewed earlier. Several resubmitted proposals were reconsidered. A summary of the actions taken is given in the text of this report.

Publications

- D. J. Liska, "Multipactoring Electron Gun for High Duty Linacs," Proc. IEEE, 59, 1253 (1971).
- D. J. Liska, "Electric Field Measurements in Klystron Cavities," IEEE Trans. on Electron Devices ED-18, 450 (1971).
- J. L. Detch, Jr., R. L. Hutson, N. Jarmie, and J. H. Jett, "Accurate Measurements of the Nuclear Processes $T(p,p)T$, $T(p,^3\text{He})n$, $T(p,d)D$, and $T(p,p)T$ from 13 to 20 MeV," Phys. Rev. C4, 52 (1971).
- J. L. Gammel, Mary T. Menzel, and W. R. Wortman, "Bethe-Salpeter Solution for Nucleon-Nucleon Scattering with Pion Exchange in the 1S_0 and 3P_0 States," Phys. Rev. D3, 2175 (1971).
- L. Rosen, "Relevance of Particle Accelerators to National Goals," Science 173, 490 (1971).
- P. J. Tallerico, "Design Considerations for the High Power Multicavity Klystron," IEEE Trans. Electron Devices ED-18, 374 (1971).
- R. L. Hutson, N. Jarmie, J. L. Detch, and J. H. Jett, " p - ^3He Elastic Scattering from 13 to 20 MeV," Phys. Rev. C4, 17 (1971).
- LA-4795-MS, "Investigation of Graphite and Carbon for Stripping the H^- Beam in LAMPF," D. J. Liska.

Papers Prepared for Publications; Papers Submitted at Conferences

- D. F. Jones and E. R. Martin, "A System for Separating Amplifiers from Wire Proportional Chambers," submitted to Nucl. Instr. and Methods.
- E. R. Martin and D. F. Jones, "A Fast Total Information Readout System for Multiwire Proportional Chambers," *ibid.*
- J. Amato, R. L. Burman, R. Macek, J. Oostens, W. Schlaer, E. Arthur, S. Sobottka, W. Lam, P. Barnes, P. Fessenden, W. Swenson, D. Axen, and M. Salomon, "New Measurements of (π^+, p) Reactions on Light Nuclei," Intl. Conf. on High Energy Physics and Nuclear Structure, Dubna, USSR, Sept. 9-11, 1971, and Intl. Seminary on π -Meson Nuclear Interactions, Strasbourg, France, Sept. 20-22, 1971.
- J. Amato, R. Burman, R. Macek, J. Oostens, W. Schlaer, E. Arthur, S. Sobottka, and W. Lam, "Cross Sections for (π^+, p) Reactions on ^9Be , ^{12}C , and ^{16}O ," *ibid.*
- J. Amato, R. Burman, and M. Jakobson, "The LAMPF Low Energy Pion Line, IV Intl. Conf. on High Energy Physics and Nuclear Structure, Dubna, USSR, Sept. 7-11, 1971.
- D. R. F. Cochran, P. A. M. Gram, E. A. Knapp, E. R. Martin, D. E. Nagle, W. J. Schlaer, H. A. Thiessen, R. B. Perkins, P. N. Dean, and E. D. Theriot, "Production of Mesons by 730-MeV Protons Incident on Various Nuclei," *ibid.*
- L. Rosen, "Status of Los Alamos Meson Physics Facility," (invited), *ibid.*
- P. W. Allison and C. R. Emigh, "LAMPF H^- Ion Source Development," Symp. on Ion Sources and Formation of Ion Beams, Oct. 19-21, 1971, Brookhaven.
- C. R. Emigh, E. A. Meyer, D. W. Mueller, and R. R. Stevens, Jr., "LASL Experience with a Duoplasmatron Feeding a 750 KV 'Exact' Pierce Column," *ibid.*

- P. A. Thompson, "Muonium Hyperfine Structure," Muon Physics Conf., Ft. Collins, Colo., Sept. 6-10.
- P. A. Thompson, "Facilities for Muon Physics at Los Alamos," *ibid.*

II. ACCELERATOR STRUCTURES

Mechanical Engineering LAMPF Accelerator Structures

201-MHz Structures

The drift-tube linac contains 165 cells made up of 12 different groups with the groups containing 6 to 16 drift tubes. All drift tubes in a given group are identical except for the body or cell length. One spare drift tube for each group is being fabricated which will be identical to the longest cell of that group. In the event of a drift tube failure, this spare can be machined rather quickly to the proper body length as a replacement for the defective component. Table I shows the status of these spare drift tubes.

The cell-164 drift tube was completed, tested, and installed in place of the spare which was temporarily used in the linac. Replacement-cell-80 drift tube was completed and tested and, during some future maintenance period, will be installed in place of the drift tube now in use. The cell-80 drift tube now in service was found to have a leak (detectable with a He leak detector) through the conductor from the water passage to the soft vacuum in the

TABLE I

SPARE DRIFT TUBES

Tank	Spare for Cell Nos.	Status
1	1 - 6	Completed
1	7 - 14	Completed
1	15 - 30	Completed
2	32 - 40	Drift-tube parts completed, magnet being rebuilt
2	41 - 49	Completed
2	50 - 59	Drift-tube parts completed, magnet being rebuilt
2	60 - 71	Drift-tube parts completed, magnet being rebuilt
2	72 - 84	Drift-tube parts completed, magnet being rebuilt
2	85 - 96	Drift-tube parts completed, magnet being rebuilt
3	98 - 116	Drift-tube parts completed, magnet being rebuilt
3	117 - 134	Drift-tube parts completed, magnet being rebuilt
4	136 - 164	Completed

TABLE II

TRANSITION REGION-MAGNET STATUS

Magnet	Status
TR-BM-01	Completed and tested at low current
TR-BM-02	Completed and tested at low current
TR-BM-03	Machining completed, coils being coated
TR-IM-04	Machining completed, coils being brazed
TR-BM-05	Completed, tested and in place
TR-BM-06	Machining completed except coils
TR-BM-07	Completed and tested at low current
TR-BM-08	Machining completed except coils
TR-QD-01	Completed and tested
TR-QD-02	Completed and tested
TR-QD-03	Completed, tested and in service
TR-QD-04	Completed, tested and in service
TR-QD-05	Completed and tested
TR-QD-06	Completed and tested

drift tube. However, the leak is too small to permit water transfer and has not impaired operation in any way.

The ceramic drive-loop dome of Tank 3 imploded on October 13, after 569 hours of high voltage operation, for no apparent reason. There was no evidence of arc marks on either the drive loop or the ceramic dome. However, black conductive spots were observed on the vacuum side of some of the broken pieces; these spots are being analyzed in an effort to determine their composition. Four additional domes are being made, with delivery expected in early November. These four domes will be coated on both sides with $\sim 100 \text{ \AA}$ of titanium. Quotations for both flat disc and conical ceramic rf window configurations are being solicited and machining of mechanical components for this new design is under way.

Transition Region

Figure 1 is a schematic of the Transition Region. The magnets shown in black have been completed. Table II shows the present status of all Transition Region magnets.

Fig. 1. Status of Transition Region magnets.
(Magnets which have been completed and tested are shown in black.)

Iron for the spare quadrupole magnets is on hand. Coils have been assembled and are being potted. A typical quadrupole doublet is shown in Figs. 2 and 3. Table III lists the magnet parameters.

Fig. 2. Typical quadrupole doublet
(TR-QD-01 before assembly).

Fig. 3. Assembled TR-QD-01 quadrupole doublet.

TABLE III

TR-QD-01 THROUGH 06 MAGNET PARAMETERS

Design gradient	4.0 kG/cm
Design current	930 A at 7 V
Overall length	13-1/2 in.
Effective length of each quad	4-3/8 in.
Outside diameter	5 in.
Bore diameter	1.30 in.
Water-cooled	
Radiation-resistant (alumina-filled epoxy) insulation	

Figures 4, 5 and 6 show the TR-BM-01 coil, iron, and the completed magnet in its housing. The housing positions the magnet within the last half drift tube of Tank 4. TR-BM-04 is identical except that it has no housing but uses protective coil covers. The coil uses metalized alumina buttons for insulation between turns and fixturing for brazing in the hydrogen furnace. Quartz tape provides insulation between the coil and ground. Impulse tests, field measurements, and high pot tests to 800 V verified the turn-to-turn insulation and winding-to-ground insulation to be adequate. The only power supply available for testing was limited to 880 A. Field, voltage, resistance, water flow, and pressure drop were measured. Axial and transverse field measurements were recorded at various levels to determine field uniformity and effective length. These low-current tests of TR-BM-01 indicate that the design requirements can be achieved as predicted analytically. The design magnet parameters are shown in Table IV.

Fig. 4. TR-BM-01 coil half.

Fig. 5. TR-BM-01 iron structure.

Fig. 6. Completed TR-BM-01 magnet in its housing.

TABLE IV

TR-BM-01 THROUGH -04 MAGNET PARAMETERS

Field	5.1 kG
Design current	1900 A at 2.85 V
Effective length	9.18 in.
Clear aperture	1.18 in. ²
Outside diameter	5.00 in.
Water cooled	
Radiation hard	

The alignment supports for all Transition Region Area components are either complete or in the process of being fabricated. TR-QD-03, TR-QD-04, TR-QD-05, and TR-BM-05 have been installed and aligned. The support structure for the 100-MeV beam dump is being designed and will be installed along with the balance of the Transition Region equipment.

The bucket rotator has been assembled by furnace brazing to form two subassemblies. Final assembly will be completed as soon as the tuning and iris dimensions are finalized.

805-MHz Structures

Installation of the 805-MHz side-coupled tanks is complete through module 33 (Tank 74) and quadrupole doublets have been installed and aligned through module 14. Cooling water systems are complete through module 28 and the vacuum manifolds have been installed through module 23.

The status of the 805-MHz furnace-brazing activity is shown in Table V.

Machining of major accelerator structure components by outside shops is complete and acceptance inspection will soon be finished. The K series

TABLE V
805-MHz BRAZE STATUS (as of 29 October 1971)

		<u>Req'd. Completed</u>				<u>Req'd. Completed</u>
Coupling Cavities	4856	4270 (88%)		Bridge Tank Cylinder Head	120	(100%)
Segment Assemblies	4856	4070 (84%)		Bridge Tank Cylinder to Head	60	(100%)
Short Stack	144	112 (78%)		Bridge Tank Cylinder to Waveguide Flange and Cooling Tubes	60	(100%)
				Bridge Tank Segment Head to Cooling Tube	120	104 (87%)
Monitor Pad to Short Stack	144	110 (76%)		Bridge Tank Coupler Assembly	60	52 (87%)
Tank Section	352	270 (77%)		Pre-Machine Braze of Heads and RF Segments	824	(100%)

coupling-cavity clamshells (Tanks 77-88) have all been processed by the brazing facility through at least the first-step braze and all parts were found to be of excellent quality. The L series coupling-cavity clamshells (Tanks 89-104) have been processed in the H_2 furnaces, and indications are that a substantial percentage of the parts may be defective. These defects are in the form of linear indications (reported previously), porosity and/or blisters. All of these 1600 clamshells are being fired in dry H_2 at 1850°F with a soak period of five hours in order that the defective parts may be identified prior to any brazing operation. One hundred additional machined clamshells are being made and 400 extra forgings are on order as a back-up measure in the event that this problem should become a major one.

Experimental Area

The purchase order has been placed and fabrication started on the switchyard magnet supports.

Temporary barricades have been erected at all openings to the switchyard in order to reduce cold air currents and improve temperature stability. Precision survey work and beam-line layout will begin in the switchyard as soon as 110-V power and building heat are available.

Design work is continuing and drafting has started on the beam line "C" and "B" magnet supports.

Quotations for forty 600 liter/sec ion pumps have been received and evaluated, and a purchase order is being prepared. Specifications, along with requests for quotations, have been sent to potential suppliers for five rough vacuum pump packages to be used in the experimental areas.

Electrical Engineering

Beam Position and Current Monitors

Beam position and current monitors are installed and are operational through module 14. The beam current monitors have been calibrated to within $\pm 1\%$ through the analog data system. Beam position monitors yield an adequate signal when the bunched (100-MeV) beam is drifted by the sensors but operational difficulties in the 201-MHz system have prevented calibration of the position monitors against the wire scanners. With the exception of the 402-MHz receiver packages, all electronics for the complete beam monitoring system through module 44 have been tested and are awaiting installation.

805-MHz Accelerator Tuning

Accelerating cells have been tuned in modules installed in the tunnel through module 26. The tuning procedure used previously, however, left a septum in the center of the tank unchanged and bent the septums, working each way from that point to tune the cells. Consequently, in certain tanks the septums have a net average deflection upstream or downstream. This tends to introduce a tilt in the field distribution. Tank 46 was found to have a tilt in excess of 20%, and it has been retuned such as to lower the net average deflection of the septums. This tilt is now less than 12%. Tank 44 of module 18 is now being retuned in similar fashion. It appears that Tanks 47, 49, and 50 will also require retuning. A modified tuning procedure will be used for modules 27-48 in order to minimize the average deflection of the septums.

Bridge coupler adjustments and checks made with the computerized beadpull apparatus are complete for modules 5 through 15, and modules 17 and 19. Module 7 and modules 13 through 21 use five post tuners per bridge coupler, where four of the posts are fixed-length, water-cooled copper cylinders and the center post is the standard adjustable tuner with a rotatable notch for setting the tank average field levels to be the same. The fixed posts fabricated for modules 14-21 are 2.0-in. diam. The coupling of the drive waveguide to the bridge coupler cavity is a function of the post lengths used. The coupling may also be modified by mounting a 0.5-in. plate with an iris between the bridge coupler and the waveguide spacer that connects to it. Preliminary bridge coupler measurements to determine post lengths (and iris plate dimensions for modules that are too far overcoupled) are complete through module 20. It is anticipated that the shorter bridge couplers of modules 22-35 can be stabilized with only one post tuner per bridge coupler.

A satisfactory single-string beadpull apparatus has been constructed and is now in use. The string is formed into a loop, partly in vacuum and partly out. The string, a nylon monofilament line, passes through close-fitting holes in Teflon inserts where it enters and leaves the tanks, and is returned via pulleys over the top of the module. Motors at each end of the module drive pulleys to move the line. The whole apparatus can be set up on a new module in

45 minutes, which is at least twice as fast as the set-up time required for the double-string apparatus.

Transition Region Magnet Power Supplies

Completion date for the power supply system in the Transition Region has slipped because of delays in delivery of the power supplies and the water-cooled bus cables. Five of the 14 water-cooled cables for the doublet magnets have not yet been completed. Four of the 13 power supplies for the doublet magnets were originally scheduled for shipment in October 1971, but are now expected in November. The first completed unit is now under test. The expected shipping date for the first of the bending magnet power supplies is the first week in November 1971.

The shunt system for the bending magnets is proceeding on schedule. The control system for the doublet magnet power supplies is now being installed. The modification to the water system so it will handle the heat load of the Transition Region magnet power supplies and shunts is scheduled for completion in November.

Accelerator Physics and Beam Dynamics

211 MeV

The major event of the quarter was acceleration of beam through module 12 of LAMPF to an energy of 211 MeV. This was achieved on August 27, some 35 days ahead of schedule.

In preparation for this achievement, beam measurements were made on the 0.75-MeV and 100-MeV portions of LAMPF. Many of these measurements were designed to yield information on the correct adjustment of the phase and amplitude of the rf fields in the four drift-tube linac cavities and the two buncher cavities.

The design excitations and phases of the bunchers and tanks have been determined to an accuracy of 1%. The buncher and Tank-1 results agree to the same accuracy with the results of the 5-MeV tests of nine months ago. These fields and phases will be refined further and tested for reproducibility.

The opening in the shield wall at Butt Line Zero was plugged with a shield maze and a shield wall was erected at the end of module 14. These new shields together with modified procedures and protection circuitry will allow safe operation of any

beam up to 211 MeV at any hour of the day or night, without interference with the installation and tuning of the side-coupled linac structure. The first extended run (60 h) is scheduled in the immediate future. The ability to accelerate beams during the day and round-the-clock will prove extremely valuable in efforts to gain the maximum performance for LAMPF.

Considerable progress was made in the development of accelerator and beam diagnostic procedures and related software. These efforts facilitate accelerator and beam measurements now, and will lead, eventually, to development of effective operational procedures.

III. RF POWER SYSTEMS

RF Control Studies

Overall System Design

The buncher, 201.25-MHz and 805-MHz rf systems through module 12 were operated for the initial 211-MeV beam tests on 27 August 1971. Prephasing of the module-to-module fields was accomplished and shown to be accurate enough to provide adequate starting points for fine tuning of the beam. Successful capture of the beam into the 805-MHz part of the linac showed that the frequency reference system operates basically as planned.

Various procedures were instituted to allow operation of rf systems, low-energy beams, and other apparatus in parallel with the installation efforts. To further expedite system studies involving performance of the accelerator up to 211 MeV, a shielding wall is being constructed in the tunnel between modules 14 and 15.

Accelerator structure tuning was completed through module 15. In the subsequent modules through 21, which require 5 posts in the bridge coupler, and through 26, with one bridge-coupler post, severely nonuniform field distributions were discovered after the cell-tuning procedure was completed. This is attributed to the septum deflecting technique, used to set the cell frequencies, which produces effects that accumulate over the length of a tank. In long tanks, tilts can result which make the bridge-coupler tuning difficult. In addition, although the "wavelength" of the tilts is short enough that calculated beam performance is not significantly affected, the high variation in power loss along the tank could be a factor in ultimate performance of the system. Retuning is being accomplished where necessary. In addition the tuning procedures are being reviewed. A method for optimizing the septum pulling technique has been found. Further experiments and calculation are being directed toward methods for adjusting the coupling constants at selected points and toward the possibility of eliminating main-cell tuning by septum-pulling.

A workable single-string beadpull apparatus used with the structure under rough vacuum was achieved. The new apparatus is much easier to use and provides high quality data.

A solution has not yet been found to the problem of the variation of slopes found in the fields detected by the magnetic probes placed in the accelerator structure for control and monitoring purposes. Experiments with shielded probes showed that electrostatic pickup is a minor effect.

The hardware for the At turn-on procedure for adjusting field phase and amplitude based on measurements of beam acceleration was received, assembled, and adjusted. Checkout of the rf circuitry was accomplished and showed very satisfactory results. The coding for data acquisition and analysis has been written and checkout of the programs using the actual hardware is proceeding well. This equipment will be ready for trial when 211-MeV tests are resumed upon completion of the shielding wall.

A program for CCR turn-on, monitoring and diagnosis of fault information for the rf systems was written in collaboration with the Controls Group and is being debugged on the 805-MHz systems.

Frequency and Phase Reference

Achievement of a 211-MeV proton beam demonstrated that the basic concepts of the frequency transition and the phase reference systems are sound. Subsequent work in this area includes installation of the final high-power 805-MHz stages and their associated phase and amplitude control systems and detailed testing of the overall reference system stability. The final 805-MHz drive line amplifier stages are now being installed. The four final amplifiers are on hand and in the process of assembly and testing. The high-voltage power supplies for these amplifiers, which were procured as complete commercial packages, have been installed and tested. Completion of the screen and bias supplies has been delayed because of slow delivery of some parts. Tube life of these amplifiers is exceeding expectations. Two of the large tubes (RCA 7213) have exceeded the 3000-h life expectancy predicted by the manufacturer and show only ~ 10% loss in gain, indicating that they may be good for several thousand more hours of service. Two smaller tetrodes (RCA 8226) in the drive line amplifier system are also giving excellent service. One at Electron Prototype Accelerator (EPA) has already reached 21,000 h and one at the Equipment Test Laboratory (ETL) has reached 11,000 h.

The phase and amplitude control system equipment is installed in the rf source room. Except for

the 201- to 805-MHz interface trombone phase shifter, the necessary equipment and wiring for computer control of the rf source room has been constructed and installed.

The rf reference line is installed through Sector D and has been checked and accepted. A program for monitoring the effectiveness of the drive line temperature and pressure control systems was initiated. A contract was awarded for installation of the remainder of the line. The air pressure regulator failed and is being replaced by the vendor under the warranty.

RF Phase and Amplitude Control Studies

Phase and amplitude control for the bunchers, 201.25-MHz, and 805-MHz systems were fully operational for the 211-MeV beam tests. Investigations leading toward final design of these systems was resumed, concentrating on the 201.25-MHz systems where loop gain variations and nonlinearities are most severe. The control of the initial turn-on of the pulse and achievement of the required phase and amplitude levels before beam turn-on has been optimized using a fully adaptive system which adjusts its programming and delay characteristics as required by system performance and which is fully recoverable from all known fault conditions. The feedforward control feature has been used during 100-MeV tests; control of the fields to better than 1% in amplitude and 1 deg in phase can now be demonstrated routinely over the entire beam pulse, including the initial transient. This is a significant achievement, since the eventual beam quality achievable from LAMPF depends very strongly on precise control of the fields in the accelerator. Further development will concentrate on optimization of compensation, study of interactions, and investigation of adaptive loops.

All of the hardware for the 805-MHz fast phase shifters has been received. Ten units have been assembled, tuned, and tested and were found to equal the prototype. A small dc blocking capacitor was incorporated into the rf input line to the phase shifter to lower the capacitance which the bias circuit is required to drive. This capacitor was included in the amplifier used as a source during prototype tests; since it does not occur in the same context in the accelerator system, it has been added to the phase shifter. There is no degradation of

the specification by this addition.

Further problems have occurred with the phase detector subsystems; the vendor will again correct the deficiencies while at LASL. Accepted subsystems are now installed through module 13; mounts are installed through module 18.

To satisfy requirements for high-gain, broad-bandwidth, low-input rf amplifiers, a class "A" amplifier was developed using a 2N 3866 which shows ~ 20 dB of gain with 1 mW of drive.

Power transformer failures in the power supplies for the interface amplifiers have been mentioned in previous reports. This problem has been solved by eliminating the input filter capacitor and adding a 50- Ω current-limiting resistor immediately after the high-voltage rectifiers.

Protective Circuitry

Duty factor interlock transducers and chassis are installed through Sector F.

The crowbar foil-test resistor banks are installed through Sector F. Minor modifications have been made in all 805-MHz crowbar trigger chassis to improve reliability and personnel safety. Design work has begun on an interlock system to protect the crowbar resistors in the event of a failure of their cooling air systems. A more reliable high-voltage (5-kV) resistor assembly has been installed in the 201-MHz crowbar logic chassis. This particular circuitry monitors crowbar operation for interlock data.

The 805-MHz monitor cards have been redesigned to improve reliability and simplify circuit operation.

805 MHz Power Amplifier

Modulator and Amplifier Production

Twenty-nine Varian VA-862-A klystrons of the 45-tube production contract have been delivered; 26 of these have been tested and accepted at LASL. All of the tested klystrons have been installed in the cluster buildings. Thus, all stands in Sectors B through E now are full.

Over 81,000 filament h and 63,000 plate h have been accumulated on all of the klystrons to date. Two Litton klystrons and four Varian klystrons have accumulated between 6000 and 9000 filament hours. Of these six, two have failed, one due to a vacuum leak (S/N 103) and one (S/N 102) due to high-voltage problems. S/N 102 was arcing internally and efforts to clean the insulators by high-potting were not successful. Thus, this experimental tube is

considered to have failed. A production klystron, S/N 222, was accidentally broken as it was being moved from the test stand at the ETL. A strain-relief clamp for the vac-ion pump lead has been designed to prevent such failures in the future. There have been three high-power klystron failures to date: two on R&D tubes and one accidental failure on a production tube.

Litton Industries has had major problems with their 25-tube production contract. The first tube (S/N 2008) was severely damaged at Litton by a crowbar malfunction early in September. In mid-October the second klystron was briefly tested at Litton, but the tests were interrupted by a window failure. Both failures occurred before acceptance tests could be started. The third production klystron is scheduled for testing in mid-November.

The LPT44 switch tubes have accumulated more than 62,000 h of running time. Only three have failed and these were early-life failures which are being repaired under warranty.

The gain of some of the VA-862A klystrons was found to be sensitive (up to 3-dB variation) to the phase of the beam current pulse relative to the 60-cycle line voltage. This gain change was found to be caused by a 60-Hz radial modulation of the beam diameter which is generated by the magnetic field of the heater current. The klystron heaters require 45 A. A minor design change was made on the internal filament wiring which will minimize this gain sensitivity on future Varian klystrons. The heater current for the klystrons which have already been delivered will be attached to a single 60-cycle phase so that the klystron will have the gain that was measured during the final acceptance tests. A rectifier for the filament current has also been designed and tested for over 100 h. The rectifier has a 120-Hz hum on its output, but since the klystrons are normally run at 120 Hz, the gain modulation is rather small, ~ 0.5 dB in the worst case. Although the rectifier substantially reduces the gain sensitivity of the klystron, the decision to put rectifiers in the 30 existing modulators will be deferred until some more life data are accumulated.

The rf modules through 24 in Sector D have been tested on water loads. Modules 25 through 30 in Sector E are almost ready for water-load testing.

The bucket rotator rf system is $\sim 60\%$ complete and should be ready for water-load testing by December 1.

Klystron Repair Facility

The leak in Varian VA-862A S/N 103 was found and repaired, but this klystron has not been reassembled yet. A klystron bakeout station and cathode repair station have been designed. The bakeout oven is being made in the LASL shops. After it is delivered, the heating elements and controllers will be installed and then an attempt will be made to complete the repair of S/N 103. Several trips to Varian and Stanford Linear Accelerator Center have been made to become familiar with the repair techniques used by these organizations.

Window Coating and Life Testing

Two Varian windows and ~ 6 General Electric windows have failed in service at the EPA and on the accelerator. Neither vendor has taken the precaution of coating the vacuum side of the window with titanium to reduce the chances of single-surface multipactoring on the window. Varian has now agreed to coat the remaining windows of their production run.

Two evaporators have been built and used to coat 22 windows (4 Varian, 18 G. E.), and these coated windows are being installed on the tanks. Tanks 5 through 19 will have coated windows installed within a week and then full-power life-testing will begin. The vacuum conditions at the accelerator window have been monitored. Pressure bursts as high as 3×10^{-4} Torr were measured during the tank turn-on procedure. At this pressure, a purple plasma becomes visible in the tank and the tank pumps must be shut off. By turning the tanks on very carefully, it is possible to limit the pressure at the window to 2×10^{-5} Torr. Even this pressure may lead to damage of the rf window. Once the tanks are brought up to full power the pressure at the window drops to the 10^{-7} -Torr range. Distinct multipactoring has also been observed in which vacuum pressure near the window rises as the critical power level is approached from either direction.

Klystron Theoretical Program

The actual magnetic field on Litton S/N 2007 (the prototype of the Litton production klystron) was measured and used as input data for a large-signal simulation of this klystron. The completed

results obtained with the one- and two-dimensional klystron analysis codes are shown in Fig. 7, along with the experimental results. The discrepancy between the experimental and computed rf output power is unusually large for the case. The most probable cause for this discrepancy is the lack of an output-gap calculation in the present codes. An output-gap code has been written and some encouraging preliminary results have been obtained. This code will be tested and used in the next quarter; it is hoped that the output-gap calculation will be a good method of establishing the output power and the shape of the power-transfer curves of a klystron before it is built.

201.25-MHz RF Amplifier

A total of 800 h were logged on 201.25-MHz rf equipment during the quarter. Most of the time was in support of beam diagnostics, phase and amplitude control studies, and tank resonance studies.

The cathode resistors in all three 7835 stands have now been modified to the nichrome furnace strip type; no problems were encountered.

The prototype oil transformers for the modulators were completed and put into service. Two hundred and ninety-four hours have been logged on the transformers, with no problems. Three more units are in the process of being constructed; the transformers will be wound in-house.

Development continued on the amplifier for the RCA 4664 tube. The tube was successfully run at 600-kW peak power and 6% duty, but is plagued by

plate-current faults. Investigation of these faults continues. Reconstruction of the output cavity for a final design is under way. The development of the amplifier is hampered by a conflict between the use of module 1 to power Tank 1 and the running of the experimental amplifier.

Work began on fixing the auto-regulation for the 7835 filament supplies. The circuits did not operate properly when the amplifiers were running at full power. Results of this work have been moderately successful in that the circuits now work if the rf pulse occurs only during a certain portion of the ac-line cycle. Further work on the circuits is planned.

A computer program to monitor the 201.2-MHz rf stands, to reset the logic and to log all resets was generated and checked out during the period. This program is now on the disk and is available for routine operation of the equipment. Flow-diagrams have been made for another, more sophisticated program to turn the stands on, monitor their operation, and recycle them if they go down.

Much time was spent in gathering spare parts and setting up storage for them. An inventory of parts and spare parts for 201.25-MHz rf equipment was begun in an effort to determine what spares need to be purchased.

The distributed screen capacitors on the screens of the 250-k modulators failed after having been in service for some time. A capacitor of a different design was ordered.

The Mylar-distributed blocking capacitors for the 7651 cavities were installed and gave satisfactory service. More of the Mylar capacitors are on order to replace the unsatisfactory silver micas now on hand.

The RCA 7835 tube (X-3) which had a grid filament short was returned by RCA after they had cleared the short. The tube was installed and after some 4 h of running, the grid filament short appeared again. The X-3 tube was removed and an effort to clear the short was again made. At the time it appeared that the effort was successful, but after the tube was placed in service and run for 25 h, the grid filament short appeared again. The tube was then removed and returned to RCA, who will open it in an effort to find the cause of the problem. X-3, a tube that has never operated properly, has now been torn down six

Fig. 7. Comparison of confined-flow and two-dimensional theoretical power-transfer curves with the experimental curve.

times, consuming about 24 man-hours each time.

A new RCA 7835 tube (P-9) arrived in Albuquerque with severe shipping damage to the packing crate and some external damage to the tube. The tube was returned directly to RCA for evaluation of any damage to the tube. RCA reported finding no internal damage and returned it to LAMPF, where it was put into service and is operating satisfactorily.

On the advice of the manufacturer, the NAL modification to the spring-ring contacts in the filament circuit of the 7835s was made in modules 3 and 4. No further problems with the spring contacts have been experienced during the quarter.

Two high-power tubes were lost during the period. One, a modulator tube, was damaged due to a filament lead connector that was not tightened sufficiently during assembly, and the other, a RCA 4616, was lost due to an apparent overdissipation of the screen grid when the screen modulator went CW.

A water leak appeared on the 4616 output cavity-cooling jacket in one of RCA's totem-pole amplifiers. When an attempt was made to resolder the jacket, it was found that it was necessary to remove the jacket to clean and modify it in order to solder it properly. Similar failures are anticipated in the other units in the future as all have had small leaks in the same area.

Magnet Power Supplies

Twelve dual 38-kW, 750-A power supplies have been received and tested as individual supplies. All perform satisfactorily. Tests of these supplies connected in series and parallel will be run early in the next quarter.

Instruction books for these supplies have been received but are not acceptable. They are being reworked by the vendor.

A complete set of spare printed-circuit boards for these supplies is on order.

Fourteen of the H-tangent winding power supplies which did not meet specifications were returned to the vendor for rework. They have been reworked and shipped back to LASL. When they are received, the two remaining power supplies will be returned to vendor for rework. All sixteen will be retested before they are accepted.

Bids were received on the SCR-type reversing switches. The cost was much higher than anticipated so it has been decided to go back to the original

concept of motor-driven mechanical switches. There will be two versions of these switches, one for currents from 500-2300 A. Both types will be computer-controlled.

An order for 56 brute power supply modules representing a total power of 6860 kW, has been placed and work on these supplies is progressing satisfactorily. Shipment of the first of these supplies is scheduled for the end of December. The last of this group is scheduled for shipment in mid-March.

Two 60-kW, 300-A supplies have been tested at the sellers and have been shipped. These are the bending-magnet power supplies for Lines A and X. One has been received and will be tested as soon as schematics and instruction manuals are received.

Regulator design was completed and preliminary prototypes of the various subunits have been built and tested. Final accurate prototypes of each unit will be made and tested before starting production.

A fairly accurate estimate places the cost of a complete regulator, with instrument power supplies, NIM bins, control and metering chassis, and capable of remote computer control, at \$3000. The decision has been made to order all the components immediately. It is expected that production can start by the end of the year, with a target date for completion of the first units by 15 March 1972.

Other Research

Simple rf detectors have been constructed to detect rf leakage. These can be made to measure power levels near 10 mW/cm^2 , of interest to health and safety, or made more sensitive, power levels near $1 \text{ }\mu\text{W/cm}^2$, for detecting rf noise sources. These rf detectors have been calibrated locally using a large coaxial line or a waveguide with known power levels.

IV. ACCELERATOR CONTROL AND INSTRUMENTATION

Injector Control Systems

The injector control systems include controls for the ion source, the Cockcroft-Walton (C-W) accelerator, and the beam transport equipment leading to the first linac tank. These systems performed well during the 211-MeV beam tests and are considered finished except for routine maintenance and improvements. To facilitate these tasks, a major effort was put into compiling and updating the documentation for the present wiring and termination records, the pertinent catalogs and instruction manuals, and the drawing package.

A Pirani-type vacuum gauge was received and evaluated. Its performance is good over five decades. Several of these instruments will be ordered for use in the Injector area. Each is packaged in a NIM module for ease in maintenance.

The staircase generator and logic circuit were designed for the new beam-current monitor and calibration system. A breadboard model of the system is nearly ready for testing. A dozen amplifiers were evaluated against the low-noise, wide-bandwidth requirements of the system. The final choice will be made soon.

A study was made of the extractor dc voltage stability. The high-voltage divider installed last quarter did not have the requisite stability. The metal film-resistance stick was replaced by a wire-wound resistor. A separate light link was connected to the extractor pulsed data to aid in the tests.

Two current-monitor transformers were installed on the beam line for testing amplifiers and beam-diagnostic equipment.

The Injector Control Room (ICR) data system based on a Nova computer continued to operate without a failure while providing both ICR and Central Control Room (CCR) with control data from the H^+ C-W. Software and interface hardware are ready for control of the H^- C-W when the equipment is installed in the dome. The system is being extended to perform the beam-diagnostics task presently handled by a separate Nova computer. This work is 80% complete.

The low duty factor/low transmission interlock logic chassis was repackaged and installed in ICR.

A beam repetition rate display using light-emitting diodes (LED) was built and mounted in ICR. Because the LED display is more easily read than

NIXIE tubes, the voltage displays remoted from the C-W and extractor were converted to LEDs.

A digital voltmeter (DVM) was mounted on the ICR console to provide a readout for the steering-magnet currents.

Substantial progress was made on the wiring for Injector B. Work started on the NIM-bin layout and chassis wiring for the light-link transmitter. The equipment for the dome of Injector B is being designed for quick changeouts to facilitate the research mission of the instrument. The H^- C-W should be ready for high-voltage testing early next quarter.

201.25-MHz Control System

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

The control system for the drift-tube linac has been in operation almost daily during the quarter. Records show that relatively little time has been lost from operations because of failures in the instrumentation and control systems. The worst offenders during this period were the steering-magnet power supplies for modules 3 and 4. The source of their repeated failures was diagnosed and corrected.

An effort was made to improve the response time of all the pulse stepper motors in the LAMPF control system. It was found that the reference phase shifters in the 201-MHz rf system would not track at the faster drive rate. The effort has been suspended for the immediate future.

Work continued on the control systems for the Transition Region. The wiring of the local control modules for the vacuum, water, quad-magnet, and temperature-control systems was completed. These modules are being installed in the control racks. Wire scheduling was finished for all systems except the bending magnets and run-permissive. These two systems are in the final design stage. Device-installation and hookup are scheduled for next quarter.

805-MHz Control Systems

The 805-MHz control system extends from modules 5 through 48 and includes the instrumentation for Sectors B through H. Prior to the 211-MeV test, the work of wiring and device-installation was concentrated in modules 5 through 12. All tasks essential to the operation of that part of the accelerator

were completed as evidenced by the success of the test. Since that time, work on the remainder of the accelerator has progressed in a systematic manner.

The contractor is nearing completion of the wiring job in the 805-MHz area. All trunk lines have been installed. Most of the wiring associated with each module, including the device-wiring in the beam channel, has been finished. Wiring for the distributed systems is progressing rapidly. All water systems up through module 28 are operational. The wiring and controls for the accelerator vacuum systems are complete. Final checkout of the systems for each module will be done as soon as the accelerator structure for that module has been finished.

The acceptance tests on the quad-magnet power supplies resulted in a relatively high rate of rejections. The manufacturer sent an engineer to LASL to repair the faulty units. Subsequent retesting indicated that the repaired units were acceptable.

The steering-magnet power supplies were put through a receiving inspection and those units not meeting specifications were returned to the vendor for repair. The supplies have been returned to LASL and the acceptance test results were satisfactory. All of the controls and wiring for the magnet systems are complete and awaiting installation of the magnets and power supplies for final checkout.

The 805-MHz temperature control systems operated satisfactorily throughout the 211-MeV beam test. The reliability of the units appears to be excellent as evidenced by the fact that the systems in modules 5 through 13 have operated for two months with no failures. The installation, checkout, and calibration of controllers have progressed through module 28.

Experimental Area Control Systems

The design of the instrumentation and control systems for the experimental areas is still lagging for lack of criteria. Developing the requirements for a single beam line takes a long series of meetings involving numerous people. Nevertheless, there has been progress.

A preliminary channel list was generated for the local and computer controls in the beam switchyard. It includes signals for magnets, power supplies, vacuum system, water systems, beam-diagnostic

systems, ventilation, run-permissive, and radiation safety. A tentative assignment was made of the space in the 20 racks allocated to Beam Lines A and X. A total of four computer control terminals will be needed for the switchyard. From the channel list and device assignments it was possible to make a determination of the wire and cable requirements. The first order for radiation-resistant cable was released for bids and inquiries are being made on possible sources of radiation-resistant coax cable for use in diagnostic devices.

A preliminary specification was developed for the radiation monitoring, TV, and personnel safety systems in Area C. The definitions are sufficiently firm so that design work can be started. A similar document was prepared for the analogous systems in Area B and along the B-C beam line.

The control philosophy for the biomedical facility was developed. Computer control without separate local controls will be utilized for essentially all aspects of the facility. The controls will be implemented in CAMAC hardware. The only hardwired control systems are apt to be target-insertion and beam shutters, the dose integration system, and the personnel safety system.

The configuration for the control computer was established. It will be powerful enough to handle all control tasks and still have capacity for aiding in treatment planning. The computer will be compatible with the LAMPF standard computer so that full advantage can be taken of the LAMPF data-acquisition system.

The design of the control console for the biomedical facility was considered. It will take advantage of the experience gained from the consoles in CCR. Work was started on a current integrator circuit for the dose integrator.

LAMPF Data Terminals

Each module of the accelerator is connected to the control computer by a data-acquisition-and-control terminal (DACT) which includes a remote-information-and-control equipment (RICE) unit, an input/output unit (RICE I/O), an analog data system (ADS), and a power supply. The DACTs in modules 18 through 48 were made operational through the control computer. All DACTs for the accelerator are now on-line. Testing of these terminals continues during

the early morning hours and on weekends in order to establish a hardware confidence factor for the control system.

Ten RICE units for the switchyard and experimental areas were received. A contract was let for 10 RICE I/O units and 10 DACT power supplies. When these units all arrive early next quarter, testing of the complete systems will begin.

Central Control Room (CCR) Systems

The second operator's console was put into service prior to the 211-MeV beam test. It was outfitted with a graphics scope, a character scope (4-color), a storage scope, a scope for pulse-viewing, a communications station, a slew knob, and a function-button panel. The knob and push buttons were connected temporarily to the first Console Interface Unit (CIU) pending completion of the second CIU. A major portion of this unit was fabricated and prepared for bench tests.

A panel was designed to accommodate the new 1/4-in. alphanumeric readouts for the slew knobs. There will be three readouts per panel, each capable of displaying 32 characters or numbers. Four of these panels will be built, two for each console. The associated slew knob panels were designed and a prototype is being built. The chassis to service these devices are designed and ready for fabrication.

The first of the new function-button panels was put into operation. It has a provision (to be implemented later) for reading a 10-bit code on the card which defines the function of the buttons. In this way, operators can change button assignments on-line. Four copies of a smaller version of this panel are being built, two for each console.

The design for a panel of status indicators is nearing completion. A prototype unit will be built for evaluation by the operators.

Several of the console devices required maintenance. The scan converter had to be taken out of commission temporarily when it got out of adjustment. A special test generator was ordered as an aid to realigning the electronics. One of the storage scopes had to be returned for a new storage tube. The hard-copy device for the storage scope was returned to the factory for modifications to improve its resolution and contrast.

The problem of excessive glare off the various

scopes resulting from natural and overhead lighting was attacked. The solution appears to be heavy drapes judiciously placed on some of the windows in CCR. The drapes will serve a second function, that of reducing the ambient noise level from the computer equipment.

Progress on the counterpoise grounding system for CCR was limited by the lack of electricians.

LAMPF Control Computer

The LAMPF control system is organized about an on-line digital computer. This computer, a SYSTEMS SEL-840MP, is on-line to the accelerator ~ 50 h each week. Virtually no time has been lost from operations as the result of computer down time although several peripheral devices failed during the quarter. The clutch assembly on the logging printer wore out and was replaced. Several minor failures in the power supplies of the vector scopes were recorded. However, the reliability of these scopes was high enough so that they were finally accepted from the manufacturer.

The character scopes on the two CCR consoles were converted to 4-color models. The multicolor presentation is far superior to the single-color TV monitors.

Programming

The programming effort was divided evenly between systems and applications programs. The systems programming was concentrated on an effort to have the control computer operational 24 h/day by next January. This goal requires that there be a minimum of system crashes which take the computer off-line and that there be a fast recovery procedure for those crashes which do occur. The latter requirement was satisfied by a restart program which saves a history of the crash as it loads a new copy of the operating system. A program was written to perform an on-line analysis of the source of the crash.

The effort to make the system less susceptible to crashes was partly thwarted by a problem in the special hardware which protects memory against illegal accesses. When the programming required to utilize this hardware was tried, the hardware induced system-crashes. The source of the problem has not been diagnosed as yet; hence, the memory

protect hardware was turned off. On the positive side, the memory parity recovery procedure developed recently has been very successful. The new programs which service the character scopes greatly improved the reliability of those devices. Several other checking procedures that were added to the operating system have proved useful in preventing crashes.

Another requirement for full-time operation is the capability for on-line testing of new programs. Checkout was started on a debug program which will provide this capability. Debug will interpret each instruction of the program under test and determine if the consequences of executing that instruction will break any rules, e.g., branch outside the memory bounds of the program. If so, Debug will give the programmer a chance to correct the error. A display on the character scope provides a means for observing and changing the registers and cells in memory. Options to single step, trace, and breakpoint are available. A scheme for handling system calls will be added next quarter.

Several application programs were written to support the 211-MeV test. One was a beamplot display which shows the beam current measured at nine points along the accelerator between 100 and 211 MeV. Another was a status display, by module, of all the systems in a sector, e.g., vacuum, water, magnets, etc. Each system is marked as Not Ready, Ready, or On, and appropriate controls are provided. Any failure in the data system is also indicated. Two programs were written to facilitate the assignment of knobs to control various devices. One is dedicated to all the steering magnets in the drift-tube linac while the other provides controls for all the devices in any 805-MHz module.

Some time was spent in developing automated sequencing programs. Three of these programs were for the 805-MHz vacuum, steering-magnet, and focus-magnet systems. An operator in CCR and a technician stationed at a given module control point collaborate under direction of the computer to check out each signal from the system. The use of the computer ensures quality control of the procedure. Checkout was started on a program to turn on any or all of the 805-MHz rf stands. A display on the graphics scope shows the operator the status of each module and alerts him to any trouble spot. Turn-on programs for the C-W and Injector A ion

source were updated and partially checked. Both programs use operating parameters stored on the disk as set points.

Several programs were written to aid operations. One checks the status of various areas and turns on a light on the console dedicated to the area if all systems are operating properly. The check is repeated every ten seconds. A new display was developed for changing parameters in the master timer. This was required because of hardware modifications to the chassis. A program to monitor the water pumps in the 805-MHz accelerator was added to the system. It runs hourly and alerts the operator by messages on the character scope of any pump troubles. Three programs-- Timeplot, Pulseplot, and the 201-MHz resonance control program-- were revised as the result of operating experience. The display program, Beamplot, is being rewritten to provide additional information.

A diagnostic program for RICE units was finished. It tests the binary data, binary command, analog data, analog command, video, and analog-to-digital converter hardware in any standard data terminal. The test results are printed on the line printer to guide the technician in repairing the unit. Work started on a program to automate the testing of any channel on the accelerator. A card deck defining the channels is read into the computer and validated against a set of criteria. The operator is given the chance to correct any mistakes. Then the computer performs the specified tests and logs the results. The part of the program which tests binary channels is nearly complete. Work will begin on the analog section next quarter.

Continued programming support was provided for the magnet-mapping system built around a small digital computer. A program to measure the fields of a quadrupole and certain bending magnets was completed. This program records the field measurements on magnetic tape for later analysis on a larger computer. A second program was written, this one to control the 3-dimensional rapid-mapper and record the measured data. This program will be operational next quarter.

Distributed Operational Systems

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

operation of the accelerator.

Timing System

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

The master timing unit is now the sole source of timing information during accelerator operations. Since its installation in July, the unit has been virtually trouble-free. During the 211-MeV beam tests, the delayed rf gate feature was used to good advantage. This feature allows the beam energy to be changed under computer control.

Toward the end of the quarter the master timer was modified to allow for repetition rates as low as one pulse every 8 sec. This feature was needed to minimize the residual radiation at the temporary beam stop during the beam dynamics studies.

The cable for the timing distribution system has been installed in all but the last two sectors. The timing distribution units for all sectors will be ready for installation as soon as an order of printed-circuit cards is received.

A maintenance course was taught to interested technicians to familiarize them with the theory of operation of the timing system.

Fast-Protect (FP) System

The FP system is hardware which can quench the proton beam rapidly in the event of a beam spill. The FP chassis required for the 211-MeV beam test were installed and put into operation. The performance of the FP system during the 211-MeV test suggested some minor modifications. These changes were made in all FP chassis and the drawing package was updated. Installation of the FP chassis in the remaining sectors is in progress and should be completed early next quarter.

Run-Permissive (RP) System

The RP system is hardware which can inhibit the beam upon detection of any abnormality which might cause a beam spill. The checkout of the RP system for Sectors B and C was completed. The system performed as specified for the 211-MeV beam test. Checkout of the system in Sectors D through H is in progress.

A modification to the RP system for Injector A was designed and installed. The change facilitates the selection of timing sources and makes it easier for the operators to determine when the beam

transport system is ready to accept beam in the chosen operating mode.

Personnel Safety System

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

The key-release panel and time-delay relay in CCR were wired permanently and checked out both in the 201-MHz and the truck access areas. Extensive modifications were made to the Sector A personnel safety system to allow more flexibility in operating the 201-MHz rf stands during 5-MeV beam tests.

The personnel safety system in Sectors B and C was put into operation prior to the 211-MeV test. A modification was made in Sector C to incorporate the service lift into the system. The time-delay chassis and status panels were installed in Sectors D through H. All NIM chassis for the system were received. Device-installation was started in Sector D. The drawing package was brought up-to-date.

The final design was completed for the Injector B personnel safety system. Preliminary wiring diagrams were started. The first diagram to be completed covered cabling, and the information was transcribed to punched cards for listing.

Radiation Safety System

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

A comprehensive area monitoring system was put into operation for the 211-MeV beam test. The five detectors of the portable area monitor system were located in modules 4, 6, 8, 10, and 12. Ten area monitors acquired as excess equipment were installed over appropriate 805-MHz waveguide shafts. Two new monitors which are part of the permanent area monitor system for Sectors B and C were calibrated and installed.

During the calibration of the permanent area monitors it was noted that the detector output was not linear with dose rate above 100 R/h. This fact did not jeopardize the use of the monitors in the 211-MeV tests, but it did require further study. The problem was traced to two elements of the

system --the detector and the electrometer circuit. An investigation of the detectors (ionization chambers) disclosed that they had developed leaks. A comparison with other detectors which were holding the advertised 4 atm showed that even the pressurized chambers were not saturating in full-scale radiation fields. This defect was ascribed to outgassing of an epoxy insulator within the chamber. (A small part of the loss was known to result from the use of air rather than nitrogen as the filling gas.) To test this hypothesis a chamber was evacuated to 10 μ and baked at 100°C for three days. It was then filled with 4 atm of dry nitrogen and prepared for testing. The results will be available early next quarter.

In a parallel investigation the charge-to-pulse-rate converter in the electrometer circuit was found to be out of adjustment. In fact, the circuit could not be aligned satisfactorily over the 5-decade range. An analysis of the electronics revealed several interdependencies which gave rise to the drifting zero point. A new electrometer circuit was devised which eliminates this drift and is far easier to adjust. The new circuit is all solid state except for two electrometer tubes. Solid-state electrometer modules were obtained for testing. The results look promising. When a design is complete, it will be laid out on a printed-circuit card which will directly substitute for the original circuit.

The beam spill monitor system was installed and checked through module 12 prior to the 211-MeV test. Since that time, the remainder of the power supplies, modules, and detectors for the system have been received. Part of the station units were delivered but the remainder are being held up temporarily for lack of parts. All of the equipment on hand has been bench-tested to verify its operation. The contractor has completed the wiring through Sector F. This wiring has been verified through Sector D. The installation of components is complete through Sector C except for module 14 where the temporary shield wall interferes. The beam spill detector for Tank 1 was permanently located following completion of the Butt-Line-Zero maze.

Accelerator tests have been scheduled for evening hours to avoid conflict with contractor operations downstream. To provide more test time

and to protect contractor personnel from radiation generated by activities induced during the tests, it was decided to construct a temporary shield wall in the beam channel between modules 14 and 15. To provide information for the design of the temporary shield wall, the neutron flux and spectrum downstream from the 211-MeV beam stop were measured by seven different sensors at six different positions. From these results, a required wall thickness of 15-17 ft of ordinary concrete was calculated. A compound wall of steel and magnetite concrete was designed to keep the total thickness to $\sim$ 10 ft. Installation work was started 18 October and was scheduled to take two weeks.

Auxiliary Systems

Communications System

The LAMPF Communications System includes interphone, paging, telephone, and FM radio services. The retrofitting of the Communications System with modifications to simplify its operation and improve its performance was begun and is now $\sim$ 90% complete. This task was accomplished without affecting communications except for a two-day shutdown. The following list of improvements is representative of the work done. Two new guard lines were established and two new interarea channels were set up. The front panel of the interphone units was simplified. Four new interphone units were added in the Injector area. The choke in the loading coils was replaced by balun to reduce cross-talk and provide increased talking power. The filtering in the loading coils and paging interface units was increased to eliminate quiescent noise. Provisions were made for using batteries to provide backup power for the entire system. The polarity of the output keying line was changed to allow for special combinations of areas to be paged. A small number of prototype headsets with amplifiers for high ambient noise areas were built and are being evaluated.

Progress on the Laboratory-Office Building (LOB) General Announcement System was limited by the availability of the crafts. The trunk-line wiring is complete. The paging console is built and checked. The electronics cabinet is installed and the wiring is $\sim$ 50% complete.

An inventory was made of the equipment available for the Experimental Communications System. It showed that only the interphone stations (with

headsets and speakers as required) were lacking. A work order covering the fabrication of these stations is being prepared.

Video System

The function of the video system is to provide a means for automatic and manual switching of signals from the accelerator to CCR for display on one or more oscilloscopes. Most of the problems encountered during initial operation of the video system have been corrected, particularly those associated with the signal conditioners.

The first increment of modules for the video system beyond 211 MeV was received. Installation of the remainder of the system will begin next quarter.

TV System

The LAMPF TV System facilitates the monitoring of accelerator operations and provides access surveillance. The installation and checkout of the operational TV system for the accelerator was completed.

Two 8-in. monitors acquired from NASA surplus were reconditioned and installed in CCR: one to serve for accelerator access TV and the second for Experimental Area access TV. A nine-position selector switch was installed to allow selection of cameras at any of the nine access points.

Access surveillance cameras were installed, tested, and placed in operation in Sectors B and C. The surveillance cameras in the beam channel were relocated for the 211-MeV test. After construction of the temporary shield wall, the cameras were moved again to provide unobstructed coverage of the beam channel.

A three-coordinate mount for translational control of a TV camera was designed, fabricated, assembled, and tested.

Experimental Area Computers

Delivery of the first two PDP-11 computers for the LAMPF data-acquisition system is still scheduled for November. A preliminary decision was made to utilize the manufacturer's disk operating system (DOS) as the basic module of the programming system. The documentation for DOS was studied to ascertain the best way to introduce interrupt servicing programs to handle the data-link, display, and data-acquisition systems.

The problem of interfacing surplus magnetic

tape drives to PDP-11 computers was investigated. This work resulted in a specification for a controller which will make the surplus tape drives perform in a manner fully compatible with the standard tape drives manufactured by the Digital Equipment Corporation (DEC). This approach takes full advantage of the DEC software. A request for quotation was issued to several companies which design computer interface gear. The responses are due on 1 December.

The LAMPF Terminal computer will be linked to the LASL Central Computing Facility (CCF) by a high-speed data link. After discussions with LASL's computing division (C-Division), it was decided to adopt their interface hardware in order to save development costs. Depending on the requirements for internal data links, the modules will be designed by LAMPF personnel, but housed in the C-Division hardware. Testing of integrated circuit line drivers/receivers was begun to determine their potential usefulness for the internal data links.

The interfacing of a surplus line printer to the Sigma-2 computer was delayed by a lightning-induced power transient which damaged the computer. Considerable manpower had to be invested in repairing the damage. Three memory modules and several logic cards were affected. The computer appears to be operational again. A request was made for an isolation transformer to prevent this sort of accident in the future.

CAMAC Prototype System

CAMAC hardware is being evaluated as a standard for interfacing experiments to data-acquisition computers at LAMPF. The experimental gear for a Compton-proton experiment was interfaced to a Nova computer using commercial CAMAC hardware. The system was functionally tested through a series of diagnostic programs. During October, data was acquired successfully and the system performed as designed. A summary of this work is being prepared.

Work continued on the design of a CAMAC branch driver for the PDP-11. The requirements to take data from a pulsed beam and simultaneously drive a data link, a display device, and perhaps other peripheral equipment dictate that the branch driver be a microprogrammed input/output processor (MIOP). The design for an MIOP is 90% complete. All of the special components for a prototype were ordered and

most have been received. Because the unit is relatively complex (~ 10,000 wires), it will be fabricated using LASL's wire-wrap machine. To support the checkout phase, a manual console will be built to exercise the unit in various diagnostic modes. February is the scheduled completion date for the branch driver.

AT Measurement Equipment

The scheme for optimizing the performance of the first eight 805-MHz modules of the accelerator is based on a measurement of the difference in time-of-arrival at a point (ΔT) of protons with and without acceleration. The equipment to perform the measurement is expensive and has to be multiplexed among the eight modules. The switching matrix to perform the multiplexing was adapted from one developed for the video system. The hardware was designed, fabricated, installed, and tested. Drawings and related documentation for the system were prepared.

Magnet Power Supplies

The high-resolution proton spectrometer (HRS) magnet power supplies were completely debugged and made operational. One of the power supplies is being used to power the EPICS prototype magnet; the other is being used as a test for a number of different magnets. In order to increase the versatility of this power supply, the control loop was modified to be stable for a wide range of magnet characteristics. The overall performance is satisfactory, but a long-term regulation test has yet to be performed.

In the Experimental Area, it will be necessary to connect several magnets in series to the same power supply. Since some of the magnets will require different currents, shunts will have to be used to bypass current around magnets requiring lower currents. This shunt will consist of a bank of transistors under closed-loop control. A prototype of such a shunt was designed and built. During a test of the prototype, a loop was closed and stabilized around a Line X bending magnet and an Acme power supply. The electronics performed satisfactorily and work started on a final design. Printed-circuit cards for the system were submitted for drafting. An evaluation of transducers was started.

Wire and Termination Records

The wire and termination records for the 805-MHz portion of the accelerator are divided into three categories: (1) wiring done by off-site contractors, (2) wiring installed by contractors off-site, and (3) wiring completed by MP-Division personnel. These three sets of records for each system (e.g., water system) are being combined into a single package. Each package reflects the latest modifications and additions to the system. The following 805-MHz systems have been updated and combined: vacuum, video, run-permissive, RICE test, quad-magnet, steering-magnet, time-delay-command, and water. These completed sets are being distributed to the Operations staff.

V. ACCELERATOR PHYSICS

The High-Intensity Injector Program

Ion Source

Extensive use of the ion source has continued during this quarter, mainly for the LAMPF accelerator tests. The source in use during this period is Model IIIa, Fig. 8, p. 33, LA-4753-MS (MEP Program Status Report for the period ending July 31, 1971). It was installed in the H⁺ dome on 22 July 1971, and has been operating with the same aperture, No. 11, and the same cathode, CT-2, for the past three months (604.2 h). On 12 August 1971, a spacer ring was inserted into the extractor electrode aperture, reducing the hole size from 2.0 to 1.6 cm. This assembly of source parts is designated as Mark IIIa/11/CT2/1.6: indicating the source body/aperture number/cathode/extractor insert. The plasma aperture is similar to that shown in Fig. 7, p. 31, LA-4692-MS (MEP Program Status Report for the period ending April 30, 1971), except that the radial extent of the iron lip is 0.040 in. instead of 0.025 in.

The source had been modified to provide for feeding the hydrogen gas through the side wall into the space between the plasma aperture and the intermediate electrode. Provision also had been made for a pressure transducer line through the side wall. This modification is shown in Fig. 8, p. 33, LA-4753-MS. Gas lines, valves, and pressure transducers were provided so that the hydrogen could be fed into either the arc chamber or the plasma-aperture intermediate-electrode region, the latter being through the side wall. No differences in behavior were detected for the two hydrogen feed paths, contrary to expectations. Differences in extracted current for a given gas flow rate and hydrogen pressure were looked for and not found. Also, no difference was seen in the proton fraction upon changing from one to the other hydrogen feed paths.

The side hydrogen-feed and pressure-transducer attachment have mechanical operational advantages; however, cathodes can be changed without disconnecting the gas lines, and the magnet coil can be changed without bringing the column up to atmospheric pressure. No insulator is required in the hydrogen feed line. The pressure transducer is at ground potential and thus less vulnerable to

vacuum sparks in the column; with the gas lines on the side walls, cumbersome gas line and pressure attachments, hanging on the cathode back plate, are avoided.

A test was made with the Hastings-Raydist flowmeter on the low-pressure ($\sim 200\mu$) side of the palladium leak instead of the high pressure (~ 1 atm) side. The response time is faster, 10 instead of 40 min, and there is no intermediate reverse indication. However, response is still not as fast as desirable. Also, the flow rate on the low-pressure side was one-third that on the normal high-pressure side. The flowmeter is still useful, even with the slow response time, as a means of checking changes in plasma aperture size.

750-kV Accelerating Column

The new network for measuring beam current to the extractor electrode has been modified to give better protection against arc-downs. Transients caused large irreversible changes in the resistance of the 1/2-W resistors sampling the extractor current and extractor voltage. Both were replaced with 10-W power resistors shunted by 90-V spark gaps. The fragile, glass-encased Glassmike capacitors were replaced at the same time with similar ceramic-encased capacitors as a precaution against breakage.

Another problem which was corrected was the erratic behavior of the extractor voltage readout. This was traced to the 400-M Ω extractor voltage divider being nonlinear at 50 kHz, the ripple frequency of the extractor power supply. The 1-pf shunt capacitance across the 400-M Ω portion was sufficient to increase the ripple voltage two orders of magnitude across the sampling resistor. This problem was eliminated by placing a 5- μ F filter capacitor across the output. There have been no further problems with the extractor electrode network in the two months since these changes were made.

The electron trap installed in front of the last electrode of the accelerating tube has resulted in significant reduction of x-ray radiation outside the Faraday cage. Radiation was reduced an order of magnitude in the 30-50 nA beam current range with ~ 10 kV on the trap electrode provided by a separate power supply. The trap presents a potential barrier of at least 2.4 kV to stop any electrons from entering and backstreaming up the accelerating tube.

Figure 8 shows the x-ray radiation measured outside the Faraday cage as a function of the total beam current extracted from the accelerating tube. The minimum radiation level was obtained over a 20-mA region of beam current, just below the 46-mA design current level for the tube. The design current approximates the space-charge conditions for which the Pierce column was designed to produce a planar beam.

Fig. 8. X-ray radiation measured as a function of total extracted current.

Radiation is high at low beam current because (1) space-charge loading in the Pierce column is insufficient to keep the beam planar and (2) the plasma surface is concave. Both factors cause the beam to converge to a waist, after which it expands and strikes subsequent Pierce electrodes. This knocks out electrons which backstream up the tube, producing x rays on impact.

At high beam current, space-charge forces overcome the Pierce focusing and, also, the plasma surface becomes convex; the beam diverges and strikes the electrodes, again resulting in x rays. Here, current to the extractor rises sharply. However, because of the difference in energy of the backstreaming electrons, the increase in radiation is

probably due to the divergent beam striking the other electrodes, as shown by the increase in electron trap current.

Correlation between the radiation and current to the electrodes is also shown in Fig. 8. The electron trap current is a measure of the beam current to all electrodes except the extractor electrode. It is obtained from a wide-band current transformer on the lead between the trap electrode and its power supply. Stray beam current to the electrodes is capacitively coupled between electrodes and bypassed to ground at the electron trap power supply rather than going to ground through the bleeder resistor string. Since the extractor draws no current at low beam current levels, radiation here cannot be caused by backstreaming electrons from this electrode.

The above experiment was conducted with the extractor electrode aperture reduced from 2.0 to 1.6 cm diam by means of a replaceable insert. The purpose of this insert was to intercept divergent ions at the extractor instead of letting them strike subsequent electrodes of the accelerating tube at much higher energy. Although Fig. 8 shows zero current to the extractor electrode at lower beam currents, it should be noted that there was a considerable amount of noise on the telemetered signal. Currents up to 0.3 mA could go undetected in the noise. If future measurements using noise reduction techniques show that this current is actually zero, use of a smaller extractor electrode aperture might be desirable.

It is important to recognize that a small spreading of the beam is to be expected during the 31-cm run in the column from the Pierce anode to the electron trap electrode, even under "exact" Pierce space-charge loading. The transit time through the accelerating column is 7.6×10^{-8} sec. The maximum radial velocity expected is $\sim 2 \times 10^6$ cm/sec; this velocity was estimated from pepper-pot emittance measurements. With the transit time in the column, the beam envelope obtains a radial increment of 1.6 mm at the exit of the column; resulting beam radius is then 8.6 mm.

Accelerating Column Arc-Downs

There is a definite correlation between the high radiation level, due to electron backstreaming, and the frequency of arc-downs. To eliminate unnecessary arc-downs, beam current is raised rapidly

through the low beam current (high radiation region) to the Pierce design current.

Although arc-downs cause little problem at the present low beam power operating conditions, the sparking process in the accelerating column is still being studied to reduce the arc-down rate at full beam power. Sparks studied this period were under normal beam current conditions as compared to those in the previous period, when the beam current was increased until arc-down occurred.

The experimental approach followed in this study is to obtain pertinent information only over the short time interval bracketing the arc-down. This is accomplished with a Biomation 610 Transient Recorder in the pre-trigger recording mode that allows one to capture and record signals just prior to an interesting event. The instrument is set to continually store incoming information electronically and discard it after a chosen time interval, i.e., 2 msec in this case. By using the arc-down as a trigger signal with suitable delay, information over a 2-msec interval bracketing the arc-down can be continually replayed, thus giving a continually reinforced signal on a scope. Since this instrument has differential input, it is possible to superimpose the arc-down signal on the same trace. Figure 9 shows a scope trace of a 200- μ sec timing pulse where arc-down occurred just at the end of the pulse. Figure 10 shows another 200- μ sec timing pulse where arc-down occurred about 125- μ sec after the start of the pulse.

Fig. 9. Arc-down $\sim$ 20 μ sec after end of 200- μ sec timing pulse.

Fig. 10. Arc-down $\sim$ 125 μ sec after start of 200- μ sec timing pulse.

These photos were also used to confirm arc-down times measured from a time-interval meter. With this technique, time to arc-down from start of the pulse is determined by subtracting (1) the measured time between arc-down and the start of the next timing pulse from (2) the time between pulses. Agreement has been excellent. When arc-down occurs between pulses, time-interval measurements will be necessary since no pulse will appear in the photographs for timing reference.

Arc-down photos have also been taken of arc voltage, arc current, beam current, and the radiation profile during the beam pulse. Figure 11 shows the radiation profile from a 500- μ sec beam pulse during arc-down. The negative arc-down pulse is shown at the center of the screen and occurs about 250 μ sec (1.25 divisions) after the start of the pulse as shown by the increase in radiation.

Observations to date show that essentially all arc-downs at 60 and 120 pps are beam-induced (here defined as arc-downs occurring within 1000 μ sec after the start of the beam pulse). At very low repetition rates (e.g., 3.75 pps) arc-downs are rare, and a much smaller percentage is beam-induced.

Accelerating Column Beam Transport

The 750-keV proton accelerating column was originally designed on the basis of a zero emittance beam. Thus, when accelerating a real beam at the designed current, one should expect the beam to diverge slightly due to beam emittance. Calculations have been made to take into account the beam divergence due to a finite emittance so that corrections

Fig. 11. Radiation profile during a 500- μ sec beam pulse. Arc-down is shown by negative pulse at center of screen, 250 μ sec (1.25 divisions) after start of pulse. Radiation reached 7 R/h just before arc-down.

to the accelerating column voltage gradients can be applied to reduce beam losses. The equation used is that derived previously in the MEP Program Status Report for the period ending January 31, 1971, LA-4639-MS, p. 40.

$$R_x'' - \frac{E_x^2}{R_x^3 v_z^2} - F_x(t) \cdot R_x = 0,$$

where R_x is the rms value of the x position of the particles, E_x^2 is the rms emittance squared and is considered a constant of the system (implies linear forces), and $F_x(t)$ is the x component of the force constant per unit mass and includes both external forces and beam self-induced forces. This time-dependent equation is transformed to a z direction (axial) dependent equation by the velocity relationship,

$$dz = v_z dt.$$

Thus,

$$R_x'' - \frac{E_x^2}{R_x^3 v_z^2} - \frac{F(z) \cdot R_x}{v_z^2} = 0.$$

The forces involved in the "exact" Pierce configuration are all linear and can be characterized by $F_{sc} \cdot r$ for the space-charge effect and by $F_{col} \cdot r$ for the focusing forces caused by the column electrodes. By inserting the x component of these force constants into the equation, the following is obtained:

$$R_x'' - \frac{E_x^2}{R_x^3 v_z^2} - \frac{[F_{sc}(z) + F_{col}(z)] \cdot R_x}{v_z^2} = 0.$$

In the "exact" theory, the first two terms are assumed to be zero, and a solution to the remainder, $F_{sc}(z) + F_{col}(z) = 0$, leads to the $V = V_0 z^{4/3}$ potential distribution law inside the beam and to the electrode configuration outside the beam. By using a perturbation approach, while still maintaining a "parallel" beam, that is, $R_x'' = 0$, the emittance term can be equated to a change in the space-charge-force term,

$$\frac{F_x^2}{R_x^3 v_z^2} = \Delta[F_{sc}(z) \cdot R_x / v_z^2] = \Delta\lambda \cdot R_x / r_0,$$

where $\lambda = 6.52 \times 10^5 I/V^{3/2}$ for protons. The current, I, is measured in amperes and the voltage, V, is measured in volts. The beam radius is r_0 . As λ is a function of both I and V, we have,

$$\Delta\lambda = (\partial\lambda/\partial I)dI + (\partial\lambda/\partial V)dV.$$

By using this equation, the column parameters can be matched at two convenient places, i.e., the 750-keV column exit and the extractor electrode.

The corrections are based on a beam emittance of 1.5π cm-mrad at 750 keV. Using the zero emittance designed current of 56 mA and the extractor voltage of 27 kV, the calculated corrections are $dI = -4.66$ mA and $dV = -1.22$ kV. Thus, the new extractor voltage should be 25.8 kV, and the 100% proton current should be 51.3 mA. By taking into account the species ratio of $H^+/H_2^+/H_3^+ = 75\%/20\%/5\%$, the total current is reduced to 45.7 mA and the corresponding proton current is 34.4 mA. It should be pointed out that these calculations provide for an rms "parallel" beam and do not imply that the trajectories of the outermost particles are parallel; some may, in fact, diverge.

The rms emittance has been defined by $E_x^2 = (v_z^2 - R_x^2)R_x^2$ in the above mentioned reference. It is interesting to derive this function from a different approach to appreciate its physical significance. Consider a beam of zero emittance, whose rms position and velocity are respectively R_x and R_x . Consider further the beam to be ideal, that is, all trajectories are laminar and $x_1/x_1 = R_x/R_x$. The added kinetic energy needed to form a beam of finite

emittance having the same rms values, but not otherwise restricted, is given by

$$KE = \sum_{i=1}^N \left(\frac{m}{2} \right) \left(\dot{x}_i - \frac{\dot{R}_x}{R_x} x_i \right)^2$$

$$KE = \left(\frac{m}{2} \right) \sum_{i=1}^N \left[\dot{x}_i^2 - 2 \left(\frac{\dot{R}_x}{R_x} \right) x_i \dot{x}_i + \left(\frac{\dot{R}_x^2}{R_x^2} \right) x_i^2 \right].$$

From the definition of $R_x^2 = \frac{1}{N} \sum_{i=1}^N x_i^2$ and

$$v_x^2 = \frac{1}{N} \sum_{i=1}^N \dot{x}_i^2, \text{ the above equation reduces to}$$

$$KE = \left(\frac{m}{2} \right) N \left(v_x^2 - \frac{\dot{R}_x^2}{R_x^2} \right).$$

Thus the rms emittance is directly related to the added kinetic energy associated with the departure of the beam from ideal (straight-line configuration in phase space). It is tempting to associate this added kinetic energy with an elevated beam temperature, 1/2 kT. Similar equations should be valid for the y and z components.

Beam Transport System

Work has been continued in correlating observed and calculated beam emittance patterns in the high-intensity proton beam line. The results of these studies are presented in detail in another report.¹ It has been found that a variety of beams transported to EM3 can be matched to a specified admittance at the input of the drift-tube linac. The experience obtained from these matching studies indicates that the tuneup procedure that should be used for establishing a desired beam to the linac is to measure the emittance at station (EM3) and then to calculate the gradients required for the final doublets to match this beam to the linac. Using this procedure, beams have been matched to the linac that have resulted in over 16 mA of accelerated beam for an input beam current of 23 mA.

Experiments have been started to study the effect of scraping the halo from the beam at various points along the beam line; slits capable of dissipating full beam intensity have been obtained and will be installed this coming quarter.

Experiments are also being planned to measure beam parameters at the exit of the column during the expected shut down this next quarter. The initial quadruplet will be removed, and pepper-pot and viewing screen measurements will be carried out directly at the column exit.

Work was initiated this quarter to study the problem of obtaining small beam currents at the entrance of the linac to provide suitable beams for initial turn-on of various experiments. Initial experiments have been carried out to determine the range of currents that can be easily set up and transported to the linac with the existing elements in the transport system. The ion source was not varied in these experiments, although an additional order of magnitude reduction in current can be achieved (at low duty factor operation) by reducing the current extracted from the source. Turning off the focusing lenses in the transport line reduces the current by a factor of 15 but results in a nonsymmetric converging emittance pattern at EM3. By inserting intermediate slits at EM2, a reduction of current by a factor of 10^6 was achieved; the limit of this measurement was determined by the sensitivity of the oscilloscope used. Subsequent tests showed that a better mode of operation was to turn off only those lenses upstream of the slits and to leave the downstream lenses (TAQL02) set at their normal values. The emittance patterns observed at EM3 were more nearly symmetrical and diverging, as shown in Figs. 12 and 13. By progressively inserting slits at EM2, the size of the pattern and the current transmitted were reduced without significant change in the orientation or shape of these beam patterns. It is expected that this mode should permit easier matching to the linac. This method, however, does imply a reduction in emittance as the beam current transported is reduced. Work is continuing on this problem.

¹Studies on the Beam Dynamics of the High-Intensity Proton Beam Line in the Injector Complex of LAMPF, B. Goplen and R. R. Stevens, Jr. (To appear as an LA Report at a later date.)

Fig. 12. Horizontal phase-space pattern for a 1.9-mA proton beam at EM3 produced by scraping an unfocused beam at EM2.

Fig. 13. Vertical phase space pattern for a 1.9-mA proton beam at EM3 produced by scraping an unfocused beam at EM2.

The H⁻ Injector Program

Cockcroft-Walton (C-W) Power Supply

The mechanical installation of the C-W unit was completed. The motor-generator set was also installed and operated at no-load. Other than a minor modification to the motor-mounting tripod, the tests were satisfactory. Shaft vibration was much less than 1/16 in., so dynamic balancing of the shaft will not be necessary.

The electrical installation of the control racks is nearing completion, and the high-voltage tests will soon follow. Operation of the C-W will be from the pit location; remote operation from ICR

must await completion of inter-room wiring.

H⁻ Ion Source

A complete set of drawings and a billet of Ferrovac-E iron for the Mark IIIc ion source were turned over to the LASL shops in mid-October. The parts ordered are those of the main body of the ion source for the H⁻ injector. The Mark IIIc source body is interchangeable with the IIIa and IIIb used in the H⁺ injector. The Mark III sources have an 8-1/8-in.-diam body with a 9-in. O-ring shoulder diameter to fit the similar H⁺ and H⁻ double cones. Mating surfaces for the Plasma Aperture and Pierce anode parts are the same for the Mark IIIa, b, and c sources except that tolerances have been tightened for Mark IIIc with decimal specifications for better interchangeability of aperture and anode parts and to eliminate possible differences in the behavior of sources.

The Mark IIIa source was modified to provide side wall-passages for the hydrogen feed lines and an arc "chamber" pressure transducer attachment.

A shrink-fit vacuum seal will be used between the intermediate electrode iron and its copper cooling jacket. This design involves a multiple-step assembly process including BT brazing of a copper segment to an outside cylindrical surface, matching the cylindrical side wall of the iron part of the intermediate electrode. The cylindrical outer surface of the iron is copperplated and machined to fit into the mating surface of the copper jacket when the iron is cooled in liquid nitrogen. It stretches the copper jacket just beyond its elastic limit when it warms up to normal temperatures. A model made up in this way provided a vacuum seal with no detectable leak.

The billet of Ferrovac-E will be used to make the Mark IIIc source. This is a gas-free, high-purity iron produced by melting and purifying electrolytic iron under high vacuum. Inclusions are minimized, magnetic saturation is high (21,600 G), permeability is good, and coercive force is low. Some voids were detected in the billet by radiography, but it is hoped that these can be avoided in the fabrication; otherwise the voids will be closed by plunging and welding.

H⁻ Source Development — Charge-Exchange Canal

The program for the H⁻ source development this quarter consisted of three main experiments and a major overhaul of the test facility. The experiments were: beam envelope profile observations, calorimetric measurement of the H⁰ beam, and H⁻ current measurements with various extraction geometries. These experiments have not yet resulted in a significant improvement in the source performance, but have led to an improved understanding of the design problems.

Beam profile may be easily observed by inserting a scintillating medium into the beam. For the beam in the charge-exchange canal, a pressure of 5 μ of hydrogen is sufficient to produce easily visible scintillation for a 15-keV, 0.5-mA beam. Exchange canal windows that had been used for pressure measurements were covered with glass, making it possible to see the beam width at two places in the 6-in.-long canal. This proved interesting, so a special canal was constructed with a window down the full length and a cap at the exit to maintain constant pressure in the canal for uniform scintillating purposes. This revealed that the beam was almost as parallel as emittance would allow for low extracted currents (Fig. 14), with an increasing size at higher currents. The most interesting phenomenon was the visual demonstration of space-charge neutralization by electrons in the canal. The canal is electrically separate from the extractor and is biased positive to trap electrons and prevent them from going back to the source. When this bias voltage was reduced below ~ 900 V, the beam size abruptly increased to maximum size and the power supply current approximately doubled. The interpretation is that electrons were no longer trapped and hence the beam rapidly diverged because of the space-charge forces.

A series of measurements was made with a three-electrode structure in place of the previously used two-electrode model. As shown in Fig. 15, the extractor and anode were the same, but the snout just beyond the extractor could be biased to try to eliminate the extractor aperture effect at the plasma surface. The canal was again biased to trap electrons. Voltage breakdown prevented carrying out experiments over the full voltage range desired, but it was found possible to reduce extractor and snout

currents to 10% or less of the canal current although the canal current was only half the anticipated amount. Further investigation of the triode is planned with closer spacing than was possible with this preliminary test. A computer program (ICIS) capable of calculating beam trajectories in the presence of arbitrary cylindrical electrodes has been obtained from LRL where it was successfully used to design high-current sources. This code will be used to investigate the triode design.

Fig. 14. Photograph of hydrogen beam profile in charge-exchange canal.

Fig. 15. Schematic drawing of triode source.

A calorimetric measurement of H⁰ beam power was made to attempt to understand the low H⁻ currents thus far achieved. The H⁰ beam impinged on a copper disk that was attached to the vacuum chamber with a thin copper rod of known thermal conductivity.

Temperatures at either end of the rod were determined by measurement of the resistance of calibrated thermistors. Unfortunately, these tests did not allow for simultaneous H^+ measurement, but the maximum recorded H^+ beam was only 6.3 mA. Two conclusions can be drawn: First, the H^+ current at low extracted current is within a factor of two of the expected value. This is reasonable in view of probable measurement inaccuracies. Second, it seems likely that canal current is not being properly measured. Reworking the system to permit simultaneous calorimetric measurements of all currents seems desirable. One can conclude that the H^+ and H^- current measurements are mutually compatible, and that either full proton current is not extracted from the ion source or else it rapidly diverges and is lost in the canal.

Measurements were made with five different extraction geometries. Design of the original anode and extractor was based on a computer code later discovered to be in error. While waiting to get the HICIS code, a set of electrodes was made based on a simple zero-space-charge mode. Internal source shorting and pump failure probably partially invalidate the results given in Table I, but there appears to be a clear preference for the $52.5^\circ/30^\circ$ design (half-cone angles for anode and extractor) electrodes derived from the simple calculations.

The 1000 liter/sec ion pump developed a progressively larger crack in a weld which finally was large enough to admit 1 atm cm^3/min and prevent pump operation. Flaking problems in the pump helped mask this difficulty, and a good deal of time was spent locating this failure and in repairing bad seals in the Roots blower roughing system. The ion pump has been disassembled, rewelded, and acid-dip-cleaned to try to eliminate persistent pump troubles. At the same time, the stand has been reworked so that the pump may be closed off from the ion source with an 8-in. gate valve when changing the H^- experimental configuration. These changes and repairs should greatly decrease pump-down time from the hours or days experienced recently.

A development recently reported by workers in the fusion research field is being examined for possible use with the LAMPF H^- source. Extraction and plasma grids of ~ 1 -mm thickness, with carefully designed and aligned apertures, have been used

on sources producing, for example, 1-kV deuterium beams with 1-A dc-beam current. Each aperture is designed to produce a parallel beam, and the sum of the individual beams is then roughly a uniform density large beam. The advantage of the grids is that by close-spacing, very high fields can be produced to extract high currents. Also the charge exchange in the gap can be expected to drop in proportion to gap length. The grid system is being reviewed to see if the LAMPF beam power, pulsing, current density, and emittance requirements are compatible with such an approach.

TABLE I
Results of Extraction Geometry Experiment

Geometry (deg)	H^- Current (μA)	Gas Flow (atm cm^3/min)	Extractor Voltage (kV)
52.5/30	95	1.47	34
	320	1.85	28
52.5/45	35	1.26	36
	110	3.00	26
45/30	58	1.25	26
	144	3.30	22
45/45	70	1.33	26
	160	3.50	22
52.5/30 (short-spacing)	55	1.42	26
	72	3.62	20

H^- Accelerating Column

The dome vacuum manifold and adjustable stand for supporting the manifold and column are completed. The large cones for cantilever support of the accelerating tube are near completion. Fabrication of the double cone assembly should start soon.

Bonding of the accelerating tube was delayed when bond tests on samples showed low tensile strength. This was traced to poor sample-jigging and warped titanium discs. Bonding of the accelerating tube will commence shortly now that this uncertainty has been removed.

H^- Beam Transport System

The construction of the H^- beam transport system has continued this quarter. The three bending magnets have been tested and are ready for installation on the beam line. The quadrupole magnets have been fabricated and are due to arrive early in November.

All the power supplies for these magnets have now been procured; testing and installation of these units will begin next quarter. The installation of the first part of this beam line will be done early in December; the remainder of the beam line will be completed after the ion source and column are installed. The design and fabrication of the beam-line hardware are proceeding on schedule, and fabrication should be completed next quarter.

Accelerator Operations

Electron Prototype Accelerator (EPA)

The EPA was scheduled for 1120.25 h of experimental beam time during this quarter. Of this time, beam was available for 802.75 h and was used for 701.25 h. Operational performance was as follows:

$$\begin{aligned} \text{Productivity} &= \frac{\text{Beam On}}{\text{Beam Available}} = 87.4\% \\ \text{Reliability} &= \frac{\text{Beam Available}}{\text{Scheduled Beam Time}} = 71.7\% \\ \text{Operational Efficiency} &= \frac{\text{Beam On}}{\text{Scheduled Beam Time}} = 62.6\% \end{aligned}$$

Unscheduled downtime was 412.25 h, with the rf window problems accounting for one-third of this total.

This quarter saw the completion of scheduled beam time for a number of experiments, including the Proton-Compton Effect experiment, the e-e' experiment, the photofission experiments, and activation analysis experiments.

The EPA target tests for LANPF are essentially completed, with one run scheduled for November and another in December.

The next quarter will mark the end of operations at EPA, and some preparations for the impending shut-down are under way.

Los Alamos Neutron Physics Facility (LANPF)

Accelerator

Injector A (high-intensity proton injector) was scheduled for 745 h of operation during this report period. Of this time, 53 h were logged as unscheduled downtime, and 82 h were logged as canceled operations. Actual beam time used was 498 h. The operational performance of injector A is presented below:

Injector Productivity =

$$\frac{\text{Injector A Beam}}{\text{Injector A Ready}} = 85.0\%$$

Injector Reliability =

$$\frac{\text{Injector A Ready}}{\text{Sched. Oper.}-\text{Canceled Time}} = 88.5\%$$

Injector Efficiency =

$$\frac{\text{Injector A Beam}}{\text{Sched. Oper.}-\text{Canceled Time}} = 75.1\%$$

$$\text{Arc-Down Rate} = \frac{\text{Arcs}}{\text{C-W On}} = 0.56/\text{h}$$

The drift-tube linac (201-MHz accelerator) was scheduled for 415 h, with no distinction in regard to 5, 40, 70, or 100 MeV beam being used. Of this time, 75 h were unscheduled downtime and 66 h were canceled. The actual beam time used was 218 h. The operational performance of the drift-tube linac is presented below:

$$\text{Productivity} = \frac{\text{Beam On}}{\text{Beam Ready}} = 82.3\%$$

Reliability =

$$\frac{\text{Beam Ready}}{\text{Sched. Oper.}-\text{Canceled Beam}} = 75.8\%$$

Efficiency =

$$\frac{\text{Beam On}}{\text{Sched. Oper.}-\text{Canceled Beam}} = 62.4\%$$

$$\text{Cro-Bar Rate} = \frac{\text{Cro-Bar}}{\text{RF On}} = 0.037/\text{h}$$

The side-coupled cavity accelerator (805-MHz accelerator) was scheduled for only 25.5 h, and of this time, 12.5 h were canceled. Of the 13 h remaining, 5 h were logged as beam on.

This quarter saw the initial operation of the LANPF accelerator at 211 MeV. However, most of the operation was confined to operation at 5-100 MeV in order to learn the accelerator characteristics at these lower energy levels. More and more time is being devoted to the turn-on of the accelerator by computer, as the injector and drift-tube-accelerator operations become routine.

It is interesting to analyze some of the causes for unscheduled downtime and canceled operations, as is done in Table II. This analysis does not cover the entire quarterly report period, as the logging procedure was not effective over the entire time.

TABLE II
BREAKDOWN OF LANP DOWNTIME

	<u>Injector A</u>		<u>201</u>	
	<u>Unsched. Downtime</u>	<u>Canceled</u>	<u>Unsched. Downtime</u>	<u>Canceled</u>
Miscellaneous inter- lock problems		5.5	9.3	3.5
Ion source filament and conditioning	10.5			
Cleaning rectifier stack (and repairing)	5.25			
Vacuum	5.5	4	14	
Electronic failures	12.25		4.75	
RF dome	16	5	15	4
Miscellaneous rf problems	0.4	4	3.9	2.5
Lightening	1.5			
Arc-down problems	1		1	
Experimenter (or his equipment)		38.75	4.75	11
Work in other parts of accelerator or work not requiring beam		17.75		43.25
Total listed	52.4	75.75	58.7	64.25

VI. EXPERIMENTAL AREA

Facility Planning

The LAMPF experimental area as presently planned is shown in Fig. 16. All of the buildings and beam tunnels are either already built or are under construction. The locations of components, targets, and future facilities along Beam Line A to the Beam Stop have been established.

Fig. 15. Overall layout of the LAMPF experimental areas.

The layout of secondary channels in Beam Area A has been modified for more efficient use of the available floor space. The new layout is shown in Fig. 17. The positions of the Stopped Muon Channel and the High Energy Pion Channel have been exchanged from the positions shown on earlier layouts.

The overall considerations are:

- 1) The layout accommodates the four permanent channels without undue crowding, inflexibility, or interference between neighboring beams.
- 2) Adequate room is provided downstream from Target A-1 for a high energy pion test beam that can be operated independent of other beams. Pion fluxes in the 10^5 - 10^6 sec⁻¹ range can be obtained with a single bending magnet and two small quadrupole magnets.
- 3) The plans include a parasite beam on the Stopped Muon Channel for essentially no additional investment.
- 4) There is space in the northeast corner of the building for one additional permanent beam line, when construction of a third target station can be justified.

Fig. 17. Revised plan of secondary beams in Area A.

A series of meetings have been held to coordinate the design progress of Beam Area A. The design effort is being supplied by various task forces, utility engineers and the beam line engineers for the secondary channels.

Meetings have been held at weekly intervals and will continue to be as needed.

Extensive design and drafting efforts have been made to establish standard layout drawings for component installation, instrumentation, utilities, and shielding. The experimental area designers and draftsmen have also been heavily involved in the development of beam targets and handling mechanisms, in the design of Merrimac and hot-cell equipment, and in secondary beam line layouts and magnet design.

Beam Area A is currently being used as a staging area for the assembly of Merrimac and the testing of magnets and power supplies. Expansion of facility services in this area has been necessary to support the increasing testing efforts.

Beneficial occupancy of the switchyard area for Line A and Line X was obtained this month. The survey of the switchyard to establish "as-built" dimensions, and to locate Areas A, B, and C accurately with respect to the 805-MHz beam line was started including preliminary alignment work and establishment of beam line monuments. Contractor installation of Phase II water lines is continuing along with the alignment activity.

The Phase III contract is proceeding and the installation of permanent shielding at Beam Stop A has been started.

The Conceptual Design Report for the proposed Isotope Production Facility extending to the north at Beam Stop A has been completed. AEC approval of the report will allow the final design of the facility to proceed.

Funds have been received for the pion line components and associated shielding and equipment for the Radiobiology and Therapy Research Facility. Final design of the beam line is under way. At a meeting of the Beam Line and Facility Subcommittee of the LAMPF Biomedical Steering Committee a revised layout of the proposed building was agreed upon. Design criteria are being developed by the planning section of the LASL Engineering Department.

Beam Area B - Nucleon Physics Laboratory (NPL)

The detailed beam design of the neutron production line (Line B) was revised once again to overcome the poor field homogeneity of the PPA 12D24 magnet. In the new configuration, the bend angles at LB-BM-04 and LB-BM-05 have been changed from 11° and 21° to 16° each. Transport calculations show the beam characteristics to be good and the magnets will fit into the physical confines of the beam tunnel.

Under the new design, magnets LB-BM-04 through -07 will be identical "C" magnets, and the PPA 12D24 magnet will not be used. Magnets LB-BM-04 and -05 will be nominally operated at 16 kG whereas LB-BM-06 and -07 will be operated at 15 kG for 800-MeV protons. Bids for these magnets have been received and an order is being placed for five magnets (four in the beam line plus one spare unit). The possibility that all four magnets can be operated in series with a single power supply of 280 kW is being explored. The fine trimming of each magnet would be accomplished by the use of current shunts, and the gaps of LB-BM-06 and -07 would be increased from 3 in. to 3.2 in. in order to make the currents approximately equal for all four magnets.

The six quadrupole magnets for Line B (LB) and the External Proton Beam (EP) have been delivered. The measurement of harmonic content of these quadrupole magnets will commence shortly. The PPA 12D60 magnet to be installed at LB-BM-08 has been tested for field homogeneity at 15.5 kG and 6-in. gap. The results showed this magnet to be acceptable for its intended service. The fabrication of a new pair of coils which would have higher resistance to radiation damage is being considered.

The status of the Area B magnets is shown on a schematic layout of Area B, Fig. 18.

An actual beam test for the liquid deuterium target has been scheduled for November 1971 at the Electron Prototype Accelerator. There has been no progress on the polarized proton target cryostat in this quarter. Design criteria for the vacuum system, the magnet stands, and for radiation safety in the Nucleon Physics Laboratory have been given to the appropriate task forces for engineering action.

Fig. 18. Status of beam line magnets in Area B.

Beam Area C - High Resolution Proton Spectrometer (HRS)

Recent effort on the HRS has been directed toward design and procurement of the beam line magnets and power supplies. Extensive computer studies were made on the narrow quadrupole magnet (LC-QM-12) and the 57° bending magnets (LC-QM-04, LC-QM-05). A design review of the 57° bending magnets led to the complete redesign of these magnets to save on fabrication costs. This redesign resulted in considerable delay and the PERT schedule is currently being reworked in order to minimize the effect on the completion date for Beam Line C.

All power supplies needed for Beam Line C and the HRS are either on hand or on order. The magnet stand task force has started the design of the various magnet stands and the vacuum pumps have been ordered.

The status of the magnets for Line C and the HRS is indicated in Fig. 19. The approximate positions of the slits, steering magnets, and beam diagnostic multivire proportional chambers on Line C are

Fig. 19. Layout of Area C showing location and status of Beam Line C components.

also indicated. As soon as the exact positions of these beam diagnostic devices are determined, the fabrication of the vacuum system to be used for the beam channel will be started.

The problems of beam monitoring, beam position, and beam intensity have not been completely solved. Two possibilities for beam intensity monitoring are currently under consideration: one is to use the beam dump as a Faraday cup, and the other is to use an ionization chamber just in front of the beam dump.

Development work for the beam stripper required at the junction of Beam Lines B and C is continuing. Means of procuring graphite foils of sufficient number and size for H⁺ stripping are still being investigated. Though the techniques for manufacturing pyro-carbon foils is available at LASL, no commitments have as yet been obtained.

In the meantime, a report has been written including all the details of the beam stripper work done at LANPP¹ and another report has been written detailing the stripper requirements for Lines B and C.²

After an extensive study of the scattering chamber it was agreed to design and fabricate a prototype all-metal sliding-seal mechanism. This new design will enable the spectrometer to be operated at extremely small scattering angles, without radiation damage. The design for the target orientation mechanism has been finished.

Fabrication of the two bending magnets for the spectrometer is proceeding without major difficulty. The machining of the steel for the yoke is essentially finished and the fabrication of the vacuum chambers for both magnets is complete. Difficulties in achieving the required mechanical tolerances have caused a slight delay in spectrometer coil fabrication, however.

Several different types of magnetic field measurements have been made on the prototype magnet which bear on the design and operation of the MRS and Energetic Pion Channel and Spectrometer (EPICS) systems. Magnetization curves were obtained and the total effective field length was measured both as a function of the lateral position coordinate (x) across the median plane, and as a function of the central induction field. All components (B_x , B_y , and B_z) of the fringing field at both the entrance and the exit of the magnet were measured in order to provide a definition of the induction field for use in ray-tracing of the actual configurations. In general, the field measurements agree with the predictions of the two-dimensional code "POISSON." Preliminary tests of the M_z -windings indicate that a field homogeneity of 1 part in 10^5 can be achieved through their use.

Energetic Pion Channel and Spectrometers (EPICS)

Considerable work was put into polishing the EPICS Channel design. An error was discovered in the design reported previously, and some modification

of the edge curves for each of the four channel magnets was required. The corrected design calls for four different magnets with edges that are significantly noncircular. This has caused a delay of approximately two months in the fabrication of the magnets, since redesign was required. The order for the steel and copper raw materials for these magnets was not affected by the changes.

Progress has been made in the ray-tracing studies of the spectrometer. The dispersion section has a calculated resolution of $\sim 2.5 \times 10^{-4}$ (full width). Effort toward reducing this to a value closer to the design goal of 1×10^{-4} will continue for a few weeks, but it is planned to settle soon on a "best design" and proceed with final engineering of the spectrometer.

Calculations show that the spectrometer input quadrupole triplet will perform satisfactorily, and a design for a 12-in.-diam slim, elliptical quadrupole has been finished. These magnets will be put out on bid by early November.

The pion production angle accepted by the channel has been changed from 45° to 35° . This change allows a two-fold improvement in the pion flux. The angular coverage of the second spectrometer was compromised somewhat, while the range of the first spectrometer has been expanded. The angular range discussed in the EPICS proposal³ was somewhat optimistic; it is now believed that the smaller spectrometer can cover the range from 0 to 155° , and the second spectrometer can be used from 0 to $\sim 45^\circ$, depending on the design chosen.

The model magnet for the EPICS particle separator has been revised to make it a consistent quarter-scale to facilitate testing. Since this is a very difficult problem, the magnet and flux box are being precision-machined. The magnet has been annealed and precision-fitted to allow it to operate better over the wide range of field required. A field coil is being used which will produce rated fields for both modes of operation of the separator.

The separator design has been changed to make it independent of the beam line for ease of removal

¹D. J. Liska, "Investigation of Graphite and Carbon for Stripping the H^+ Beam in LANPP," LA-4795-MS, Los Alamos Scientific Laboratory (October 1971).

²Internal memo from C. F. Huang to D. J. Liska, "H⁺ Strippers for Lines B & C," dated October 14, 1971.

³H. A. Thiessen and S. Sobottka, "A Proposal for EPICS: A High-Resolution Pion Beam and Spectrometer Facility for Nuclear Structure Research at LANPP," LA-4534-MS, Los Alamos Scientific Laboratory (September 1970).

during maintenance. The flux box is a 76.5-in. cube, constructed of 1.5-in.-thick steel plates. The separator is mounted on a heavy steel block which slides into the box on tracks and forms one wall of the box. When the block is fully inserted, the separator is aligned between beam lines which open into opposite walls of the flux box. The beam enters the box and passes between the separator electrodes before exiting through the other wall and continuing along the other beam line. The steel block forms a vacuum seal with the flux box and the entire interior of the box operates at vacuum or at low gas pressure. The block is thick enough to allow personnel to disconnect the vacuum seal and high voltage lines easily when the beam is shut down. When the beam is turned on, additional shielding is placed about the block. This technique does not require the use of Merrimac for removal of the separator.

The cables for the separator high voltage have also been redesigned to be radiation-hard by allowing them to operate at the same vacuum or low pressure as the separator itself. The lines are made large enough to limit the voltage gradients to less than 120 kV/in. at the highest pion energy. The lines are carried through the steel block to vacuum disconnects. The magnet power lines also pass through the steel block.

Some progress has been made on the conceptual design of the channel support system and the separator. Basically, the channel will be supported as a single rigid body by two large, 6-in.-thick steel plates on either side of the channel. The separator will be enclosed in a large vacuum box which is sealed at the surface of the support plate. This system allows for easier service on the separator and a rigid support system. On the other hand, the separator magnet must be inside the vacuum chamber. This appears to be a practical arrangement, and work will begin shortly on the design of the separator and support system.

A decision was made to make no offer for the $n=1/2$, 1100-MeV/c spectrometer to be disposed of by Orsay. This spectrometer, which might have been suitable as the second EPICS spectrometer, is too large to fit conveniently into the space available, and would have too long a flight path for low energy experiments. Present effort will be concentrated on making an optimum first spectrometer and any work on the second spectrometer will be postponed.

Low Energy Pion Channel (LEP)

A horizontal layout of the LEP Channel is shown in Fig. 20. The concrete shielding enclosure surrounding the experimental area at the exit of the channel is meant to be suggestive only; the actual shielding arrangement will be varied for individual experiments. However, the enclosed space of $\sim 12 \times 16$ ft should be adequate for most of the initial experiments. The 5-ft-thick concrete walls, and a suitably thick roof, will reduce radiation outside the walls to below tolerance levels. Portable counting-room structures are shown which are meant to be large enough to accommodate two experimental groups.

Bids have been requested on the last two channel magnets to be designed. These are the second and third bending magnets as shown in Fig. 21. Conceptual design of the support structures has been completed and detailed design has started. An actuator design for the slit- and collimator-systems has been completed and work has started on a prototype.

Fig. 20. Proposed layout for the low energy pion experimental area.

Fig. 21. Elevation view of the Low Energy Pion Channel.

Design studies have begun for the channel collimation system using the Monte Carlo program, NPFLUX, written by R. Hutson. The program has been modified to handle collimating apertures with finite thicknesses. It is being used to calculate the pion beam momentum and space distributions at the end of the channel. The most convenient location for collimators which define the angular phase space is at the entrance and exit of the first quadrupole where the beam is large in the horizontal and vertical directions, respectively.

From the calculations, it appears that tantalum collimators 2-in.-thick will be adequate. This thickness will result in an acceptably small tail to the momentum distribution at $\Delta p/p = \pm 0.05\%$. For example, at 50-MeV pion energy, the area under the tail will be 2% of the main peak when the solid angle is reduced by a factor of 2.

P³ High Energy Pion Channel

In the past quarter the location of the P³ channel was changed from the south side of Target A-2 to the north side. This resulted in a few minor design changes to the first bending magnet. No other components were affected.

The status of the magnets for the P³ Channel is indicated in Fig. 22. Most of the magnets for this channel were included in the allotment consigned to LASL from Princeton-Penn Accelerator (PPA). The work of overhauling and refurbishing these PPA magnets is under way. For example, the PPA 18D40 magnet which will be used for the second bend in the P³ Channel is shown disassembled in Fig. 23. All parts have been inspected and cleaned, the iron parts have

Fig. 22. P³ Channel layout showing status of magnet procurement.

Fig. 23. The PPA 18D40 magnet disassembled for inspection and renovation.

been repainted, and the coils have been tested for water flow and for breakdown under high potential. The fusible link microswitch thermal interlocks used by PPA are being replaced by thermostats of a proven design.

The secondary shielding requirements for the P^3 beam line have been analyzed and a preliminary shielding design has been made. Additional computations using neutron Monte Carlo codes are needed before the P^3 beam stop requirements are known. Attempts will be made to use the lower layers of shielding to provide a common foundation for the channel as far out as the third bend.

The muon contamination has been computed using a newly-written Monte Carlo code. A typical result for 400-MeV pions is 13% muons in a 30 x 30 cm region around the exit focus, with the muon contamination reduced to 4% when considering a 4 x 4 cm spot.

Stopped Muon Channel

As a result of the consideration of floor space needs in Area A and the expected short- and long-range development of the various beams, the Stopped Muon Channel has been shifted from the north side of the building to the south side, as was shown in Fig. 17. The channel design itself is unaffected, and the new layout incorporates a desirable production angle with liberal allocation of the available floor space.

The status of magnet procurement is shown in Fig. 24. Seven of the 12QE20 quadrupoles have been completed and delivered (see Fig. 25). Work on cement-potting is under way in preparation for fabricating the first two quadrupoles and the first bending magnet. Coils for the quadrupoles will be wound as soon as the vendor perfects the required fluxless splicing technique.

Measurements of the effect of shielding iron on the first bending magnet are being made.

Analysis of the beam transport properties of the two-bend analyzer system continues. Predicted fluxes and spot sizes will be calculated and reported when a few problems with the code are solved.

The most recent version of the layout shows a 90° bend in a C magnet at the beginning of the analyzer section of the channel. This configuration permits the extraction of a 45° parasite beam at the main pion momentum when the analyzer is set for backward decay muons. The parasite beam would have approximately equal numbers of pions and muons with a μ^+ flux of $\sim 10^5 \text{ cm}^{-2} \text{ sec}^{-1}$ when the decay part of the channel is operated at 180 MeV/c. The unfocused and uncollimated spot size is 30 x 30 cm with a

Fig. 24. Stopped Muon Channel layout showing status of magnet procurement.

Fig. 25. Large aperture quadrupole magnet for the Stopped Muon Channel.

momentum bite of $\pm 10\%$. Beam purity and background levels will not be as good as the primary beams.

The first set of shielding calculations for the Muon Channel has been carried out. Simple attenuation methods were used in estimating neutron fluxes, but an attempt was made to consider all secondary sources as well as the production at the primary target. The calculations are now being reviewed and checked. Meanwhile, a preliminary design of the shielding needed for the beam line and the experimental cave has been made. The estimate of the neutron flux (neutron energies in the MeV range) in the cave from the beam line and leakage from outside sources is ~ 5 neutrons/cm²-sec. To this the experimenter will have to add neutron fluxes generated in his target.

Biomedical Pion Channel

Preliminary study of the Biomedical Pion Channel design alternatives was completed in August. Some of the conclusions are:

1. Initial collection of the pions emitted from the production target should be done with a quadrupole triplet operating in a mode such that there is a bend plane crossover of the pion rays within the triplet. This tuning assures the maximum channel solid angle.

2. A three-bend channel with the center bend split into two halves is superior to a two-bend channel. This is based in large part on the fact that second-order aberrations are generally smaller in the three-bend configuration and that second-order corrections are more easily made in the three-bend system.

3. Because of the exceptionally large solid angle and momentum spread accepted by the Biomedical Pion Channel, it does not seem feasible to correct the chromatic aberrations at both the momentum dispersion plane and at the end of the channel simultaneously. A design alternative that is being pursued is to use a sextupole in conjunction with bend magnet pole edge curvatures to correct chromatic aberrations at the dispersion plane focus, and to reduce all the pion energies to essentially the same energy at this focus with a wedge degrader. The pion beam is nearly monochromatic beyond that point, thus solving the problem of chromatic aberrations in the last part of the channel, but the pion stopping

region must then be swept in depth to cover the target volume.

4. In a channel which transmits a large phase space, as does the Biomedical Channel, it is more suitable to remove contaminating electrons by means of an electron energy radiator than to use an electrostatic separator.

Work is proceeding to find the optimum design parameters based on the conclusions outlined above. Initial magnet design and engineering, based on several alternative channel configurations, is in progress. One channel design is shown in Fig. 26.

Monte Carlo calculations of neutrons streaming down the channel and penetrating the shielding are being carried out. The results will better define the amount of shielding required and might affect the configuration of the bends and straight sections of the channel.

A number of meetings have been held to discuss and clarify the requirements and problems of channel maintenance and repair. Calculations of activation of the first elements of the channel are being carried out in order to estimate the extent of the problems of maintenance of radioactive components.

Fig. 26. Top and side views of tentative biomedical pion beam.

It is proposed to use a wheel-type pion production target for the Biomedical Channel. Design is under way of a target that will be 2-5 cm thick as seen by the proton beam but will be only a few millimeters thick with respect to the channel as measured in the bend plane.

A number of informal meetings with LASL personnel and with interested non-LASL members of the LAMPF Users Group have been held to discuss the probable and potential requirements in the area of beam diagnostics and physical dosimetry. This was done in close collaboration with the LASL Pion Radiobiology Group (H-9) and with local members of the Physical and Biological Dosimetry Subcommittee of the LAMPF Users Group.

Control philosophy for the biomedical facility has been considered and at present it is planned that computer control without separate local control will be utilized for essentially all aspects of the facility. Control will be implemented through the CAMAC hardware system. The only hard-wired control systems are apt to be target insertion and beam shutters, the dose integrator system, and the personnel safety system.

It appears feasible to start the design of the control console and the console-computer interface immediately. Work is starting on a current integrator circuit for the dose integrator.

The detailed specifications for the biomedical computer are being considered. The controlling factor is whether or not treatment planning is to be done on this computer. A good pion treatment planning program seems desirable, but will require a larger computer system than can economically be dedicated to the biomedical facility. Hopefully, this point will be resolved within a few weeks. The computer system will be some configuration of the DEC PDP-11 series so that it can tie into the LAMPF experimental data-acquisition network and take advantage of both the hardware and software support which will be available for this system. If treatment planning is to be done on it, it will utilize the recently announced PDP-11/45 central processor with floating-point hardware and memory segmentation.

Primary and Secondary Beam Transport

The current status of the mineral-insulated, indirectly cooled magnets for the switchyard is:

1. The five 2° bending magnets, H2211117M/4,* show sufficient change of internal field shape (B vs x) with excitation to make side-shims impractical. Figure 27 shows the effect of end-shimming (not necessarily optimal) on $\int B \cdot dl$ vs x . The measured values of $\int B \cdot dl$ are being compared with the allowed limits of first- and second-order coefficients of the dipole field expansion.

2. The 8° magnets (H1011169M/4) are ready for inspection at the vendor's plant.

3. The 12° magnets (H1311199M/4) have been accepted, and the magnetization curves are shown in Fig. 28. The fact that saturation does not occur until well beyond the operating point arises from the yokes being designed for mechanical stability rather than flux return.

4. Parts for the first two 6-in. quadrupoles, 6Q22M/5, are completed, and the iron assembly has been checked. All seven magnets are expected by early November.

5. The 2-in. quadrupoles have been subcontracted in sections. All parts are on order, and some of the iron has been machined.

Other mineral-insulated (m.i.), directly-cooled magnets are in various stages of manufacture. The first 8Q16M/7 has been assembled; Fig. 29 shows the connection end with the coverplate removed. Measured harmonic content for this magnet (the iron of which was poorly assembled) is:

	$n = 3$	$n = 6$	$n = 8$	$n = 10$	
$\int B \cdot dl$	0.05	0.585	0.54	0.78	(all values are $\int B \cdot dl$)

These pole ends are chamfered 0.85-in. at 45°. Further chamfering is expected to reduce the $n = 6$ component. A second version of the same magnet, better put together, is now being connected for testing. Figure 30 shows coils for both an 8Q16M/7 and 11Q22M/9 made from 0.53-in.-sq. hollow m.i. cable (see the insert) at the vendor's plant.

* Magnet designations have been changed to give the actual pole width, rather than "usable" width as given formerly.

Fig. 27. The effect of end shims on B/dx vs x for one of the switchyard magnets.

Fig. 28. Magnetization curve for the 12° switchyard bending magnets.

Fig. 29. End view of 8QW16M/7 quadrupole magnet with cover plate removed.

Fig. 30. Coils for 3- and 11-in. quadrupoles made from mineral-insulated conductor.

The nine Line C twisting and focusing quadrupoles, 6Q29/7, are now on order. The second pair of bending magnets for the Low Energy Pion Line, PR20VI37/15, is ready to go for bids. These magnets use an epoxy-fiberglass insulation in the coils, and epoxy-novolac with methyl nadic anhydride has been specified for this potting. A recent test of this epoxy, to over 10^{10} Rad of fission flux in LASL's Omega West Reactor (OWR), showed some discoloration, shrinkage of 3%, and a weight loss of 2.5%. Further irradiations are in progress, but the initial result is encouraging.

The radiation-damage test rig for components of the mineral-insulated magnets is being checked out for use in OWR. An assembly of m.i. cable, end seals, and water insulators is to be irradiated in an environment which includes water flow at realistic pressure and temperature, as well as the radiation flux and applied voltage.

The magnetic tape unit from PICO which was purchased for the magnet measuring program is now 90% operational and is being used in the acquisition of data on quadrupole magnets. Tapes from this unit are compatible with the CCF tape units and the data analysis programs are already operational on the CDC-6600. Programs are being completed to operate a rapid mapper, Fig. 31. The data from this device will also be stored on magnetic tape for later analysis on CCF computers.

Fig. 31. Rapid mapper. The computer controls the x, y, and z motion of the coil. Stands also used for long coil $\int B \cdot dl$ measurements.

Measurements on the end shims of the H22III17 bending magnets are continuing. Figure 27, previously referred to, shows the improvement possible with this type of shim. Several quadrupoles have been measured. A set of four small point coils was used for some measurements. The value of the duodecapole $n = 6$ component is obtained with high precision when these are set up in a bucking arrangement such that the dipole and quadrupole components cancel. The effect on the $n = 6$ component of chamfering the poles on one particular quadrupole, an 8QN16, is shown in Fig. 32. The quadrupole component for the 8QN16 before chamfering is shown in Fig. 33. Two of the four coils are used for this measurement.

A series of measurements was completed on the EPICS prototype magnet. These measurements indicated the field was poorer than could be tolerated in the actual beam line. A subsequent physical inspection showed an indentation in the pole surface of the same order of magnitude as the field error. Further measurements after the poles are remachined will include some measurements with the rapid mapper.

Several new types of measuring gear are being constructed at the present time. These include a harmonic analysis coil arrangement with all components at a single radius, a pair of long coils to measure gradient and deviations from a constant gradient in quadrupoles, and a series of physically

Fig. 32. Reduction in duodecapole field component achieved by chamfering the poles of quadrupole magnet.

Fig. 33. Quadrupole field for the 8QN16 magnet.

small ($\sim 1 \times 1$ cm) coils with effective areas of $4-5 \text{ m}^2$. The use of coils with larger effective area will reduce some problems associated with integrator drift.

The interactive TRANSPORT code on the Berkeley Remote Facility has been augmented to incorporate space-charge effect, as per S. Sacherer's addition to the TRANSPORT code at CERN, and the beam buncher. These two additions may be particularly useful for TRANSPORT use in Linac tuning calculations and in the design of the Beam Line D from the storage ring to the Weapons Neutron Research (WNR) facility at LAMPF.

Experimental Area Equipment and Experimental Support

Target testing of water-cooled graphite targets at EPA has come to a successful conclusion. An ATJ graphite target, G-63, with a copper water jacket and a nickel coating on the jacket o.d. was tested at 1.05 of LAMPF conditions for 103 hours. No water leakage or graphite deterioration was observed. Several other targets were similarly successful in showing no water leakage or graphite deterioration. A ZTA graphite target in a 316 SS jacket with a copper coating on the jacket i.d. operated with the lowest center temperature, 700°C. Good results were also obtained from an ATJ graphite target in a 316 SS jacket with a copper coating. A target of previously irradiated ATJ graphite pressed into a new 316 SS jacket showed good results. The latter three targets had lifetimes in EPA of only ~ 50 h because they were destroyed either as the result of accelerator malfunction or operator error.

On the basis of experience gained thus far, a target for testing in the 100-MeV LAMPF beam has been designed. It is ZTA graphite in a copper jacket with nickel coating on the jacket o.d. to reduce water corrosion. The ZTA graphite which is partially pyrolytic was chosen over ATJ because of its lower operating temperature and its 10% greater density.

The wheel targets of molybdenum and graphite and their drive mechanism have been fabricated. Testing has begun at EPA. Limited results show no fundamental problems with the wheels or spokes, but the gears which rotate them have not performed satisfactorily. Solution to the gear problem is being vigorously pursued so that meaningful results can be obtained at EPA prior to its shutdown, January 1, 1972. All work on the EPICS stationary, graphite, water-cooled target has ceased.

The 100-MeV beam test area is being designed. Design and fabrication work is proceeding on the beam stop. The target box, vacuum pump, and other parts of the EPA testing equipment will be used in the 100-MeV beam test area.

Calculations were completed on a water beam stop for the 800-MeV LAMPF beam. The beam will pass through a window of stainless steel 0.035-in.-thick and then be stopped in a tank containing ~ 1000 gal of water.

The preliminary design of a 6-in. linear actuator has been completed, and detail drawings are in

process. Approximately 20 units, including spares, will be required for the various instrumentation in the switchyard portion of Line A and Line X. These units may also be useful at four locations in Line C which require a 6-in. motion.

Drawings for the switchyard magnet stands have been completed and a purchase order has been placed for the 15 stands required. Three permanent alignment stands have also been designed and built, and are currently being installed. The switchyard area was made available for survey and alignment work during the last week of September. Three temporary walls have been placed in the beam channels: at the end of the 805 sections, Line X, and at the entrance to Area A. Temporary heaters are being installed.

Power supplies for the switchyard magnets have been relocated in the service aisle to allow space for an additional set of electrical racks. Installation drawings of the u.i. cable-runs between the service aisle and the switchyard magnets have been completed and final revisions are being made.

Good progress has been made on the pump-heat exchanger packages which handle potentially radioactive water. A 1-MW package is scheduled for completion on 29 November 1971, while the first 3-MW package is due on 20 December 1971. Components for the ion exchanger and filter systems are being fabricated in the LASL shops. An experimental model of a hydrogen recombiner has been designed and the components for this device have been ordered. The design for the interface piping for the switchyard has been completed and is out to several contractors for bids. The temporary water system which was provided in Area A has proven to be very popular; five different magnet experiments along with four power supplies are currently using this system. A 150-kW, 20-gpm portable pump-heat exchanger package has been fabricated. Performance tests will be run on this equipment in the near future. Permanent Area A cooling water mains and secondary water distribution systems are currently being designed.

The prototype Beam Profile Monitor-Nonintercepting (PF) is currently installed on the 750-keV LAMPF Injector beam line. In mid-October the first usable beam profile information from this device was obtained. In this test a 1-mm-diam, 50-μA peak intensity proton beam was formed with a collimator upstream of the profile monitor and the resulting

"image" was viewed both visually and with a PMT-slit combination. The effective slit width in these first tests was ~ 1/16 in., which widened the response considerably. The beam profile information was recorded by means of an oscilloscope and camera. The centroid of the resulting beam profiles was easily resolved to within 0.01 in. by examination of the scope trace photographs. The width of the slit is now being decreased and an attempt at better alignment with the centerline of the beam transport is being made, which should result in increased spatial resolution for the instrument. The gas pressure in the beam transport during these tests was 10^{-6} Torr and there was no difficulty in directly observing the "image" of the proton beam on the phosphor screen at the end of the column. When the photomultiplier-slit assembly was used to measure profiles, it was necessary to use only 500 V on the PMT to obtain signal-to-noise ratios of better than 100 to 1. Therefore, it would seem that the sensitivity of the instrument is quite adequate for use at LAMPF and that the main difficulty to be overcome is that of shielding it against background radiation.

Test results of the Beam Centroid Monitor-Non-intercepting (CN) at EPA are as yet inconclusive; it will be moved to the LAMPF Injector beam line as soon as possible. No progress is reported on the Beam Profile Monitor-Intercepting (WS). The epoxy-fiberglass ion chamber Insertable Strip Ion Chamber (II) is still in the fabrication stage. Tests of this device will start when the ion chamber is complete.

The high-sensitivity Beam Current Monitor (CM) (1- μ A resolution) has been in operation for the last three months at the LAMPF Injector. Base-line jitter has been a problem which is not yet solved; otherwise its operation is satisfactory.

The delta-ray energy monitor is complete. Bench-top calibrations are under way. It will be ready to install in the LAMPF 100-MeV transition region the start of next quarter.

Preliminary planning for the LAMPF Equipment Pool has begun. A survey of submitted research proposals has been made and spokesmen for proposals approved and granted time have been polled with respect to their Electronics Pool needs. The information gathered is being compiled and assessed for use in helping to establish priorities for expenditure

of pool funds. The recommendations of the Equipment Pool Committee of the Technical Advisory Panel will also be taken into consideration.

Remote Handling

Construction of Merrimac is continuing. The landing gears have been reassembled and the wheel drive and steering mechanisms have been attached to them. The gears are presently being attached to the gantry frame. The jack frame has had the ball screw jacking system mounted upon it and awaits only the receipt of its hydraulic motor and brake package for completion. The hydraulic package that powers the gantry and provides pressure for opening the large target cell shield doors has been placed with a vendor. The system is based upon electrically operated hydraulic valves and a diesel-powered dual pump package. One pump has very fine control and provides the power for the propulsion and box-lifting system. The second pump provides fluid for steering, braking, leveling, and for the target cell opening mechanisms.

The Zia Co. has completed the lamination of the shield box walls and is presently bolting in the inner roof structure. Each wall is painted a different color - red, blue, yellow, and white - for orientation purposes for the manipulator and hoist controls. The box as it now stands will be disassembled and transported to the 6990-ft level of the Merrimac service portion of Experimental Area A. Complete assembly and equipment installation will be performed there. Essentially all drawings have been finished that are required to assemble Merrimac. These include the manipulator hoisting rig, the tool board, lighting system, and pass-through doors.

Difficulties have arisen with cleaning the excessed "Beetle" windows for use in Merrimac. These windows had resided in the NRDS salvage yard exposed to the elements for some time before they were found. The glass surfaces had become clouded and will require window disassembly for abrasive cleaning of each surface of the four lead-glass panes which are in each window. Means are being sought to clean the windows.

All the manipulators required for the Merrimac area hot-cell facility have been borrowed from the R-MAD hot-cell complex in Nevada, subject to six month's recall. These are high-quality machines that have been well maintained. LAMPF personnel

will remove the manipulators and pack them into a 40-ft trailer on racks for transport to Los Alamos in order to avoid the usual shipping method which utilizes a crate into which the manipulator is packed upside down. Very few manipulators withstand the latter treatment without damage.

The air filter system has been installed.

The last quarterly report mentions that the removable beams over the window boxes and the hot-cell covers which roll on the beams had been designed and were awaiting fabrication. The order has yet to be placed with a vendor. The drive system to open the doors and the steel floor for the service cell have been designed.

The heavy doors over target stations A-1 and A-2 have been conceptually designed. The vertical target-handling mechanism now complicates the door system. Alternate target mechanisms are being considered to reduce the complication. Work is beginning on vacuum flanges that can be remotely disassembled. A pneumatic stepping motor is being considered for use on slits and magnet-stand jacks in high radiation fields.

Shielding, Residual Radiation, and Radioisotope Production

Using the ORNL radiation transport code NMTC, information is being compiled to facilitate the design of shielding and beam stops.

Although not particularly applicable to the design of an actual 100-MeV stop (the dimensions are closer to that expected for 800-MeV protons), Figs. 34 and 35 show the kind of information available. Neutrons below 15 MeV have not been followed in the transport. This problem will be rerun for 800-MeV incident protons, and similar plots will be available soon.

In an attempt to provide information on pion beam stops, the following studies have been made using 150-, 350-, and 550-MeV positive pions incident along the axis of a concrete cylinder of dimensions $r = 10$ m and $h = 10$ m:

- 1) For the three incident π^+ energies, the angular spectra (summed over all energies) of the neutrons escaping (backscattering) from the entrant face were obtained. See Fig. 36 for a representative plot.

Fig. 34. Total number of neutrons escaping from the surface of the carbon cylinder per 50 cm increment of distance along the beam axis; 18,500 incident protons at 100 MeV were considered.

- 2) Again, for the three incident π^+ energies, plots of the backscattered neutron energy spectra (summed over all angles) were obtained. See Fig. 37 for a representative plot.
- 3) Number of backscattered neutrons/incident π vs incident π^+ energy (see Fig. 38).

From Fig. 38 we note that the number of backscattered neutrons produced is not a rapidly varying function of the incident pion energy. For the worst case there is approximately one neutron produced per 10 incident pions. The shape of the angular distribution (Fig. 36) leads to the conclusion that the pion stop should have a re-entrant hole. Additional information on the spectra (both angular and energy) of escaping charged particles is also available.

Fig. 35. Energy spectrum of the escaping neutrons given in previous figure.

In an effort to determine the proper design depth of a pion beam stop that will attenuate the forward-scattered neutron flux to an acceptable level, one encounters computational difficulties. For example, to get two neutrons to penetrate to a depth of 4.5 m of concrete, it was necessary to initiate 14,000 incident particles (400-MeV π^+) and consume 1 h of CDC-6600 computer time. Crude estimates show if one were to attempt to model neutron attenuation exactly with sufficient statistics, it could take as much as 100 h of computing time. To avoid this, internal boundary tallies are introduced into the concrete slab. One then makes a log-linear plot of the number of neutrons versus depth. An extrapolation of this curve to an acceptable attenuation should yield a proper design depth. Fig. 39 is an example of such a plot.

Fig. 36. Angular distribution of the neutrons emerging from the entrant face of a concrete stop for 550-MeV positive pions.

Fig. 37. Energy spectrum of the neutrons emerging from the entrant face of a concrete stop for 550-MeV positive pions.

Fig. 38. Number of neutrons emerging from the entrant face of a concrete stop per incident pion for several pion energies.

Fig. 39. Sample calculation of the neutron attenuation vs depth for 400-MeV positive pions on thick concrete.

The Monte Carlo cascade code NMTC does not transport protons or neutrons below 15 MeV. Work is in progress to employ other LASL codes to model the effects of this component of the radiation.

Preliminary estimates of total stacked shielding requirements for the Experimental Area have been developed. Known requirements at this time, excluding the proposed WNR and Mass Separator Facilities, total 39,900 tons of steel and concrete shielding. As various designs are finalized these quantities may be changed somewhat. Procurement actions to date provide the needed steel but some additional concrete blocks are required. About 2400 tons of magnetite concrete blocks and some 4100 tons of ordinary concrete blocks in special shapes remain to be built. The most recent shielding acquisition completed was 200 one-ton concrete shield blocks obtained from the Univ. of Texas and 900 tons of iron counterweights from Vandenberg AFB in California.

The stacking of about 400 tons of scrap steel around the outside of the Beam Stop "B" structure has been completed to provide the necessary shielding of this beam stop in the direction of the Areas B and C service aisle and trailer stations.

Preliminary design for the stacking of the massive shield for the targets in Area A has been started. Broad conceptual plans are being prepared defining the material boundaries. These will be refined into stacking patterns as the design progresses. Known shielding parameters for the secondary channels are being fitted with those of the main beam line and targets.

Analysis of the large volume of radioisotope production data obtained from the series of irradiations made at SREL this past June continues. Some of the new target materials included in this second series were: Na_2CO_3 , SiO_2 , Ti, Co, Ni, Cu, Zn, Ge, Sn, Ba, La, Ce, Tb, and Au. In addition, one of the target materials irradiated in December 1970, viz. V, was repeated June 1971. Significant discrepancies with other published data have been noted, whereas the results of the two separate V experiments carried out at LASL agree very well. Also, calculations have been carried out for these new materials using Rudstam systematics. As with the first series, the calculated cross sections generally agree within a factor of two or three; however, there are many disquieting cases of deviations of more than an order of magnitude.

VII. LAMPF SCHEDULING AND FACILITY CONSTRUCTION

Craft Equipment Installation Activities

In the 100-MeV Facility, the Zia/LACI crafts continued installation of H⁻ injector controls, completed about 75% of the installation of transition region control wiring and terminations and had about 90% of the transition region magnet cables installed. The L. E. Meyer Company was contracted for \$28,900 to install water systems A01b and A05; this work is now 40% done and completion is expected by 31 December 1971.

In the 805-MHz accelerator portion, LACI completed installation of a beam channel radiation shield plug for 211-MeV operations and is 90% completed with bucket rotator installation work. The Beatty Electric Co. received added work on their existent contract which reduced the completion status to 96% and were the apparent low bidder at \$4,960, on 20 October, for installation of the rf reference line in sectors E through H. It is expected that a contract for the latter work will be issued by mid-November. By the same time, it is expected that a contract will be issued to the L. E. Meyer Co. who, at \$27,000, was low bidder on module 24 through 48 for the vacuum manifold welding. This same company is now about 60% done with the mechanical installation work under its present contract.

For Experimental Area installation, bids were opened at the close of this period covering Merrimac cell beams and covers for which a contract should be awarded in about two weeks to the low bidder, Richard Peck Co., at \$33,700 and a bid opening is scheduled for 11 November for \$80,000-\$100,000 of mechanical extension work on the X01 through X06 cooling systems.

Building Construction

The Nuclear Chemistry Wing of the Laboratory-Office Building is now 97% complete and occupancy is scheduled for the end of December.

In the Experimental Facility Phase I package, five punch list items remain to be completed; on Phase II, the contractor is presently forming Service Aisle A grade beams, erecting Equipment Room B steel, placing forms and concrete reinforcing steel for the top of the C Area dome and is 62% complete in comparison with a scheduled 64%.

The Experimental Facility Phase III contract is now 37% complete compared with a scheduled 45%. At the biomedical stub-out, wall forms are being placed above the slab and backfilling is in progress. Shielding steel is being fabricated into girders for the Mass Separator stub-out and is being stacked for the Beam Stop.

VIII. PHYSICS RESEARCH

Pion Absorption Experiment

Two papers on the (π, p) and $(\pi^+, 2p)$ experiments were prepared for presentation at the IVth Int. Conf. on High Energy Physics and Nuclear Structure, Dubna, USSR, 7-11 September 1971 and at the Int. Seminar on Pi-Meson Nucleus Interactions at Strasbourg, France, 20-22 September 1971. These papers are available in preprint form.¹

Meson Chemistry

In order to understand the relationship between the high-energy-level perturbations that occur in chemical systems and the shifts in intensities of low-level transitions that are observed in muonic x-ray spectra, a thorough understanding of the cascade process in these sometimes complicated systems is required. Presently, theoretical studies are under way to delineate the influences of the various interactions, such as radiative vs Auger processes, Stark-mixing, etc. Although much has been known regarding the mesonic cascade in the simplest atomic systems, little work has been done with the more complicated molecular systems, and it is to this end that these studies are directed.

Medical Applications of Muonic X Rays

Studies are being continued of the possibilities of utilizing the characteristic pi- and mu-mesic x-rays, resulting when stopped pions and muons are captured in given elements in tissue, as a tool for tumor localization or for *in vivo* tissue analysis.

One hundred hours of beam time were approved by the LAMPF Program Advisory Committee for mu-activation experiments.

Proton-Compton Experiment

During this quarter data were taken for a total of ~ 100 h using the 27-MeV beam from EPA. During this time, the liquid hydrogen target performed well, and the electronics systems functioned without failure. Since the data were taken in large time blocks, this was an excellent test of computer-based data-acquisition systems. No human intervention was necessary for data taking, and no electronics failures

were encountered. After the major data runs were completed, an effort was made to replace the custom-built interface with CAMAC units which were purchased for evaluation on this experiment. After several man-weeks of effort a short data background run was successfully taken using the CAMAC system. The data from these runs are now being evaluated.

Multiwire Proportional Counters (MWPC)

A LAMPF Users Study Session was held for a week in August, and half of the time devoted to the study of multiwire proportional counter applications in experiments. Ten speakers from outside laboratories were invited to talk on various aspects of the new counters, and many fruitful discussions were held.

Construction has been started of a wire winder for large wire chambers, based on the design used at NAL. It is expected that this machine will be operational during the next quarter, and then large chambers can be wound at LAMPF. As chamber sizes are increased, new problems are anticipated with frame stability, gas flow rates, and winding tolerances.

An effort has been started to standardize on MWPC interfaces at LAMPF, based on LASL's original design; a paper has been submitted to Nuclear Instruments and Methods for publication. This standard interface will be submitted to various manufacturers of CAMAC units for bids. It appears that the hardware interface for 200 wires can easily be put in a single-width CAMAC module.

In the rare-pion-decay experiment, construction of electronics for the insert chambers was continued. Virginia Polytechnic Institute has started construction of the amplifier boards as per previous agreement, but with disappointing results to date. At LASL, construction is nearly complete of one prototype interface unit. We have wound a 40 x 40 cm chamber at NAL, which is full insert size, and evaluation of this unit will start shortly. The magnet for the experiment has been mapped and is ready for shipment to LAMPF.

¹"New Measurements of $(\pi^+, 2p)$ Reactions on Light Nuclei," J. Amato, R. L. Burman, R. Macek, et al., LA-DC-12389; "Cross Sections for (π^+, p) Reactions on ^9Be , ^{12}C , and ^{16}O ," J. Amato, R. Burman, R. Macek, et al., LA-DC-12781.

IX. LAMPF USERS GROUP

Summer Study Session

The 1971 LAMPF Summer Study Sessions were held at Los Alamos on 9-13 August 1971. The Summer Study Sessions were held at the suggestion of the Executive Committee of the LAMPF Users Group. The program was organized and carried out by James E. Simmons, Robert J. Macek, and E. Ray Martin of LASL. The first three days were devoted to the topics of beam measurements and monitors, with sessions on proton beams, pion beams, muon beams, and neutral beams. The last two days were spent on the topic of position-sensitive detectors, with sessions on multi-wire proportional counters, low-temperature wire spark chambers, electronic systems, and computer-based data-handling and reduction. The program was well balanced in content and the contributions were enhanced by the participation of a number of experts from other laboratories and universities. Some forty presentations were heard during the session--about one-third of these were given by LASL speakers. Total attendance was about 100, with 60 of these being non-LASL. The "Proceedings of the LAMPF Summer Study Session," LA-4824-MS, are presently in press and will be distributed to all members of the LAMPF Users Group soon.

Election of Officers for 1972

The annual election of officers was conducted by mail ballot during October. A Nominating Committee consisting of Roy P. Haddock, Chairman (University of California, Los Angeles); Bruce J. Dropesky (LASL); Glen A. Rebka, Jr. (University of Wyoming); Robert J. Shalek (M. D. Anderson Hospital and Tumor Institute, Houston, Texas); and Benjamin Zeidman (Argonne National Laboratory) prepared the following slate of candidates:

Nominees

Chairman-Elect:	Mark J. Jakobson (University of Montana)
Executive Committee:	George J. Igo (University of California, Los Angeles)
	Lee C. Northcliffe (Texas A&M University)
	Louis P. Rosenberg (Brookhaven National Laboratory)
	Chaim Richman (LASL)
	Stanley R. Sobottka (University of Virginia)

Robert E. Welsh (College of William and Mary)

As of 1 September 1971 ballots were mailed to the full Users Group membership (currently 733). By the 29 October voting deadline, 480 members had returned ballots. Haddock, Chairman of the Nominating Committee, announced the following results:

Officers Elected for 1972

Chairman:	Kenneth M. Crowe (University of California, Berkeley), succession from 1971 post of Chairman-Elect
Chairman-Elect:	Mark J. Jakobson
Executive Committee:	George J. Igo Lee C. Northcliffe Chaim Richman
Liaison Officer:	Lewis E. Agnew (LASL), serving on appointment by LASL

Annual Users Meeting

Preparations for the Fifth LAMPF Users Meeting to be held at Los Alamos on 8-9 November 1971 were made by Users Group Chairman Gerald C. Phillips (Rice University) and the Liaison Office. The program will include a number of invited papers, a business session, status reports on the Users Group and LAMPF, a series of short reports on the LAMPF experimental facilities, meetings of all the Working Groups, and a summary round-table discussion involving: the Chairman of the Working Groups, the officers of the Users Group, Chairman Phillips and Chairman-Elect Crowe, the Director of LASL, Harold M. Agnew, and the Director of LAMPF, Louis Rosen.

The following invited talks are scheduled:

Harold M. Agnew, Welcoming Remarks
George A. Kolstad (Assistant Director for Physics and Mathematics Programs, Division of Research, USAEC), "Will Medium Energy Research Fly or Die?"
Norman Fainbach (Massachusetts Institute of Technology), "An Overview of the LAMPF Research Program."
Louis Rosen, "Status Report on LAMPF Research Proposals."
The meeting will be featured by a banquet address entitled, "Promotion of the Academic Uses of LAMPF," by Paul W. McDaniel, Director, Division of Research, USAEC.

Research Proposals

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

- 72 "A Study of the Di-Neutron and Tri-Neutron as Intermediate States of Double Charge Exchange on ^3He "
Marvin M. Hoffman, Spokesman
Marvin M. Hoffman, Leon J. Brown, William Mort Sanders, George J. Berzins and Albert J. Lieber (LASL)
- 98 "Preliminary Survey of Elastic Scattering of 800 MeV Protons"
N. Tanaka, Spokesman
E. R. Flynn, O. Hansen, N. Tanaka, H. A. Thiessen, J. Spencer (LASL); B. Zeidman (ANL); H. Palevsky, R. Sutter, R. E. Chrien, T. Kozlowski (BNL); G. Igo (UCLA); N. Hintz (Univ. of Minnesota); R. Sheline (Florida State Univ.); C. F. Perdrisat (VARC); W. C. Olsen (Univ. of Alberta); E. V. Hungerford (Rice Univ.); R. Eisberg (Univ. of California Santa Barbara); P. Fessenden, L. W. Swenson (Oregon State Univ.)
- 90 "Measurement of the Cross Section for $\pi^- + p \rightarrow \pi^+ + \pi^- + n$ with a Magnetic Spectrometer"
Glen A. Rebka, Jr. and Peter A. M. Gram, Spokesmen
C. Bordner (Colorado College); P. C. Gugelot (Univ. of Virginia); P. A. M. Gram, W. V. Hassenzahl, E. A. Knapp, R. J. Macek, M. A. Paciotti, F. T. Shively (LASL); E. Lomon (Massachusetts Institute of Technology); Glen A. Rebka (Univ. of Wyoming)
- 100 "Tissue Chemical Analysis with Mu-Mesic X-Rays"
Richard L. Hutson, Spokesman
Richard L. Hutson, Arvid S. Lundy (LASL)
- 101 "Feasibility Studies: Measurements of Muonic X-Rays and Nuclear Gamma-Rays with Crystal Diffraction Spectrometers at LAMPF"
F. Boehm, (California Institute of Technology) and D. C. Lu (Yale Univ.), Joint Spokesmen
F. Boehm, P. Vogel (California Institute of Technology); R. D. Ehrlich, V. W. Hughes, D. C. Lu (Yale Univ.); M. Y. Chen, C. S. Wu (Columbia Univ.)
- 102 "Excitation Functions and Angular Distribution Recoil Studies of Simple Pion Induced Nuclear Reactions"
Samuel S. Markowitz, (Univ. of California, Berkeley), Spokesman
Norman P. Jacob, Jr., Samuel S. Markowitz (Univ. of California, Berkeley)
- 103 "Spallation Yield Distributions from Pion Interactions with Complex Nuclei"
J. Hudis (BNL), Spokesman
A. E. Norris, C. J. Orth, B. J. Dropesky (LASL)
- 104 "Proposal for LAMPF Experiment: Studies of the Proton- and Pion-Induced Fission of Medium Mass Nuclides"
Brian D. Pate (Simon Fraser Univ.), Spokesman
- 105 "Nuclear Spectroscopy Studies of Proton-Induced Spallation Products"
M. E. Bunker, Spokesman
W. R. Daniels, B. J. Dropesky, D. C. Hoffman, M. E. Bunker, J. W. Starnner (LASL); J. E. Cline, R. C. Greenwood, R. L. Heath, R. G. Helmer, L. D. McIsaac, C. W. Reich (Aerojet Nuclear Corp.)
- 106 "Proton-Induced Spallation Reactions Related to the Isotope Production Program at LAMPF"
H. A. O'Brien, Spokesman
J. W. Barnes, M. E. Schillaci (LASL)
- 107 "Activation Analysis Near the Beam Stop"
Victor A. Ryan, Spokesman
John C. Hill (Texas A&M Univ.); E. Gerald Meyer, Victor A. Ryan (Univ. of Wyoming); in consultation with B. J. Dropesky, J. D. Knight (LASL), others from LASL and Graduate Students from Texas A&M Univ. and Univ. of Wyoming
- 108 "Excitation Functions of Simple Pion-Induced Reactions"
H. S. Plendl, Spokesman
S. Kaufman, E. P. Steinberg (ANL); P. J. Karol (Carnegie-Mellon Univ.); H. S. Plendl (Florida State Univ.)
- 109 "The Study of the Microscopic Structures of Collective Modes by Medium Energy Protons"
E. R. Flynn, Spokesman
E. R. Flynn, N. Tanaka, J. Spencer (LASL); Ole Hansen (Niels Bohr Inst.); N. Hintz (Univ. of Minn.); B. Zeidman (ANL)

Program Advisory Committee

The third meeting of the Program Advisory Committee (PAC) was held at Los Alamos on October 21-23, 1971. Presentations were heard on about 25 research proposals that had not been reviewed earlier, and several resubmitted proposals were reconsidered. The PAC considered each proposal in detail and drew up a set of recommendations. On the basis of these recommendations, LAMPF Director Louis Rosen has sent individual letters of notification to the members of the research teams informing them of action taken on their proposals. A partial summary of the action taken is given below:

- 51 "Techniques for Materials Identification and Analysis"
John J. Malanify, Spokesman
John J. Malanify, R. H. Auguston, R. B. Walton, C. J. Umbarger (LASL); I. L. Morgan (Univ. of Texas)

100 hours

- 65 "Neutron-Proton Polarization Measurements Using a Polarized Target: Phase I. The n-p Polarization Observable $P(\theta)$ "
J. E. Simmons, Spokesman
 J. C. Hopkins, C. F. Hwang, G. Keyworth, J. D. Seagrave, and J. E. Simmons (LASL); H. C. Bryant, B. Dieterle, and C. P. Leavitt (Univ. of New Mexico); L. C. Northcliffe (Texas A&M Univ.); I. L. Morgan (Univ. of Texas); D. McDaniels (Univ. of Oregon)
 240 hours for tune-up and 400 hours for data-taking
- 70 "A Sensitive Test of CPT and Precision Measurements of Elementary Particle Masses"
John G. Fetkovich, Spokesman
 J. G. Fetkovich and G. Keyes (Carnegie-Mellon Univ.); L. G. Hyman (ANL)
 150 hours for pi-mesic cascade studies
- 74 "Study of Pion Induced Double Charge Exchange Reactions on Low Z Elements"
V. Perez-Mendez, Spokesman
 V. Perez-Mendez, Albert W. Stetz, J. M. Sperinde (LRL, Berkeley); Kamal K. Seth (Northwestern Univ.); H. A. Thiessen (LASL)
 50 hours for ^3He part
- 76 "Search for Muonium-Antimuonium Transition"
C. Y. Chang, Spokesman
 M. Eckhause, J. R. Kane, C. S. Hsieh, R. T. Siegel (College of William and Mary); C. Y. Chang, G. B. Yodh (Univ. of Maryland)
 Beam-time assignment deferred
- 77 " π^+ Elastic and Inelastic Scattering from Carbon, Magnesium, Strontium, and Lead Isotopes at 100 MeV"
H. A. Thiessen, Spokesman
 H. A. Thiessen, R. Macek, D. E. Nagle, and J. Spencer (LASL); S. Sobottka, J. McCarthy, D. Lee, and M. Thomason (Univ. of Virginia)
 Beam-time assignment deferred
- 78 "Protot. Beam Monitor"
G. C. Phillips, Spokesman
 G. C. Phillips, E. V. Hungerford, C. Fletcher, M. C. Taylor, G. S. Mutchler, L. Coulson (Rice Univ.); J. C. Allred, C. D. Goodman, L. Y. Lee, and B. W. Mayes (Univ. of Houston)
 100 hours to test instrumentation with Proposals Nos. 79 and 83
- 79 "Calibration of the Pion Beam Transport Systems and a Pion Beam Monitor"
G. C. Phillips, Spokesman
 G. C. Phillips, E. V. Hungerford, V. Valkovic, C. Fletcher, G. S. Mutchler, L. Coulson, and M. C. Taylor (Rice Univ.); J. C. Allred, C. D. Goodman, L. Y. Lee, B. W. Mayes (Univ. of Houston)
 See Proposal No. 78
- 80 "Forward Elastic Scattering of π^+ and π^- from ^{12}C , ^{13}C , ^{16}O , ^{40}Ca , ^{208}Pb "
G. C. Phillips, Spokesman
 G. C. Phillips, E. V. Hungerford, V. Valkovic, M. C. Taylor, G. S. Mutchler, L. Coulson, C. Fletcher (Rice Univ.); J. C. Allred, C. D. Goodman, B. W. Mayes, L. Y. Lee (Univ. of Houston)
 300 hours
- 81 "Study of Neutron-Proton and Proton-Proton Coincidence Spectra from $p+d \rightarrow n+p$ Reaction"
G. C. Phillips, Spokesman
 G. C. Phillips, V. Valkovic, E. V. Hungerford, G. S. Mutchler, C. Fletcher, L. Coulson, S. D. Baker, M. C. Taylor, I. M. Duck, R. F. Guertin and 2 graduate students (Rice Univ.); J. C. Allred, C. D. Goodman, B. W. Mayes, L. Y. Lee, and 3 graduate students (Univ. of Houston)
 200 hours
- 82 "Investigation of Pion Induced Reactions on Light Elements with Three Particles in the Final State"
G. C. Phillips, Spokesman
 G. C. Phillips, V. Valkovic, E. V. Hungerford, G. S. Mutchler, C. Fletcher, L. Coulson, M. C. Taylor, S. D. Baker, I. M. Duck, R. F. Guertin, and 2 graduate students (Rice Univ.); J. C. Allred, C. D. Goodman, B. W. Mayes, L. Y. Lee and 3 graduate students (Univ. of Houston)
 Beam-time assignment deferred
- 83 "Investigation of Multi-Wire Proportional Counters for Treatment Volume Visualization"
G. C. Phillips, Spokesman
 G. C. Phillips, M. C. Taylor, V. Valkovic, E. V. Hungerford, G. S. Mutchler, C. Fletcher, L. Coulson (Rice Univ.); J. C. Allred, C. D. Goodman, B. W. Mayes, L. Y. Lee (Univ. of Houston)
 G. D. Oliver (M. D. Anderson Hospital and Tumor Inst.)
 See Proposal No. 78
- 84 "Quality of Meson Radiation Fields"
G. C. Phillips, Spokesman
 G. C. Phillips, M. C. Taylor, V. Valkovic, E. V. Hungerford, G. S. Mutchler, C. Fletcher, L. Coulson (Rice Univ.); J. C. Allred, C. D. Goodman, B. W. Mayes, L. Y. Lee (Univ. of Houston); G. D. Oliver (M. D. Anderson Hospital and Tumor Inst.)
 100 hours
- 85 "Gamma-Neutrino Correlation after Negative Muon Capture"
Robert E. Welsh, Spokesman
 Morton Eckhause, John R. Kane, George H. Miller, Robert E. Welsh (College of William and Mary)
 100 hours

- 86 "Counter Experiments in the Thin Target Area"
A. M. Poskanzer, Spokesman
 J. B. Natowitz (Texas A&M Univ.); F. Plasil (ORNL); L. P. Remsberg (BNL); A. M. Poskanzer (LRL, Berkeley)
 300 hours
- 89 "Detailed Study of the Resonance Behavior of the Total Elastic Cross Section in Pion-Nucleus Scattering"
P. D. Barnes, Spokesman
 Peter D. Barnes, Robert A. Eisenstein, and 2 Postdoctoral Appointees (Carnegie-Mellon Univ.)
 150 hours
- 91 "Proton Polarization in Radiative π -Proton Scattering at 300 MeV"
K. C. Leung, Spokesman
 K. C. Leung, R. P. Haddock, B.M.K. Nefkens, and D. Sober (Univ. of California, Los Angeles)
 Beam-time assignment deferred
- 92 "Search for Structures in π - π Mass-Spectrum Near Threshold"
B. C. Maglic, Spokesman
 J. Alspector, K. Cohen, W. C. Harrison, F. Sannes, M. Lieberman, D. Van Harlingen, B. C. Maglic, and B. Weber (Rutgers Univ.)
 Beam-time assignment deferred
- 93 "Mechanism of (π , π N) Reactions on Complex Nuclei"
H. S. Plendl, Spokesman
 M. Blecher, K. Gotow (Virginia Polytechnic Inst. and State Univ.); V. G. Lind (Utah State Univ.); H. S. Plendl (Florida State Univ.); P.A.M. Gram, W. V. Hassenzahl, and C. J. Umbarger (LASL)
 150 hours
- 96 "Scattering of 20-40 MeV π^+ by Hydrogen and Deuterium"
D. E. Nagle, Spokesman
 D. E. Nagle, E. A. Knapp, W. Schlaer, M. Paciotti, E. Ray Martin, and R. Mischke (LASL)
 150 hours
- 98 "Preliminary Survey of Elastic Scattering of 800 MeV Protons"
N. Tanaka, Spokesman
 E. R. Flynn, O. Hansen, N. Tanaka, H. A. Thiessen, J. Spencer (LASL); B. Zeidman (ANL); H. Palevsky, R. Sutter, R. E. Chrien, T. Kozlowski (BNL); G. Igo (UCLA); N. Hintz (Univ. of Minnesota); R. Sheline (Florida State Univ.); C. F. Perdrisat (VARC); W. C. Olsen (Univ. of Alberta); E. V. Hungerford (Rice Univ.); R. Eisberg (Univ. of California, Santa Barbara); P. Fessenden, L. W. Swenson (Oregon State Univ.)
 500 hours for HRS tune-up measurements
- 99 "Measurement of the Cross Section for $\pi^- + p \rightarrow \pi^- + \pi^+ + n$ with a Magnetic Spectrometer"
Glen A. Rebka, Jr., and Peter A. M. Gram, Spokesmen
 C. Bordner (Colorado College); P. C. Gugelot (Univ. of Virginia); P.A.M. Gram, W. V. Hassenzahl, E. A. Knapp, R. J. Macek, M. A. Paciotti, F. T. Shively (LASL); E. Lomon (Massachusetts Institute of Technology); Glen A. Rebka (Univ. of Wyoming)
 250 hours
- 100 "Tissue Chemical Analysis with Mu-Mesic X-Rays"
Richard L. Hutson, Spokesman
 Richard L. Hutson, Arvid S. Lundy (LASL)
 100 hours
- 101 "Feasibility Studies: Measurements of Muonic X-Rays and Nuclear Gamma-Rays with Crystal Diffraction Spectrometers at LAMPF"
F. Boehm, (California Institute of Technology) and D. C. Lu, (Yale Univ.), Joint Spokesmen
 F. Boehm, P. Vogel (California Institute of Technology); R. D. Ehrlich, V. W. Hughes, D. C. Lu (Yale Univ.); M. Y. Chen, C. S. Wu (Columbia Univ.)
 300 hours
- 103 "Spallation Yield Distributions from Pion Interactions with Complex Nuclei"
J. Hudis (BNL), Spokesman
 A. E. Norris, C. J. Orth, B. J. Dropesky, (LASL)
 50 hours
- 104 "Proposal for LAMPF Experiment: Studies of the Proton- and Pion-Induced Fission of Medium Mass Nuclides"
Brian D. Pate (Simon Fraser Univ.), Spokesman
 6 hours of proton beam and 6 hours of pion beam
- 105 "Nuclear Spectroscopy Studies of Proton-Induced Spallation Products"
M. E. Bunker, Spokesman
 W. R. Daniels, B. J. Dropesky, D. C. Hoffman, M. E. Bunker, J. W. Starnner (LASL); J. E. Cline, R. C. Greenwood, R. L. Heath, R. G. Helmer, L. D. McIsaac, C. W. Reich (Aerojet Nuclear Corp.)
 50 hours
- 106 "Proton-Induced Spallation Reactions Related to the Isotope Production Program at LAMPF"
H. A. O'Brien, Spokesman
 J. W. Barnes, M. E. Schillaci (LASL)
 20 hours

CM/is:480 (130)