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GLOSSARY OF TERMS USED IN THIS REPORT

ADC	- Analog Digital Converter
ADS	- Analog Data System
APL	- A Programming Language
ASCH	- American Standard Code for Information Interchange
CCF	- LASL Central Computer Facility
CCT	- Color Character Terminal
CCR	- Computer Control Room
CCTV	- Closed Circuit Television
CU	- Console-Interface Unit
CPU	- Central Processing Unit
CRT	- Cathode Ray Tube
cw	- Continuous Wave
CW	- Cockcroft-Walton
DACT	- Data-Acquisition and Control Terminal
DPM	- Digital Panel Meter
DVM	- Digital Volt Meter
EFB	- Effective Field Boundary
EIA	- Electron-Prototype Accelerator
ETL	- Equipment Test Laboratory
FET	- Field-Effect Transistor
fh	- Filament Hours
FWSS	- Fast-Wire-Scanner System
hfs	- Hyperfine Structure
hvh	- High-Voltage Hours
IC	- Integrated Circuit
ICR	- Injector Control Room
IDS	- Information Display System
IEC	- International Electrotechnical Commission
IFA	- Interface Amplifier
I/O	- Input/Output
ISIC	- Insertable-Strip Ion Chambers
IVR	- Induction Volt Regulator
LAM	- Look-at-Me Interrupt
LAMPF	- Clinton P. Anderson Meson Physics Facility
LCF	- Localized Current Fields
LED	- Light-Emitting Diode
LEEP	- LAMPF Electronics and Equipment Pool
LET	- Linear-Energy Transfer
MBD	- Microprogrammed Branch Driver
m.i.	- Mineral Insulated
MIG	- Metal Inert Gas
MPU	- Microprocessing Unit
MSSC	- Multistrip Scintillation Chamber
MTBF	- Mean Time Between Failures
MWPC	- Multiwire Proportional Chamber

NCL	- Nuclear Chemistry Laboratory
NIM	- Nuclear Instrumentation Module
NMR	- Nuclear Magnetic Resonance
pc	- Printed Circuit
PHA	- Pulse-Height Analyzer
PIGM	- Pion Generator for Medical Investigations
PLI	- Procedural Language Interface
RAM	- Random Access Memory
RBE	- Relative Biological Effectiveness
RGB	- Red-Green-Blue
RICE	- Remote Information and Control Equipment (remote data terminal)
RIU	- RICE Interface Unit
ROM	- Read-Only Memory
S2K	- System 2000 (a large software package for information storage and retrieval)
SCC	- Serial Crate Controller
SCR	- Silicon Control Rectifier
SSD	- Serial System Driver
SY	- Switchyard
TDC	- Time-to-Digital Converter
TDI	- Temperature Difference Integrator
TIG	- Tungsten Inert Gas
TOF	- Time of Flight
TR	- Transition Region
VSWR	- Voltage Standing-Wave Ratio

Experimental Area

Primary beam lines in experimental area:

- Line A - Main Beam Line
- Line B - Nuclear Chemistry Facility
- Line C - High-Resolution Proton Spectrometer
- Line D - Weapons Neutron Research Facility

Experimental beams:

Beam Area A:

- BSA - Beam Stop A
- EPICS - Energetic Pion Channel and Spectrometers
- LEP - Low-Energy Pion Channel
- Neutrino A
- P³ - High-Energy Pion Channel
- RADIP - Radiation Damage and Isotope Production
- SMC - Stopped Muon Channel
- TA-1 - Target A-1
- TA-2 - Target A-2
- TTA - Thin Target Area

Beam Area B (Room BR):

AB - Neutrons

AB - Nuclear Chemistry

EPB - External Proton Beam

Beam Area C:

CCH - Area C Control and Counting House

HRS - High-Resolution Proton Spectrometer

QUARTERLY REPORT ON THE MEDIUM-ENERGY PHYSICS PROGRAM

FOR THE PERIOD ENDING APRIL 30, 1976

I. SUMMARY

Engineering Support

Over 91 000 socket hours were accumulated on the accelerator during this quarter. Four klystrons were rebuilt, and reprocessing was required for 25 klystrons and 51 switchtubes. Work was started on a 1/2-MW, 201-MHz klystron for use as a replacement for the 4616/4664 gridded-tube family. Final engineering design is under way, and a full-size, cold-test model is being fabricated.

A 20-m shock tube was assembled to test shock-wave effects on beam-line windows and harps. Current emphasis is to develop a fast-acting detector and valve for hardware isolation in the event of a precipitous beam-line vacuum failure.

The rebuilding of the EPA accelerating structures is ~70% complete, and the EPA should be ready for shipment to Yugoslavia in July. The 100-kW, 805-MHz amplifier assembly has been rebuilt and tested, and work started on the 1 1/4-MW unit.

Approximately one-third of the group effort was in support of the experimental program. Over 25 experiments were actively supported during the quarter, and 49 experiments have received Experiment Engineer assignments.

Accelerator Support

The results of a continuing emphasis on reliability through a strong preventive maintenance program, coupled with the benefits of the great shutdown, continue to be exhibited in improved equipment availability. In most cases this maintenance program is built around and completely dependent upon the biweekly maintenance days.

The 201-MHz test stand is now available for tube processing and evaluation of 201-MHz hardware.

The benefits of this stand to the 201-MHz section will be significant. It will also be used as a training aid. The stand is manned by technicians from all rf sections. Engineers from sections other than 201-MHz were involved in the construction and continue to be involved in day-to-day operations and special development projects at the test stand.

The study of operations and maintenance reports to pinpoint those rf units with high failure rates continues.

Modification of both the LAMPF standard power supplies and the early dual-Acme supplies continues. These modifications will result in a standard magnet power supply for almost all of the LAMPF experimental areas.

A detailed study of 805-MHz IFA phase shift with changes in power output has led to the conclusion that all IFAs will have to be serviced and retuned for maximum power output before the June high-intensity run. This is the only way to keep phase shift to a minimum as the unit output is varied to compensate for beam loading.

New specifications were written for a computer test program which will allow faster performance of the tests of beam diagnostics equipment. In addition, the design of a portable microprocessor-controlled test system which will provide the capability for performing some of the operational tests without the use of the central control computer was initiated.

Vacuum and mechanical support of the accelerator and various experimental groups continued.

Accelerator Systems Development

A major breakthrough in the calculation of electric and magnetic field distributions in cylindrically symmetric geometries was achieved in a collaborative effort with LBL and several JASL groups. The new code is named SUPERFISH and is

much more powerful than older codes of the LALA or MESSYMESH types.

Work on the analysis Tank 1 performance continued. Machine experiments included work on halo measurement, beam-position monitors, automatic steering correction of the horizontal oscillation, TR control-vector steering, and high-pulse-current investigations.

The automation of the Δt procedure to include both phase and amplitude adjustment was completed.

Data base development was concentrated on preparing summaries and calculating availability and forecasts from the information in the operations-maintenance data base, and upgrading and combination of the Visitors Center/LUGI data base.

Instrumentation development continued in numerous areas. A new activity which showed considerable progress was microprocessor development and application.

The biomedical pion range-shifter was brought into full operation and fitted with a microprocessor command system which allows pushbutton operation of the servo system and a selection of treatment profiles.

The EPICS particle separator was also successfully tested for the first time with beam.

Injector Systems

The H^+ and H^- injectors are now both in continuous on-line operation and are providing simultaneous H^+ and H^- beams for the operation of LAMPF. With the present tune, production beams of 80- μA average of H^+ ions simultaneous with 10- μA average of H^- ions can be provided. The on-line maintenance required to provide this simultaneous operation has been minimal, although considerable preventative maintenance has been done during scheduled downtimes.

Beam studies have been carried out with the tune now employed to achieve this dual-beam operation. These studies indicate that there is still a problem in obtaining exact alignment of both beams throughout the linac, and that an adequate tune in the side-coupled linac is most easily achieved by separating the two beams in the injector area at the input to the drift-tube linac. Nevertheless, it has been found that once a proper tune is established for the H^+ beam, it

is then relatively easy to tune the low-current H^- beam to run at the same time. Thus, dual-beam capability on LAMPF is now an operational reality.

A new automatic arc-down recovery system has been installed on the H^+ injector which effects automatic restoration of operation after high-voltage faults. Development work is still in progress to isolate spurious input transients in this system and to provide capability of sensing spark precursors.

The risetime modification made last quarter to the H^- ion source has now become a permanent part of this system. Beam current risetimes of 30 μs are now employed for the H^- beams in order to minimize transient loading of rf systems.

Construction of the polarized ion injector is proceeding well. Most of the ion source parts are being fabricated, and installation of necessary utilities and other craft work is under way.

Work continues on development of new modulators and on the implementation of a more versatile ion source test stand.

Electronic Instrumentation and Computer Systems

Fabrication of the new Master Timer was partially completed. We will proceed with assembly and checkout of the unit next quarter.

Development work on the information exchange bus for the third console continued toward a system test scheduled for next quarter. The bus analyzer, function button panel, microprocessor development machine, and supporting programs all received attention.

The emphasis of software developments was on programs to aid operations. Programs were written to display, monitor, and log the personnel safety radiations monitors. The software to diagnose failures in the Run-Permit system was put into operation. Progress was made on the application of the control vector concept to the TR.

The first version of the transmission monitor software which forms a major part of the beam-line protection system was put into operation.

Work began on a new and comprehensive control system for the EPICS separator. The basic voltage-regulating loop was designed, built, and tested successfully.

Considerable progress was made in the design and installation of the wiring plant for Line C and the HRS. The checkout of equipment along Line C kept pace with the installation of devices.

A long-standing problem with the CCR communications line was diagnosed and equipment was ordered to correct the problem.

All components for the two new PDP-11/45s for LEEP were delivered except for one disk system. These computers will be commissioned early next quarter.

A disk pack for distributing the general data-acquisition program, Q, was created. The performance of this program was increased five-fold. Subsequent enhancements of the program were defined in consultation with the users.

The usage of LEEP equipment and services ran near capacity with 25-30 experiments receiving support. Some new equipment was ordered.

Several temperature-control systems for the liquid hydrogen refrigerators were designed and built.

The problem of keeping the technical staff abreast of the latest technology was attacked by organizing a series of seminars on various subjects and levels of training.

Accelerator Operations

The accelerator was in continuous operation throughout the quarter for a total of 270 shifts. With the completion of the renovation of Experimental Areas A and A-East late in the quarter, H^+ and H^- beams were used simultaneously for research for the first time. All research beam delivered to Areas A and A-East in 1974 involved accelerating only H^- beam and then stripping a portion of the H^- beam to these areas. Machine availability during research shifts averaged 83% for the H^- beam throughout the quarter, and 86% for the H^+ beam during the three-week period it was in use.

Because upgrading of Experimental Areas A and A-East was still in progress during much of the quarter, research beams were initially limited to Lines B and EPB, with the machine operating at average currents ranging from 0.1 to 2 μA of H^- . On April 5, Areas A and A-East were brought on-line, marking the start of cycle 1 of dual-beam operation with 10 μA of H^+ going to Area A in addition to the low-intensity H^- beam to Lines B and EPB. Cycle 2 of

dual-beam operation began April 26 with 20 μA of H^+ going to Area A. Cycle 3 is scheduled to start May 16 with 35 μA of H^+ in Area A. Research-quality proton beam currents to Area A totalled 4450 $\mu A\cdot h$ as measured at the A-1 target station. An additional 380 $\mu A\cdot h$ of H^- went to Area B. Eighteen experiments received beam during the quarter.

Much of the time allotted for facility development was used for checkout of beam optics and diagnostic systems in the beam switchyard and Experimental Areas A and A-East. The harps and profile monitors worked very well, and the beam optics results were as expected. Shielding surveys detected some penetrations which needed to be plugged, but general radiation levels were as expected. A computerized beam-transmission monitor employing beam-current monitors and a PDP-11 computer was checked out successfully and constitutes the first part of a burnout protection system. Two new operating modes were checked out and employed: a one-in-ten mode in which the amplitude of every tenth beam pulse is attenuated by a factor of several hundred to permit measurements of secondary beam-line particle distribution, and a second mode in which selected H^- beam pulses are suppressed while the corresponding H^+ beam pulse is routed into the WNR beam line.

Methods were explored for measuring beam halos in the accelerator with wire scanners, employing both secondary emission and beam spill detection techniques.

A mechanism was developed for degrading the risetime of the proton pulse in the ion source in an effort to reduce the effects of beam-loading transients in the accelerator cavities. With a 10-90% risetime of 30 μs , the amplitude controllers on the 805-MHz systems were able to maintain cavity fields within tolerance for peak beam currents of at least 8 mA. An apparent reduction in the frequency of high-voltage arcs in the H^+ accelerating column was a welcome side effect.

Development was started on a computerized control vector for the TR. If it is successful, the operator will be able to make one-knob adjustments of beam position, angle, and phase.

Machine operation was again more reliable and stable than at any time in the past. A significant decrease in downtime of the 201-MHz rf systems can probably be attributed to a new preventive maintenance program.

Experimental Areas

Routine beam operation for research in the main experimental area was resumed after completion of the great shutdown. Checkout runs in Areas A and A-East were carried out during February and March. Production cycle 1 started on April 5.

The experimental caves for the SMC, LEP, P³, and test channels were completed, the beams were checked out, and the experiments were started. Lines B and EPB were also in research operation during this quarter.

The bulk shielding in Area A was completed and several radiation leaks, revealed during beam tests, were corrected. The present shielding appears to be adequate for at least 100 μ A.

With the resumption of research operation, more effort is being devoted to support of experiments. The Area Manager's Office (AMO) is being manned by two shifts a day during week days and one shift a day on the weekends. A general cleanup of residue from great shutdown activities has been carried out.

All five radioactive water systems are operating satisfactorily. The three new auxiliary systems are being placed into service. Efforts to improve controls and monitoring of the water systems have continued.

The hydraulic servomanipulator, supplied by the Remotion Co., was delivered. The manipulator, which is called "Servoarm," is quite fast, but the lack of force-reflection poses some operational problems.

Improvements to the Monitor control system were made and a new shoulder assembly was installed. "Telearms," a second system that is similar to Monitor, is planned. It will be outfitted with the two-arm, force-reflecting servomanipulator that is now on order.

A successful run of the cryostat for the polarized proton target was carried out. The ³He loop was operated and an indicated temperature of 0.4°K was reached. The observed refrigeration capability substantially exceeds the design value.

Beam-Line Development

During this quarter installation of the hardware developments initiated for the great shutdown was completed, the experimental area beam transport system was checked out with beam, and production

beams of 20- μ A average of H⁺ injected simultaneously with 1- to 3- μ A average of H⁻ were achieved. The hardware included magnets for Line A, collimators, and a variety of beam diagnostic and protection instrumentation. The latter included wire scanners, harps, current monitors, and spill monitors. Detectors for secondary emission guard rings and beam-on-target monitors have been installed and work on prototype electronics was started.

The H⁺ production beams were achieved with minimal empirical adjustment of the quadrupoles away from tunes calculated using measured H⁺ phase-space parameters. The phase-space parameters were measured in Line A-Direct using data from 3 and 4 wire scanners and analyzed with recently developed programs.

The low-energy pion, high-energy pion, and stopped-muon channels were checked with the beam to verify that the channels were working properly and that rates and spot sizes were consistent with 1974 operational data. Muon rates (normalized to 1 μ A) are now a factor 2 higher at 130 MeV/c to 10 times higher at 65 MeV/c than they were before the shutdown. This is attributed in part to the new vacuum system and in part to better tunes.

Shock tube tests reveal that fragments from window rupture travel at a velocity of about Mach 1 and are capable of breaking other windows. The velocity of the disturbance which can break harp wires travels at about Mach 3.5. These results were needed to determine closing times required for fast-closing valves which are planned for protection of the Line A harp.

Large-Spectrometer Systems

Energetic Pion Channel and Spectrometer

There were two major accomplishments during this period, namely, the installation of the new concrete floor for the spectrometers and the tuneup of the beam line with pions for the first time (Exp. 130). The floor installation was accomplished with no significant interruption of the main beam line or other users in Area A. A four-week interruption of work in the EPICS area resulted during the time the

floor was installed. The channel tuneup showed that the beam line is operating according to its design specifications, i.e., the output phase space is as planned in all dimensions, no unexpected beam impurities were found, the separator removes protons with a rejection ratio of >100 to 1, and the beam intensity is close to the design predictions. No resolution tests are possible without a spectrometer; however, 2×10^{-4} $\Delta p/p$ resolution (FWHM) was demonstrated with a ^{242}Cm alpha source as noted in previous progress reports. Consequently, the EPICS channel can be considered successfully completed, and full technical attention will be focused on the completion of the EPICS spectrometer. During the time when the spectrometer magnets are being assembled, several experiments have been approved for the channel by the PAC. The first such experiment, Exp. 156, is presently running on the EPICS channel with preliminary data up to the expectations of the experimental group.

High-Resolution Proton Spectrometer

During this quarter, the spectrometer cable bridge containing all dc power cable was installed and the dc cable connected to the magnets. Control and interlock wiring and checkout are still in progress. The spectrometer pump and heat-exchanger package were operated and flow-tested through the spectrometer magnets until the system was leak tight at full pressure. The spectrometer jib crane has been installed, and the elevator cage and safety interlocks are now being installed. Catwalk modifications to accommodate the various hardware are progressing well so that we hope to install the remaining vacuum plumbing and perform vacuum tests on the spectrometer by mid-June. Pending installation of the air-compressor system required for driving the spectrometer, the frame has been positioned at a laboratory angle of 30° . The alignment of the spectrometer was performed at this location with good results — all tolerances having been met.

The outer TOF support structure was received from UCLA during this period and has been wired, tested, and installed on the top level of the spectrometer frame. The inner TOF remote position and support hardware built at the Univ. of Texas has been checked out and installed on the exit end of the MWPC detector box. This box is in the final stages

of helium leak testing. Survey measurements and alignment of the MWPCs has been completed, and the detector support stand has been installed on top of the spectrometer.

The spectrometer drive control and interlock system has been built and used to run the sliding-seal curtain and curtain-rod transfer mechanism on the scattering chamber. A forming die was designed and built for the fabrication of the 0.25-mm stainless-steel curtains. Vacuum tests on the scattering chamber with these windows showed no leaks.

The Area C shield door was installed at the end of this quarter and is now in routine operation. Subsequent to this, beam was run into the area for the first time since the Great Shutdown during cycle 2. Alignment of Line C relative to the SY appears to be acceptable since initial insertion of the stripper resulted in a narrow pencil beam at the end of the twister which was centered in both x and y.

Other work accomplished during this period includes:

- Assembly and tests of a Line C ISIC and its drive and control hardware;
- Installation and calibration of high-sensitivity transducers on all Line C supplies;
- Construction, testing, and installation of an automated target-thickness gauge for HRS targets;
- Construction of two special beam scanners for the scattering chamber;
- Completion of a remotely programmable logic-delay system based on lumped-constant delay lines;
- Complete installation of a PDP-11/20 computer system for off-line analysis;
- A complete layout of the HRS data-acquisition software.

Research

With the resumption of limited accelerator operation last September, a number of experiments were performed within the proton and neutron beams of Area B. Several of these experiments, ranging over particle physics and nuclear physics interests, are described in this progress report.

A search for direct lepton production from proton-proton collisions (Exp. 241) was carried out in the EPB. There is currently intense interest in the unex-

plained large direct production rate of electrons or muons ($1/10^4$ of that for pions) seen in many high-energy experiments. This experiment was designed to measure positron production at 800 and 256 MeV to determine if a threshold exists. Data at both energies are consistent with no direct lepton production, at a level two orders of magnitude below that extrapolated from the higher energy data, and thus indicate a threshold for this phenomenon.

A comprehensive series of three-body final-state measurements on proton-proton, proton-deuteron, and proton-lithium reactions (Exp. 81) is reported. The main effort was directed towards pion production, with data taken for ($n\Delta^{++}$), ($d\pi^+$), and ($pp\pi^0$) production from p-p collisions. Production of π^+ from ${}^6\text{Li}$ showed a strong enhancement at the "spectator" mass-five systems, supporting the conjecture that the pion production proceeds through deuteron clusters in ${}^6\text{Li}$.

Break-up reactions on ${}^6\text{Li}$ and ${}^7\text{Li}$ (Exp. 42) were measured in the EPB. The reactions (p,pp), (p,pd), and (p,pt) were studied both on and off the "quasi-free" kinematical regions.

Neutron spectra at 0° from proton interactions in a variety of targets (Exp. 205) were done in Line B. The observed cross section for elements heavier than aluminum varies approximately as $A^{2/3}$, perhaps explained as a peripheral, but coherent, process.

A new procedure for analyzing coulomb-nuclear interference experiments was developed. The technique was applied in particular to π^+ scattering from ${}^{16}\text{O}$.

Nuclear Chemistry

Two low-background β -proportional counters have been made operational in the Nuclear Chemistry Laboratory counting rooms. Also, new electronic components have been ordered for use in a dual-parameter Ge(Li)-Ge(Li), γ - γ coincidence system to be built around a PDP-11/03-AA microcomputer. Component failure problems with the counting room CRT terminals of the data-acquisition system (DAS) will presumably be corrected with new, higher capacity cooling fans. The software development for the DAS is proceeding rapidly now that operating system RSX-11D, version 6A, and program Q have been installed.

Two of the three stills for providing pure water to the chemistry laboratories failed during this quarter. Components for a new system which will require less maintenance and purportedly provide higher quality water by utilizing reverse osmosis and demineralization have been received.

Considerable efforts have been made to bring the "rabbit" system closer to operational status. Most of the mechanical deficiencies in the system components have been corrected. After removal of dents from the "rabbit" tube to the beam-stop Energetic Neutron Station, a carrier was successfully sent through the line. All components are on hand for making that station operational. Further design work was completed for the special neutron station at the WNR facility.

A further improvement has been made to the ISOBAR version of the VEGAS intranuclear cascade program. A phenomenological form factor has been introduced into the isobar absorption process. Use of this improved model results in a reduced yield of high-energy protons at 90° from pions on nickel and the calculated yield compares favorably with experimental results.

Practical Applications of LAMPE

A number of modifications have been incorporated into the biomedical pion channel to increase versatility, simplify operation, and improve reliability. The channel now contains a new target mechanism, two slit systems, a reworked 40-cm beam monitor, and a dynamic range-shifter. Channel-tuning studies have been directed toward developing therapeutically useful beams with emphasis on first obtaining a pion dose distribution which is uniform throughout a volume 4 by 4 by 4 cm^3 . Some experimental biology and dosimetry data were acquired on dynamically range-shifted pion beams which produced depth-dose distributions flat over a range of up to 10 cm. Work is continuing on codes for calculating both biologically effective dose distributions and treatment-planning parameters including inhomogeneities.

In the biomedical engineering area, the treatment of spontaneous animal tumors has been expanded from heat (LCF) alone to combined heat/radiation

therapy in collaboration with the Univ. of New Mexico CRTC personnel. One human case with squamous cell carcinoma received palliative treatment. A portable LCF generator for treatment of squamous cell carcinoma of the eye and eyelid in beef cattle is almost completed. Tests on cattle with this type of cancer are planned for the summer. Experiments involving the use of low-frequency electrical currents to rapidly but uniformly thaw frozen organs are in progress.

Management

The ERDA financial plan for FY-76, allocating \$18.5M for LAMPF, was received late in February. To date, about 85% of the capital equipment allocation has been obligated. The average number of full-time-equivalent employees chargeable to medium-energy physics funding is 346, slightly less than forecast.

Revised and updated radiological safety procedures for LAMPF were distributed this quarter. A temporary procedure for operation of the RADIP facility was prepared. Safety reviews were conducted for 24 experiments. Safety information forms are being sent to experiment spokesmen prior to their engineering reviews. These forms identify areas of safety the experimenters are to evaluate in relation to their experiments.

Individual as well as total man-rem exposures continued at acceptable levels. Twenty-six operational plans for work involving radiation were reviewed and approved this quarter.

Preparations are under way for the next meeting of the PAC which is to be held August 15-21, 1976.

The LAMPF management is acutely conscious of the difficulties encountered by graduate students assigned to work at LAMPF by their universities. In most cases, if stipends are available from their universities, the stipends are not sufficiently high to meet the cost of living at Los Alamos. In an attempt to alleviate this problem, a work/participation program has been set up whereby graduate students, with concurrence of their thesis advisors, may be paid for work up to 40 hours per month in the LAMPF experimental areas where a need for assistance to MP-Division staff is required. A letter has been mailed informing experiment spokesmen of

this work/participation program. A list of available job assignments is maintained in the LAMPF Safety Office.

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II. ENGINEERING SUPPORT

LAMPF Accelerator

Accelerator Support

Six spare vacuum windows for the 805-MHz accelerator were received in this quarter, more than one year behind schedule. Because of the long delay experienced in procuring these components, alternative sources are being considered for replacement components. Both alumina and beryllia window blanks have been ordered to support in-house design fabrication efforts.

A spare TR bending magnet was fabricated and tested in this quarter and is now ready for installation when required. Two small TR mainline steering magnets, TR-SM-03 and -04, were fabricated and installed.

A total of 101 fabrication activities were completed in the quarter. Forty-two H₂ furnace heats were run, mostly in support of the EPA rebuilding activity. The remaining furnace heats were for the klystron rebuilding efforts, accelerator support, and experimental area development.

805-MHz RF System

The VA-862A klystrons have accumulated over 708 000 fh, with 8 failures, and the L-5120 klystrons have more than 127 000 fh, with 7 failures. One klystron, VA-362A, S/N 238, failed in this quarter. The average age of the VA-862As in service is ~13 650 fh, and the average age of the L-5120s is ~5440 fh.

The klystrons were operated for a total of 91 462 fh in this quarter. Fourteen modulators and klystrons were replaced, and 35 modulator switchtubes were replaced on the accelerator. Twenty-five klystrons were processed or tested at the ETL. The LPT-44 modulator switchtubes have now accumulated more than 817 000 fh, with 51 requiring reprocessing during the past quarter. Twenty-one of the original 104 switchtubes have failed and are not repairable. Twenty-three switchtubes are on order, with 12 expected to be delivered during the next quarter.

Klystron Repair Facility

One L-5120 klystron (S/N 2009R1) and three VA-862A klystrons (S/N 202R2, 101R1, and 233R1) were rebuilt during the quarter and were tested to 1 1/4 MW.

The klystron-assembly clean room has been erected and is now completely operational. A filter-blower module mounted on the roof supplies the room with clean downflow air. The interior equipment, including laboratory work benches, storage cases, and a parts-warming oven, has been installed.

The stainless-steel rinse tanks for the klystron cleaning operations have been received. These tanks have electric heaters built into them to maintain the bath temperature. The entire cleaning system has now been received, and an installation bid package is being prepared.

The vacuum system for the bakeout oven was modified to include a 600-ℓ/s ion pump and a remote-controlled isolation valve. The new vacuum system has worked well in a bakeout test.

201-MHz Klystron

Work has been started on a 1/2-MW, 201-MHz klystron. This klystron will have the capability of powering Tank 1 of the accelerator, and can be used as a driver for the 7835 rf systems. The final engineering design is under way, and some raw materials, such as the 61-cm outer vacuum wall and the ceramics for the rf output window, have been received. The copper forgings for the collector and nose pieces have been ordered.

A full-size cavity, cold-test model has been designed and is being fabricated.

Experimental Lines

Area A

A 20-m shock tube was assembled using 30-cm vacuum pipe to test shock effect on beam-line windows and harp wires. To date the shock tube has been fired 14 times with shock velocities of the order of Mach 4. Initial tests showed that the debris from a

ruptured window was capable of destroying other in-line windows as well as the harps. A check valve was designed, fabricated and mounted ~3 m downstream from the window being ruptured during testing. It was demonstrated that the check valve could contain the debris. However, it was ineffectual in inhibiting the shock, and we found that the shock could rupture the monofilament carbon harp wires. It would appear that the most viable protection for the harps will involve the use of fast-acting isolation valves activated prior to the arrival of the shock. Current emphasis is on testing detectors for fast sensing of a vacuum failure and procuring and/or designing a fast-acting valve.

A turbomolecular pump with airbearings, and which requires no forepump, has been ordered for evaluation for possible Area A application.

A special alignment fixture to permit remote monitoring of beam-line components in the Line A target A-5 area was aligned in the tooling dock, and a preliminary setup was made to permit positioning of the reference targets. Two magnet mappers were also inspected and realigned in the tooling dock.

Biomedical Beam Line

The testing of the first slit, RT-SL-01, was completed and the slit was installed in the beam line. The drive motors, drive shafts, and a dust cover were also installed. The drawings for the final configuration of these parts were completed.

Slit No. 2 (see Fig. II-1) was installed on the rails in the beam line, aligned, and lowered to the second level to permit further tests to be conducted.

The biomed triplet was checked for alignment and realigned. The upstream, helium-chamber window was replaced with a 0.076-mm aluminum window. This helium chamber is now leak tight. The first three bending magnets were checked for alignment. An adjustable-base assembly for the cooled phantom attenuator and its detector assembly was designed and is being fabricated. This will allow faster and more accurate alignment for beam calibration.

Energetic Pion Channel and Spectrometer

A 61-cm reinforced concrete floor was poured for the EPICS spectrometer. The new floor will provide adequate strength to support the magnet frame as

Fig. II-1.

Slit No. 2 before installation in the biomedical beam line.

well as a flat and level runway for the air pads. Inspection measurements were made on the spectrometer magnet frame.

A significant amount of redesign on this frame has been accomplished. The frame rest areas were determined, the assembly procedures were resolved, and the drawings have been revised. A prototype air-bag subassembly has been fabricated and assembly checked.

Specifications have been written and drawings made to initiate a contract to install the two 82 000-kg magnets for the EPICS spectrometer.

Weapons Neutron Research Facility — Line D

Three HQ11 quadrupole magnets were reworked and tested in preparation for installation in the line.

Harmonic tests indicated a nonuniformity in one of the tunnel quadrupole magnets. The vendor fabricating the coil sections used an opaque epoxy which prevented visual inspection, although impulse tests indicated that no shorted turns existed. A test setup, consisting of a coil section coupled by a

laminated iron core with a known number of primary turns, was driven by a Variac. The coil section being tested formed the secondary winding. Tests of several coil sections revealed conclusively that one coil section had one less turn than all of the other units. This coil section was replaced and installed on the magnet.

The magnet stands, to be mounted from the ceiling of the tunnel, were positioned; the magnets were installed and are ready for alignment. Beam-transport problems in the SY area occasioned alignment checks of several of the magnets. However, no misalignments were found, and the transport difficulty is as yet unresolved.

Three quadrupole magnets were processed in the tooling dock to install alignment fixturing. Four beam boxes were accurately measured and received reference tooling holes.

Full power testing of the fast-kicker system has begun. To date, 3×10^7 pulses have been run at 120 Hz and 5000 A or greater. An 8-h heat run was completed. Two of the 0.05 μ F capacitors in the pulse-forming network failed during the test. It is believed that these failures resulted from case rupture, stemming from volumetric expansion due to dielectric heating. Steps are now being taken to procure replacement capacitors with a more conservative gradient design. Testing at full power will continue until mid-June, at which time $\sim 10^8$ pulses should be accumulated on the system.

The slow-kicker timing system was modified to permit CCR selection of the pulse sequence to be sent to Line D.

Line C

The two large HRS magnets, CBA and CBB, were aligned in their final beam-line position. A three-dimensional tooling dock, with two horizontal and one vertical tooling bars, was employed. An XYZ coordinate system was established and used to obtain the very tight tolerance requirements.

Four additional magnets (LC-SM-03, -04, LC-QM-12, and HS-QM-01) were aligned to final position.

Instrumentation

Two current monitors with 30- and 19-cm apertures were wound for Area C. The hardware to assemble these units to their lids is now being built.

All of the material and purchased components for the low-momentum detector are now on hand, and fabrication is $\sim 75\%$ complete.

Six pneumatic and five motor-driven beam-line actuators have been assembled and checked.

Electron Prototype Accelerator

Considerable effort was expended on the EPA rebuilding activities during this quarter. One tank section (4A) was damaged during handling and will require replacement of 50% of the segment assemblies. The three bridge couplers and eight of the thirteen accelerator sections are ready for shipment. All cooling tubes and cooling pads have been fabricated, flat milling on all but one section has been completed, and all but two sections have been clean-fired in H_2 . The rebuilding of EPA is $\sim 70\%$ complete and should be ready for shipment to Yugoslavia in July.

Copies of all the drawings and parts lists necessary for the 805-MHz rf and control systems were made, and the long lead-time parts have been ordered. The 100-kW modulator was tested with a LASL-repaired klystron. A $1\frac{1}{4}$ -MW modulator for the old-style L-5120s is being built.

Experimental Support

The Bicentennial spectrometer magnet, to be used in Exp. 29/54, was modified to permit a 54-mm gap and fixtured in the tooling dock to permit future alignment. The new water-cooled coils, manifolds, and electrical connectors were installed and delivered to MP-13 for field mapping. A set of magnet drawings was prepared to reflect the extensive rework. The assembly of the Bicentennial magnet stand is continuing. All purchased parts are on hand, and the final assembly is almost complete.

The scintillator and rotatable mounts for Exp. 29/54 are complete and in use. Modifications to the target holder are under way. The design and drafting of the Bicentennial magnet vacuum chamber are complete.

For Exp. 35, flange modifications to mount a vacuum valve are complete, and the scattering chamber is in the test channel. One of the two hodoscope magnet cores (H34XXIV18) in the magnet pool has been reworked for Exp. 221/222. The gap has been increased from 457 to 610 mm and spare H18VI36 coils have been installed along with

new water manifolds and electrical connections. The completed magnet is ready for preinstallation testing and field mapping. New water-cooled coils for the Ames "C" magnet were ordered last year, but because of budgetary limitations the order was cancelled. This order has been resubmitted, and the coils are scheduled for delivery after July 1, 1976.

Engineering and technician support was furnished for mounting Exp. 197 in Area B, Exp. 176 in EPB, and Exp. 80 in P³-East. Technician support was also provided for Exps. 164 and 130.

The Cerenkov chamber for Exp. 130 was installed in the temporary EPICS cave (see Fig. II-2). A lifting mechanism, Fig. II-3, was designed, fabricated, and installed for Exp. 2 in the LEP cave.

Consultation has been provided on a continuing basis for Exps. 200, 90, and 179. Design, fabrication, and alignment support is being supplied for Exp. 179, and some support was given to Exp. 121 to supply the necessary trailer hookups. The design modifications of the existing vacuum chamber for

Exp. 28 have been completed and are being implemented.

The mechanical design of stands for Exps. 93, 181, 124, 221/222, and 65 has started, and an air-pad system for the 54 500-kg LBL magnet for Exp. 50 is also being designed.

The shutter mechanisms, Fig. II-4, for Exp. 137B, which were described in the last report, have been completed and delivered to the user.

Fig. II-2.

Cerenkov chamber for Exp. 130, installed in temporary EPICS cave.

Fig. II-3.

Lifting device prior to installation in the LEP Cave (Exp. 2).

Fig. II-4.
*One of six shutter mechanisms designed and
fabricated for Exp. 137B.*

III. ACCELERATOR SUPPORT

201-MHz RF System

An average of 1935 h was accumulated on each of the 201-MHz rf stands during the quarter.

Low emission caused the loss of one 7835 (SN S9) with 14 300 h of filament time. This tube, along with another 7835 (SN X4), was returned to vendor for rebuild evaluation. The X4 had been run in the test stand, and plate voltage breakdown was noted at voltages over 15 kV. It was assumed that this failure was due to silver plated onto the inside of the anode ceramic.

Three 4616s were lost during the quarter. Low emission caused one failure, and the other two were grid shorts which developed when the filaments were hot. One of the new 4616s with a vac ion pump developed a vacuum leak after 70 h of running time. Investigation showed the leak to be at a braze joint at the top of the anode structure. After discussions with RCA, it was decided to attempt to patch the leak at LASL rather than return the tube to RCA. The leak was sealed with vacuum sealant. Since the leak was in a water course, the tube will be run at the test stand to see if water will erode the sealing material or if temperature cycling will open the seal again.

The addition of the vac ion pump to this series of tubes proved to be most valuable in this instance, as the tube probably would have been destroyed by running it gassy if no vacuum indication had been available. Finding and sealing the leak would have also been impossible with the older style tube that only had a getter and no way of indicating vacuum.

The test piece of Belden hv cable and terminations in module 1 failed after 3200 h of running time. This is a significant improvement over the old-style terminations, but this cable continues to give problems. Machine work on another termination for RG-17 was completed, and it will be tested on the hv cable tester.

The Rexolite vacuum barrier on Tank 2 was changed after 5700 h of running time. The window had deformed slightly and bound up on the center conductor causing strain on the plastic. There was a slight deflection inward on this window and a small amount of discoloration on the vacuum side.

A vacuum barrier made from Corning MACOR machinable glass ceramic was constructed as a pos-

sible replacement for the present unit. Work is in process to design and construct a vacuum fixture which will allow the window to be run at the test stand. An insulator for the 4616 output cavity was also constructed out of this same material to prevent corona.

The amount of shunt resistance on the PA modulator grids was increased in order to reduce the voltage drop across the modulator tubes. A new tube for the Modulator Video Driver was received, but time has not allowed evaluation of the tube.

Work was begun on a new pc card for the IPA Modulator. This card is an effort to linearize the interface transformer driver circuitry, improve the voltage divider buffer amplifier, and incorporate a voltage control loop on the IPA Modulator.

The 201-MHz test stand has progressed far enough for 7835 operation. Work is progressing at the stand for the checkout of the 8501 amplifier, but considerably more work is needed before a 4664 tube can be run at full power in the stand.

Considerable effort was expended on repair of numerous pieces of hardware and chassis that had failed in the past. Three new 4616 input sections were modified to meet our criteria; and a considerable amount of work was put into two new 7651 cavities that do not appear to work properly. Hardware is being developed to rack mount the two new 7651 cavities for test stand use. Work on the 4664 cabinet for the new cavity continues as time permits. It is hoped that this cavity can be checked out during the next quarter.

The periodic preventive-maintenance program for 201 MHz appears to be paying for itself through improved reliability of the equipment. A considerable amount of effort is required for this program as ~50% of the technician time in the 201-MHz section appears to be devoted to maintenance days and checkout and repair of hardware removed during the maintenance day.

805-MHz RF System

Routine maintenance, periodic inspections, and preventive maintenance utilized the greater portion of this quarter.

The total number of klystron crowbars for the third quarter of FY-76 was 260, or an average of 3/day. On an hourly basis, the crowbar rate for all 44 klystrons is 3.24 crowbars per 1000 h, an increase

from the previous quarter. Of the 260 crowbars, 176 were on the 6 Litton tubes and 84 on the 38 Varian tubes.

A long-standing maintenance problem at LAMPF is the short life of the No. 387 indicator lamps used throughout the facility. A new type of lamp supplied by MP-1 is now under test. Sector D has the new type (No. 376) lamps, and Sector C is the control sector with the old type (No. 387) lamps. In the two months of the test thus far, 43 of the old-type lamps have failed. None of the new-type lamps has been lost.

Construction, installation, and testing of the ignitron assembly, crowbar trigger chassis, crowbar resistors, and modification of the capacitor bank for the 201-MHz test stand have been completed.

Other activities during the quarter included the following:

1. To alleviate startup problems with the quad magnet power supplies, four open relays are being replaced with enclosed relays.

2. Cables have been constructed and parts ordered for the modification of the tank resonance system power input to free a tank power loop for use in the tank-to-tank phase-monitoring system.

3. The ΔT system was modified by removing rf amplifiers and centering phase shifters from the calibration loop.

4. The modification of "ground fault detectors" for the LAMPF standard magnet power supplies has been completed.

5. Tests are continuing on the RG-218 insulation creepage rate.

6. The Belden 8871 hv cable under test at ETL has 8410 hvh and 7019 h drawing current.

7. High voltage tests were conducted on isotope separator cables.

8. A new technique for replacing the klystron modulator tank hv cable was devised which will greatly reduce the downtime due to cable failure.

9. Three spare klystron modulator tank oil pumps were modified to allow quick change in the event of an oil-pump failure.

10. The hv control chassis have been modified to assure that the interlock relays drop out when a prior relay has opened.

11. The section is studying the tank resonance system. The study is 90% complete, and several minor modifications will result.

12. The section is assisting MP-9 with construction of chassis, terminators, and pc cards.

Low-Level RF System

Phase shifts with changes in power output across 805-MHz IFAs have been observed. These phase shifts could be a serious problem when accelerator beam power is increased since greater power output changes will be required to compensate for beam loading.

Measurements were made of the amount of phase shift with changes in power output for a properly tuned IFA and for an IFA mistuned in various ways. These measurements were made with a vector voltmeter across an IFA operating into a dummy load. The power output was varied between 5 and 15 W by changing the base voltage on the control transistor. This is the same method used to vary output during accelerator beam loading.

Mistuning is a very subjective thing. Different phase shifts can be obtained for different amounts or directions of mistuning. It would also be possible for more than one control to be mistuned. This can make for different shifts, but in all cases no worse than the worst case discussed.

A phase shift of 1.5° was observed between 5 and 10 W; no shift was found between 10 and 15 W for a properly tuned IFA. Mistuning of either stage's output, "final," or input to the first stage resulted in phase shifts of 4° between 5 and 10 W and shifts of 1° between 10 and 15 W.

The worst case observed was when the input to the final stage was mistuned. This resulted in a 7° shift between 5 and 10 W, and 3° between 10 and 15 W.

It would appear from the above that:

- Mistuning increases the amount of phase shift with power changes.

- Power may be varied between 10 and 15 W with no phase shift on a correctly tuned IFA.

- Any IFA, regardless of tuning, will exhibit considerably less phase shift if operated above 10 W.

A prototype 201-MHz solid-state IFA is under evaluation at the test stand. It has operated 1100 h without any problems.

The 8501 201-MHz amplifier has been installed at the test stand. Tests on the unit should begin shortly.

Work was begun this quarter on development of an 805-MHz solid-state IFA using microstrip techniques. Two amplifiers, one running 3 W and the other running 10 W have been constructed and are under evaluation.

Phase and Amplitude Control System

Installation of solid-state diodes in all 201-MHz phase subsystems is complete. Performance of the modified units is presently under evaluation. In addition, the phase subsystem major modification program, which includes the improved drive-system components, electrical pad changes, and other general improvements, has been completed on 13 units. This program will continue as units are taken out of service for routine maintenance.

Redundant phase-monitor systems are being fabricated to monitor phase stability on modules 13 through 24. This task is about 40% complete. It is estimated that these units will be complete and installed by the end of June.

Other projects in which the section is involved are as follows:

1. Layout, fabrication, and checkout of the new amplitude control cards for both the 201-MHz and 801-MHz source rooms.
2. Modification of all 201- and 805-MHz amplitude boards to allow 1° and 1° amplitude and phase permissive trip-level calibrations.
3. Modification of the phase system diode load to protect new solid-state diodes when phase boards are removed from the stand.
4. Checkout of a new H⁻-buncher phase and amplitude control.
5. Support of feedforward studies.
6. Routine repair of defective phase and amplitude control systems.

Power Supplies

Modification of the LAMPF standard magnet power supplies has continued during this quarter. Only seven supplies remain which have not yet been modified. The units and their location are as follows:

1. Three Acme supplies which drive Line B quadrupoles.
2. One Acme supply in Experimental Area B.
3. Two spare Acme supplies in the SY and service aisle.
4. One spare Ling supply stored in the 13.2-kV switchyard.

Installation of the two power supplies in the WNR line is 50% complete. These supplies will each drive four quad magnets in series.

The first dual-Acme power supply which was extensively modified to use the LAMPF standard regulator system is now operating in the SMC. Work has started on modification of a second unit. Eventually all 12 dual-Acme power supplies will receive this modification.

Review of the mechanical drawings for the 2000-A reversing switches is complete, and eight new switches have been ordered. The new switches will be used to replace old 2000-A switches which can then be rebuilt and installed elsewhere. In this manner it will be possible to upgrade all of the 2000-A reversing switches without shutting down any power supplies.

All spare 500-A reversing switches (~24) have been cabled with two parallel 4-0 cables in place of the one 4-0 cable in the original units. All 500-A reversing switches that are in service with only one 4-0 cable will be replaced by the modified spares. The switches which are removed will also be modified as time permits.

Beam Diagnostics

Routine maintenance was, as usual, the major activity during this quarter. Repairs were made to linear actuator driver modules, frequency tuner drivers, sample-and-hold boards, and actuators with mechanical problems. Damaged absorbers and collector plates were replaced, and wire-scanner amplifiers were repaired and recalibrated. The TR sample-and-hold chassis was removed and all cards inspected and adjusted.

More time on the central control computer was obtained for maintenance day testing of beam diagnostics equipment than had been available in the past. However, specifications were written for a computer test program which will allow even faster performance of these tests. In addition, the design of a portable microprocessor-controlled test system was initiated which will provide the capability for performing some of the operational tests on actuators without the use of the central control computer.

Additional tests were conducted to determine the source of noise in the transport sample-and-hold system. It was found that the emittance collector plates at EM3 had been damaged by the beam and were the noise source.

Development activities during this quarter included the following:

- Design work was continued on the new sample-and-hold system. Most of the parts required for fabrication of the system were ordered and have been received.

- The design of a smaller harp board was initiated. This board will provide greater clearances between devices in the same beam box.

- Additional testing of the new harps with ceramic boards and carbon wires indicates that these materials perform well. In the future all harp boards will be replaced with the new ceramic board/carbon wire type.

- An emittance collector plate made of kovar and glass was obtained and has been installed in the EM2 vertical collector. Evaluation tests will be conducted during the next quarter.

- A 5-MeV carbon absorber was installed between Tanks 2 and 3 of the drift-tube linac. This device will be used in the performance of Tank 1 phase scans.

- The design of a flat 40-wire cable (for use with harps and emittance collectors) with better vacuum characteristics than the type presently in use was initiated. The wires will be wound on the LAMPF wirewinding machine, and several different types of insulation will be tried.

- Specifications for an improved emittance measuring system were written for submission to the Accelerator Development Committee. A design proposal will also be written.

Vacuum Systems

It has been observed that Tank 2 is more sensitive than the other tanks to the quality of the vacuum. While working on this problem, it was discovered that a large leak that is not repairable exists between the hard and soft vacuum, so it was necessary to substantially improve both systems.

Moderate support was required in the maintenance of diagnostics equipment. Most of this support was in the removal of all the actuators between Tanks 2 and 3 and Tanks 3 and 4 to reposition the position monitors.

A long-standing, nagging problem was solved this period involving module 9. The ion pumps in this

module had been running at about 10 mA for years despite repeated and sustained efforts to improve the vacuum. The latest effort was to change the window even though no leak could be found. The ion pumps now run at an acceptable (few hundred) μA rate.

The usual spacer and pump problems in the 805 linac were encountered. It was decided to order 10 new spacers to replenish dwindling spares.

The final vacuum checkout was made in Areas A and A-East, with the vacuum in the 10^{-4} torr range.

Moderate vacuum support of experiments continued in Area B. A 260-l/s turbopump was installed in the B tunnel and will be tested as a means of starting the Line B ion pumps. The blower package (root blower and forepump) that is normally used for this is old and no longer very reliable.

Some support has been given to the experiments in the shock tube, both in the actual test setup of experiments and fabrication of parts.

Mechanical Support

Work on diagnostic hardware for the accelerator has been a continuing and evolutionary process. The 201-MHz scraper jaws and high-powered emittance jaws have proven to be adequate for the power levels run thus far. However, some problems have been encountered with the absorber/collector assemblies located between Tanks 2 and 3 and Tanks 3 and 4. The absorbers cannot handle a sharply focused beam at even modest power levels without damage. The solution so far has been replacement of the damaged parts.

Five new actuators and spare parts have been ordered for the WNR beam line, and spare and modified devices for beam diagnosis are being fabricated.

Due to a vacuum leak, a new 201-MHz tank tuning slug was installed. Another unit is being reworked for a spare.

Support for MP-10 is continuing. Final plumbing of the HRS magnet is progressing satisfactorily, and the HRS elevator is finished except for a small amount of iron work.

Work on ΔT drawings has been a continuing project.

Reliability Study

The study of operations and maintenance reports to pinpoint those rf units with high failure rates con-

tinues. Table III-I lists those units with the most failures during this report period. All other rf units had 19 or less failures during the quarter.

TABLE III-I
MAJOR RF UNIT FAILURE-RATE HISTORY

<u>Unit No.</u>	<u>Name</u>	<u>Section</u>	<u>No. of Failures</u>
6711	Ion pump power supply	805-rf	42
1147	Klystron modulator switch tube	805-rf	40
1799	Category (failures that cannot be attributed to a particular unit)	201-rf	27
135	PA Modulator	201-rf	22
82	High voltage power supply controller for modules 2-4	201 rf	21

IV. ACCELERATOR SYSTEMS DEVELOPMENT

Beam Dynamics

201-MHz-Linac Field Distribution

Analysis of the experimental data obtained on Tank 1 last quarter was continued. Two major steps were completed, both of which brought the experimental data and the analytical model into significantly better agreement. First, the quadrupole fields were remeasured and entered correctly into the codes. Second, a fitting procedure was devised and applied to the data which determines the correct linear relationship between the amplitude set point of the rf field control system and the tank field. The main difference between the equation so found and the one which would be expected from calibration of the rf system appears to be error in the absolute measurement of injection energy. Comparison of the field relation with the data allows a hypothesis about the actual injection energy to be made.

Accelerator Structure Field Distributions

A major breakthrough in the calculation of electric and magnetic field distributions in cylindrically symmetric geometries was achieved in a collaborative effort which applied techniques originated at LBL for magnet design to the general problem of rf cavity design. The new code is named SUPERFISH. It fits the geometry with a variable triangular mesh, and solves for the field distributions using a block matrix inversion technique. The speed and convergence properties are many times better than those of the previous over-relaxation methods used by codes such as LALA and MES-SYMESH. For example, for geometries having a radius-to-length ratio of 9 to 1 or greater, which have traditionally presented the greatest convergence problems, MESSYMESH requires many sequential runs (as many as 50); LALA takes 15 minutes and doesn't give good results; SUPERFISH takes 10 seconds or less. Also, SUPERFISH can solve the rf problem for many cavities at once, which was not possible previously.

Work is now in progress on derivation and programming of the secondary quantities such as

transit time factors, field integrals, and utility sub-routines to facilitate use of the main codes.

This work has generated considerable interest throughout the LASL. Application has been made or is being considered in the PHERMEX upgrading in CTR, and energy conversion and storage work.

Beam-Halo Analysis

Development of groundwork for measuring, analyzing, and trying to understand the sources and transportation of beam halos was continued during the quarter.

The experimental approach involves developing instrumentation and techniques for measuring beam profiles over several orders of magnitude using wire-scanners and loss monitors. The wire-scanner and loss-monitor electronics were checked over the whole machine; noise levels were reduced as much as possible by improved grounding techniques, and parts were replaced as required. Higher gain amplifiers were tested, including the design being used in the SY, and good performance was achieved down to 1- μ A secondary-emission current at full scale. Measurement of halos along the machine will have to be made by exchanging amplifier modules as the sensitivity is increased in the edges of the distribution. Codes for collecting the data are ready. Initial attempts to obtain data were complicated by the horizontal oscillations of the beam and poor availability during development periods.

Analysis of the experimental data will be done using three techniques:

- Calculation of rms emittance is presently possible using application codes on the central control computer.

- More detailed reconstruction of emittance can be contemplated using a variety of techniques — some of these are presently being investigated by MP-13 for use in the SY and beam lines. The linac problem is complicated to some degree if acceleration between wire scanners is to be allowed in the measurements. Exploration of this aspect will begin during the next quarter.

- Beam profiles are often characterized descriptively as a core having an essentially Gaussian distribution plus a halo. Formal decomposition of the measured profiles into a sum-of-Gaussians model will be investigated in order to characterize the underlying distributions and their movement along the

machine. Test cases have been studied using general nonlinear least-squares techniques.

In order to begin to understand the basic origin and spatial and time development of halos, a study was begun in which the beam dynamics of a high-current linac were examined analytically and numerically. This work involved the question of stability of a two-dimensional (transverse) particle distribution under the influence of space charge forces. Following a program suggested by R. Gluckstern of Univ. of Maryland, a simple model was used in which there is no acceleration and in which the external focusing forces are linear and constant. A preliminary version of a Monte Carlo computer program to pursue this problem has been completed.

Δt Automation—805-MHz Linac

The automation of the Δt tune-up procedure for adjusting both amplitude and phase was completed in this quarter. This procedure has been used extensively. Its use has significantly reduced the time required for tuning the side-coupled linac and has improved the consistency of the results.

The documentation of the Δt procedure was written during this quarter. It includes the theory behind Δt , as well as a description of the hardware and software.

Parts for digitally controlling the voltage to the electronic phase shifters were ordered. This will further increase the speed of the measurements. More heaters were added to the Δt temperature control system and its performance was evaluated. The system was turned over to the support group; drawings are being completed and brought up to date.

New Linac Development

PARMILA, a computer program for calculating linac beam dynamics, has been further developed to include features for studying alternating phase-focusing phenomena. In addition, output routines have been prepared to generate graphic output on teletype terminals. Making use of these new features, PARMILA was employed to search the space of accelerator parameters to find suitable designs for a linac which could comprise the low-

energy part of a pion generator for medical applications.

Horizontal Oscillation Control

Encouraging progress was made during this quarter on horizontal oscillation control. Preliminary attempts were made to determine if the H^+ and H^- beams contained any reasonably coherent properties in the 201 region which would allow simultaneous control. None was found, so attention was directed to control of the H^+ beam only. The oscillations occur at ~ 12 Hz and were picked up by a fast beam-position monitor between Tanks 3 and 4. These signals were fed into a sample-and-hold circuit which reproduced the oscillation waveform when the beam was operated at 120 pps. The sample-and-hold output signal was fed through a simple analog computer to give sign and amplitude control and used to drive a steering-magnet power supply to control the beam upstream in Tank 3. When the feedback signal was properly adjusted, reduction of the oscillation amplitude was seen; with the opposite sign of feedback, an increase in oscillation amplitude was seen. A comparison of these two responses is shown in Fig. IV-1.

This method has the following disadvantages: 1) the magnet power supply and its load are inherently slow so that it works only at high beam-pulse repetition rates; 2) eddy-current shielding reduces the strength of the field intensity actually reaching the beam; and 3) a beneficial effect on the H^+ beam may make H^- oscillations worse due to lack of coherency between the two beams. To overcome these disadvantages, an attempt will be made to control the H^+ beam only, on a pulse-to-pulse basis, by feeding the oscillation signal back directly from the pick up point (Tanks 2/3 or 3/4) to a set of ultrafast electrodes in the H^+ transport line.

Long-Term Stability Development

A new version of the plot program package for accessing data on the "endless belt" and other recording files has been written, tested, and documented. The new version allows each of several displays to have a name and parameters that are remembered by the program for future use. Displays may be re-defined by an operator as required.

Various modifications and improvements were incorporated in the programs which generate stability plots from data recorded on disk at CCR by data-scan programs.

As noted above, the successful automation of the Δt procedure is a significant contribution to this area of development.

Also, see the discussion below of the development of methods for analysis and forecasting of facility availability based on information from shift and equipment performance reports.

Horizontal beam positions at Tank 3/4 interspace with positive feedback at maximum gain before instabilities begin.

Horizontal beam positions at Tank 3/4 interspace with negative feedback at intermediate gain.

Fig. IV-1.

Horizontal oscillation control using active feedback (0.1 V/cm; 102 data points).

Operations-Support Development

Operations/Maintenance Equipment Data Base

An extension of this data base to provide summary information from the equipment performance records and shift reports was designed during the quarter. Performance will be analyzed on a machine cycle basis for various types of scheduled production, tuning, development, and maintenance activities. The analysis can be performed on the major categories of equipment or on specific types as needed. Statistics on availability, mean-time-to-failure and mean-time-to-repair, are derived on a per-cycle basis and on a long-term-cumulative basis. Forecasting of performance to future periods will be done initially using simple exponential-smoothing techniques. Provisions have been incorporated in the design for more detailed analysis of the underlying performance patterns once a background of operating cycle data has been accumulated. In these investigations, time-series-analysis techniques will be used, starting with adaptive filtering methods and correlation analysis. Once the basic patterns have been evaluated, more precise forecasting and the hypothesis of models based on reliability theory could be done. It is important to this long-term effort that the quality of input data remain high; in particular, a tendency toward too much aggregation in reporting of performance must be avoided.

The operations/maintenance data base was redefined to store additional information on cycle number and scheduled mode of operation with each report. Strings for defining the schedule and adding data were written, and all information from the first of the year through the end of cycle 1 has been added.

An auxiliary data base was created to handle the summary, availability, and forecasting information. A PLI program to transfer data from the operations/maintenance data base was completed, and work on the analysis programs was started.

Strings for listing all equipment for the Index books needed by the operators were completed, and new catalogs distributed.

At the request of MP-11, an S2k report writer program was prepared for routine summarization of rf system performance. Other specific requests for information have been handled by interactive retrievals.

Experimental Schedule Data Base

Design work was completed for storing additional information and deriving more comprehensive reports.

Visitors Center/LAMPF Users Group, Inc. Data Base

The streamlining of this information system was completed and put into production. Data common to both areas are now stored in only one place, which will help maintain consistency. Training was provided in the use of the system. Problems with tapes, perfiles, and general CCF reliability continue to plague smooth operations and required the trainees to learn more about recovery procedures than perhaps desirable, but in the long run the system will be better protected by the increased knowledge.

LAMPF Experimental Equipment Pool Data Base

This data base was transferred to S2k this quarter, and procedures for updating were completed. Work continues on retrieval programs.

PDP-11 Computer Maintenance Data Base

This data base was redefined, to incorporate new features, and reloaded. Worksheets were prepared, all computer systems were reinventoried, and the data base was updated. Retrieval programs have been written.

Bibliographic Data Base

Essentially all of the material published by MP-Division personnel has been included, and a compilation of internal material written by MP-1 is in progress.

Diagnostic Equipment Development

Beam Position Monitors

The final pc boards for the simple diode detector version of the beam position monitor electronics have been designed, fabricated, and tested. These are two-plug boards designed to eliminate pin coupling, due to the high dc gains present, by placing input and output bins on opposite ends of the board. One of these boards has been installed at module 6. The system has been tuned to its optimum condition, representative of the final production model of this design approach. This method uses rf detector diodes which operate in their nonlinear regions at microvolt signal levels and must be balanced to give the most uniform response possible over the desired beam current range.

A second version of the beam position monitor using the heterodyne method which operates the detector diodes over their linear range at low frequency is also in its final stages of construction. One such unit has been completed and has been installed at module 5 for initial testing with beam.

An algorithm has been worked out which calculates the transverse behavior of the beam centroid in up to eight modules at any position along the 805-MHz linac, based on wire-scanner data. This will permit calibration of the beam position monitors using wire-scan data. A program to make a profile plot (signal level vs position along the linac) for a signal converted to engineering units has been written and tested. Once beam position monitor calibration data has been entered in the channel tables, the profile plot will allow an operator to display and update the position of the beam centroid using the position monitors much faster than now can be done using the wire scanners.

Feedforward System

Some accelerator development beam time was devoted to tuning for a higher pulse current mode of operation. Experiments investigating the transient response of the rf field control system along the machine were completed using the feedforward system and also using a slow rise-time beam pulse

from the injector which was generated using an inductor in the arc circuits. Cross-coupling effects between phase and amplitude loops caused by mistuning of the interface amplifiers were diagnosed and corrected. Rough adjustment was made of waveguide length on some modules to correct the sign of the phase transient.

Emittance, Wire-Scanner, and Phase-Scan Hardware

The apparent problem with the EM-2 beam position was traced to burned and shorted EM-3 collector wires (all collectors are in parallel). When new EM-3 collectors were installed, the EM-2 position was no longer anomalous. Time was also spent on the definition of new specifications for the emittance system.

The 40- and 70-MeV absorber-collector assemblies were removed and found to be damaged. The 40-MeV assembly had holes in both the absorber and collector while the 70-MeV absorber showed severe melt damage but was not burned completely through. Severe thermal damage was also done to the 70-MeV collector. New units were installed and the possibility of using tungsten collectors is being studied.

In an effort to better understand the longitudinal dynamics of Tank 1, a 4.4-MeV carbon absorber/collector has been made and installed for testing at the end of Tank 2. If this device performs as expected it will be installed between Tanks 1 and 2, thus eliminating the filtering effect of Tank 2 on Tank 1 experimental data.

Low-Momentum Component Detector

All of the long lead-time components for the Line X low-momentum component detector have been procured and are on hand. The multiplexer and amplifiers have been borrowed from MP-13 for evaluation of the prototype system. Machining of all mechanical parts of the detector is complete and testing will proceed pending assembly and vacuum checks.

Radiation-resistant phosphors made of chromium-doped alumina have been procured for use in conjunction with a television camera as a visual backup to the low-momentum detector.

Injector Electronics

A hydrogen pressure controller was designed for the test stand source. This unit is being built and will be evaluated for use in the injectors. The extractor amplifier and dome fast-protect circuits received continued attention.

Microprocessor Development

A driver which used the Fermi Crate and its standard interface boards was designed and implemented for the biomed range shifter. This microprocessor-based driver uses tables put into memory to program the range-shifter movement. The initial experiments were carried out using the Fermi Crate/LASL-debug box and its associated operating system. Now experiments are done using a dedicated, specifically configured control panel and dedicated software which were developed in this quarter. Modifications to one of the standard Fermi Crate boards must be made before the final drive configuration is achieved. CDC 6600 software was written to allow the dose tables to be entered in engineering units; the program then converts them to hexadecimal numbers which are stored on a file. This field is then dumped on punched paper tape or TI cassette and subsequently entered into the programmable memory (PROM) programmer, which enters the tables into erasable memory chips.

The microprocessor unit board designed last quarter is now in use. The biomed range shifter controller uses this new board.

The second-generation modifications to the debug box have been designed. These modifications have come about from the extensive use which has been made of the box of the original design. The debug box has facilitated rapid checkout of hardware — especially the biomed range-shifter controller.

A Fermi Crate frequency counter interface board which will be used for the new beadpull apparatus has been designed and fabricated but has not yet been checked out. A Fermi Crate linear actuator board has been designed in cooperation with MP-11 and will soon be submitted for layout and fabrication. A general-purpose pushbutton/LED "front panel" board was designed and submitted for layout. This board was needed for the new beadpull apparatus and would have been useful in the design of the biomed range-shifter driver. Two more Fermi

Crates and their boards have been fabricated and checked out.

A TI ASR-733 terminal with dual cassettes and commercial PROM programmer boards have been ordered. These will allow the assembly of a complete development system which will be able to communicate via the TI terminal cassettes to the CCF computers.

Two 1-1/2-h seminars on the Motorola 6800 microprocessor family were given to interested people in the LASL. These sessions covered the capabilities of the 6800 family parts and software. Three more sessions are planned which will get into actual application with emphasis on the Fermi Crate.

Central Computer Control System Code Development

In addition to the coding activities mentioned above, a version of the LAMPF alignment data base printout program has been compiled which allows one to obtain a printout of the device positions on disk at CCR in metric units. Also, a system subroutine has been written which accumulates the products needed to do least-squares parameter fitting for up to six parameters.

Collaborative Programs

Biomed Pion Range Shifter

The biomed pion range shifter (shown in LA-6195-PR, p. 23) was brought into full operation during this quarter. A large amount of effort was dedicated to perfecting the hydraulic servomechanism and its command and control system. The unit has been used with a low-intensity pion beam (0.1 pA) to test the total dose uniformity of theoretically derived sweep curves over strokes of 5 and 10 cm. The results are encouraging and show excellent flattening of the dose over the stroke of the unit as shown by the dose-depth curves of Fig. IV-2. The absorbing medium is ~2 cm of polystyrene and a variable column of clear, high-grade transformer oil.

Tests of the servo show it to be exceedingly fast for a large mechanical device. To check its capabilities, the supply pressure to the servovalve was set to

600 psig and the pressure relief valves blocked on the actuators. Normally these valves limit the actuator pressure to about 100 psig, which is the rating of the cable cylinders. With a full 600-psig overpressure capability, the unit was driven with a cusp-shaped sweep curve which commanded a rapid reversal at the top of the stroke, and in fact ~1500 cm/s² of acceleration was achieved. This is shown by the analog rate and position signals taken directly off the unit during operation (Fig. IV-3a). The unit was also operated (with a sinusoidal drive) at 2.5-cm peak-to-peak amplitude at 5 Hz. However, this sort of operation unnecessarily stresses the system. So, for normal operation, the relief valves prevent pressures above 100 psig from reaching the actuators. Under these conditions the servo is somewhat slower and the tracking response to a typical 5-cm isodose command function is shown in Fig. IV-3b.

A block diagram of the command and control system is shown in Fig. IV-4. Control is achieved by analog rate and position feedback loops closed around the servovalve, and the command function and certain interrupt functions are provided by a microprocessor unit (dedicated microcomputer) which allows pushbutton operation of the system. Gain settings on the analog controller are set to provide adequate response in the presence of nonlinearities such as actuator stiction and regulator valve pressure variations.

The microprocessor is used as a simple-command-function generator which can store a selection of sweep curves in programmable read-only memories. In its present form, up to 64 command points can be stored on a single chip. An example for a cusp-shaped function is shown in Fig. IV-5. In addition, the microprocessor has sufficient software to provide interrupt control as described by the flow chart in Fig. IV-6. The range shifter can be made to halt in midstroke or to continue or restart on command, and allows cyclic rates to be changed by altering stored constants. It can run continuously and automatically counts cycles completed. Figure IV-7 shows the layout of the command panel.

Ultimately it is planned to mount a shaft encoder on one of the three redundant analog potentiometer shafts and feed the digital position signal back into the microprocessor memory. This will give a record of results achieved and can possibly be used to provide an outer loop adjustment on the command function level if the steady-state position achieved differs from that which is desired. This can be done

by a comparison of the counts delivered and the counts fed back in response to a pre-run steady-state test signal and avoids the necessity of A/D conversion of the analog feedback signals.

Biomed Automated Collimator

Preliminary work has begun on the design of a servocontrolled collimator to provide an x-y aperture of

Fig. IV-2.
Depth-dose uniformity produced by range shifter.

arbitrary "simple" shape or full beam stop. This unit will mount beneath the range shifter and is composed of 40 collimating fingers, each driven by a servomotor operated as a simple-position servo. Each finger will be independently controlled by a separate data channel through a microprocessing unit. The analog inner loop gives promise of good dynamic response using small, powerful dc servomotors, but

an open-loop digital system using stepping motors is also being considered. The maximum aperture available will be 24 cm and the housing in which the collimators are mounted will have a controllable positioning screw to provide a y-axis offset of the aperture of as much as ± 12 cm.

This will be a high-speed adjustable collimating system capable of interfacing with the range shifter to give two-axis control of the pion dose distribution in the general case. In specific instances, three-axis control will be available for treatment volumes within the limits of the available aperture.

Fig. IV-3.

Analog responses of range shifter under various commands. (x_0 = Response; x_c = Command.)

Fig. IV-4.

Range-shifter command control system.

Fig. IV-5.

Digital/Analog converted cusp sweep and system response.

(x_0 = Response; x_c = Command.)

Fig. IV-6.

Microprocessor command and interrupt flow diagram.

EPICS Beam Separator

The beam separator functioned as a purifying filter in the EPICS line for the first time during this quarter. Its main function is proton elimination, but since it is a velocity discriminator, it deflects all off-energy particles out of the beam, regardless of sign or mass, though its effect on most of these particles is much smaller than on protons; particles such as muons and electrons are hardly separated at all. It was used with detector instrumentation to verify that protons were effectively swept out of the beam by velocity discrimination in a predictable manner. The resulting pion beams were very clean when the separator was operated at a voltage appropriate to the pion energies present. When the voltage was below the level required to produce about 18 mr of separation angle for a given pion energy, purification was incomplete but consistent with prediction. Such

Fig. IV-7.
MPV command panel.

Fig. IV-8.

Separation of 370-MeV/c (π, π^+) at 200 kV.

a case is shown in Fig. IV-8 where 370-MeV/c π^+ (256 MeV) were separated from protons. For an 18-mr separation angle, 244 kV is required for the 8.6-cm separator gap. Only 200 kV was delivered because of inadequate control safety, so incomplete

but predictable separation was achieved as shown. These results were extremely encouraging and testing continued for more than a week. The electronic system was run continuously for a total of 204 h during which time 78.5 h of high-voltage time was logged, broken down as: 50.6 h at 37 kV, 7.5 h at 150 kV, and 20.4 h at 200 kV. The longest continuous run at 200 kV was 19.5 h, with no apparent faults.

Despite these encouraging results, the separator system still requires more development, especially on the control electronics. The slow voltage regulator used in the above tests (0.3%) was replaced with a more accurate, faster circuit designed with extremely high dc gain but also very slow response to fast

transients. Unfortunately, this circuit does not work well in the system and more development is required. The final electronic control will resemble the PPA system using voltage and current feedback through an automatic cross-over network which allows safe conditioning as well as accurate operation.

The channel vacuum at present is inadequate for good high-voltage conditioning of the electrodes and vacuum quality is poor because of organics, so electrode contamination may be occurring. The redesigned vacuum line containing a large vacuum valve and cold trap at the separator flux box is ready for fabrication and should improve vacuum quality after it is installed. At present the separator is being conditioned and run in a vacuum of 3×10^{-5} torr.

V. INJECTOR SYSTEMS

H⁺ Injector

The H⁺ injector is now fully operational, and for the past two months has been operating almost continuously at 10-mA peak current extracted at 6% duty factor. Linac beams for production runs to date have been limited to peak currents <0.5 mA by appropriate collimation with the EM2 jaws in the injector beam transport line. Proton beams for accelerator development up to 20-mA peak in the injector have also been run this quarter at lower duty factor.

The use of the EM2 jaws for a variable collimator has proven quite successful except when very small peak currents (<100 μ A) are required. When the jaws are used to produce these low peak currents, the beam profiles become distorted, presumably because of a nonuniform aperture formed by the jaws. It is known that melting damage has occurred on the edges of the jaws as a result of beam impingement. No difficulty has been experienced at higher peak currents.

The operational beams that have been run for the past two months have usually employed simultaneous operation of both H⁺ and H⁻ beams in the linac. With the present tune, it is possible to run operational beams (no integrated spill) of 80 μ A of H⁺ simultaneously with 10 μ A of H⁻ beam. This tune, however, can only be achieved by separating the two beams at the entrance of the 201-MHz linac in the vertical plane. This separation results in acceptable transverse oscillation in the 805-MHz linac. The present phase-space distributions of the two beams at the entrance of the 201-MHz linac (EM3 emittance station) are shown in Figs. V-1-4. Although this tune has proven to be acceptable for peak currents of several mA, present aperturing in the final section of the beam-transport line precludes running higher peak currents in this manner, and further study is needed to determine the reason for this separation.

The injector fault rate continues to have a long-term average rate of 0.2 to 0.5 arcs/h. The fault pattern is characterized by long periods (up to two shifts) with essentially no faults, and then a series of sparking faults which gradually clear up in 1-2 h. The exact cause of these faults has not been

correlated with any of the observed injector operating parameters. Certainly, the most important parameter presently recognized in achieving a low fault rate with high-power beams is the base vacuum of the accelerating tube. It has been found after the tube is let up to air for even a short time, that many days are required to regain this low fault rate during which time the accelerating tube reaches its equilibrium base vacuum (low 10^{-9} -torr range).

Work has been initiated this quarter to design instrumentation to observe microdischarges and precursors to sparking faults in accelerating tubes. Suitable instrumentation packages will be installed on the outside of the accelerating column which will transmit information to ground level concerning microdischarge currents flowing to the accelerating tube.

The risetime modification to the beam-current pulse that was developed last quarter has now been made a permanent part of the H⁺ ion source. A beam-current risetime (10 to 90%) of 30 μ s is now employed for all operational beams. With this risetime, no feedforward system is needed for peak currents up to 8 mA in the linac.

Work was also initiated this quarter on a modification to the slow-stabilizer circuits of the H⁺ C-W high-voltage generator. A system has been designed and installed which permits automatic recovery of the H⁺ high-voltage generator and ion beam after an arcdowndown. Upon receiving a suitable signal indicating such a fault, the system clamps the 5-kHz oscillator to zero output, grounds and discharges appropriate input circuits to the slow stabilizer and the bouncer, and then inhibits the beam-gate pulse. It then restores operation in the proper sequence. If three such faults occur within a prescribed time interval, the system crowbars the anode power supply of the C-W generator. This system has functioned as expected and provides the required automatic recovery after arcdowndowns. There is, however, a problem of excessive clamping rate (1/h) caused by what is believed to be spurious transients in the system. The cause of these transients is still being investigated, and the system now being used employs a greatly desensitized sensing circuit which responds only to arcdowndowns. If suitable precursors to sparking faults can be properly sensed, this clamping system should prevent any such arcs from ever occurring.

Fig. V-1.

Vertical phase-space distribution for a 0.5-mA peak current H^+ production beam at the EM3 emittance station. The beam has been displaced 3 mm down from the 201-MHz linac axis at this point in order to obtain an acceptable transverse oscillation envelope in the 805-MHz linac.

Fig. V-3.

Vertical phase-space distribution for a 10- μ A peak current H^- production beam. The beam is centered on the 201-MHz linac axis in this plane at the EM3 emittance station.

Fig. V-2.

Horizontal phase-space distribution for a 0.5-mA peak current H^+ production beam at the EM3 emittance station. The beam is centered on the 201-MHz linac axis in this plane at this point.

Fig. V-4.

Horizontal phase-space distribution for a 10- μ A peak current H^- production beam. The beam is centered on the 201-MHz linac axis in this plane at the EM3 emittance station.

H⁻ Injector

The H⁻ injector now provides production H⁻ ion beams for Areas B and C simultaneously with the H⁺ ion beams being produced by the H⁺ injector for Area A.

The only serious problem experienced this quarter in the operation of the H⁻ injector was a flood that occurred in electronics racks due to water pressure surges rupturing the cooling water lines to the power tubes in the C-W generator. As a result of this flood, additional protection from such surges has been implemented.

The use of stainless-steel spacer rods in the H⁻ ion pumps appears to be effective in increasing pump lifetime, but longer operating time is required to substantiate this conclusion.

The 5-kHz ripple that was observed on the H⁻ dome has been found to be spurious and is now believed to have been due to extraneous pickup from the rectifier stack. The wallplate capacitor has been moved to a position comparable to that employed in the H⁺ injector so that the equipment dome now blocks this sensing capacitor from seeing the rectifying stack. The wallplate system was calibrated and, under normal operation, ~200-V peak-to-peak 5-kHz ripple is observed. This measurement is consistent with beam spectrographs taken with the beam-transport system run in a dispersive mode and with the ripple observed in the H⁺ C-W generator. Both machines are now believed to be operating within specifications.

Some difficulty is still being experienced with the binary command channels in this injector. Suitable filtering of the control circuits now permits reliable turn-on of the extractor power supplies, but will not permit the necessary turn-off capability which is required to reset crowbars. Work is continuing to resolve the ground-loop problems rather than bypassing the control circuits with "cheat" circuits.

Polarized Ion Injector Program

The fabrication of components for the polarized ion source is progressing well. The NOVA interface and systems program now has the greatest priority, and the control system should be operational early this summer. The motor generator (MG) set was moved from its original position to the opposite side

of the equipment dome in order to provide more convenient utilization of space in the dome. The installation of power wiring for the MG set, C-W power supply, and equipment dome is now under way and should be completed in the next few months. The current status of these various activities is summarized in Table V-I.

Development work at P-9 has indicated that improvement in the argon-exchange cell is needed before the proposed large-diameter cesium cell and magnetic lens can give greater beam intensity. Therefore, it has been decided to use a cesium cell of proven reliability in the initial phase of operation of the LAMPF polarized ion source.

The design of the rapid spin-reversal region has been postponed until further investigations on the P-9 source have been completed. The present design for this region is being modified in an attempt to reduce position modulation which presently limits polarization asymmetry measurements to a resolution of about 1 part in 10⁶. Concurrently, the feasibility of using an adiabatic spin-reversal technique (a common method in ground-state sources) is being investigated as is the possibility of using a diabatic transition. Source usage by experiments not requiring rapid reversal will not be delayed by this development program since the LAMPF ion source is a modular design which can operate with or without this rapid-reversal unit.

The argon cell cryopumping system for the LAMPF source is presently being used for experiments at P-9, and functions satisfactorily. This unit will not be transferred to LAMPF until it is needed.

High-Intensity H⁻ Ion Source Program

The development work on the high-intensity H⁻ ion source has been transferred entirely to P-11, although some LAMPF support is still being provided to help carry out this work.

During the past quarter, the contributions to this program made by LAMPF injector personnel were mainly in the further development of the arc-pulse modulator and in building test stands.

The new transistorized arc-pulse modulator is being used for tests with the surface ionization ion source. Engineering drawings for this modulator have been completed, and several additional pulsers are being fabricated by an outside vendor for various

TABLE V-I
STATUS OF POLARIZED ION SOURCE COMPONENTS

	<u>Design Completed</u>	<u>Drawings Completed</u>	<u>In Shop or to Vendor</u>	<u>Received from Shop or Vendor</u>	<u>Installed</u>	<u>Tested</u>
Duoplasmatron	x	x	x	x	x	
Cesium Cell	*	*				
Spin Filter	x	x	x	*		
Rapid Reversal Region						
Argon Cell	x	x	x	x		
Focusing Lens	x	x	*			
Extraction Lens	x	x	*			
Accelerating Column	x	x	x			
Precursor Magnet	x	x	*			
Transport Quadrupoles	-	-	x	x		
Transport Diagnostic Equipment						
Ion Pumps	-	-	x	x		
Ion Source Stand	x	*	*			
Ion Source Gas Systems	x	x	x			
Injector Dome	x	x	x	x	x	
Injector C-W Power Supply	x	x	x	x		
Injector M-G Set	x	x	x	x	*	
Dome Wiring	x	x	*			
Ion Source Electronics	x	x	x	x		
NOVA Computer Program	x	x	x	*		
CCR Computer Program						
NOVA Interface	*	*	*			
Control Modules	*	*	*			
ICR Console	*	*	*			

x = Previously completed

* = Completed this quarter

applications, both with the high-current ion source program and for on-line injectors at LAMPF.

Work has also been carried out this quarter on high-voltage regulators and a test stand for the surface ionization source. A mass analyzer was designed, fabricated, and put into operation on the Osher source. Tests were then carried out with molybdenum liners installed in this source, and the results indicate a substantial improvement in the species ratio of H^+ ions to H_2^+/H_3^+ ions. It is anticipated that LAMPF will continue to provide some support to this program.

Injector Beam Development

A new beam-intensity modulation system has been designed and installed in the H^+ injector for evaluation. This system provides the capability of producing an attenuated beam pulse for a selected subset of all beam pulses. The modulation scheme is effected by a suitable resistance in series with the modulator and ion source which is switched in and out of the arc-pulsing circuit by SCR switches. With this technique, it is possible to obtain an attenuation of a factor of 50 in extracted ion current, and of over 100 in analyzed proton current when the resistance is

switched into the pulsing line. By suitable collimation at the EM2 station, it is then possible to achieve preferential attenuation of the low-intensity pulses and thus to provide an overall reduction of several hundred in injected current to the linac. The system is presently being used to provide peak currents injected in the linac of $1\text{ }\mu\text{A}$ on every tenth pulse, with 200- to 400- μA peak injected in the linac on the remaining nine pulses. This modulation pattern is being used to provide low-peak current beams for tuning EPICS and the Biomed area during the initial production runs.

The H^+ ion source test stand has been moved to the basement of the injector to a screened cage to provide proper high-voltage protection. Interlock systems and various utility services are now being installed for this test stand. The test stand will initially be operated in the same manner as it was previously run, with the ion source at ground potential, since the necessary power supplies for running the test stand at high voltage have not yet been procured.

VI. ELECTRONIC INSTRUMENTATION AND COMPUTER SYSTEMS

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

Computer Control System

Control of the LAMPF accelerator and major experimental area beam lines is accomplished through a central control computer (SEL-840MP) interfaced to operator consoles, remote data terminals (RICE), and a network of satellite processors for certain dedicated tasks.

Control Computer

The SEL-840MP control computer and all CCR operator interfaces were available throughout the quarter for accelerator/experimental area development and facility operations. A difficult computer problem relating to index register gating in a recently added instruction was solved. The technician training classes were continued with an emphasis on both the computer and peripheral devices.

The Texas Instruments Silent 700 printer, ordered to replace the worn out Kleinschmidt printer as the operator logging device in CCR, arrived and was installed. It has been operating satisfactorily since installation.

The disk capacity of the control computer was exceeded once again during the reporting period. Administrative measures, consisting of deleting files not absolutely necessary for accelerator operation and moving those that remain to create a supply of contiguous free space, have provided a temporary solution. These measures can provide only interim relief, however, and a procurement action for a new disk system was initiated.

Control Console

Interface level translators were fabricated for two more ANL 840/CAMAC crate controllers. These con-

trollers will augment the existing CAMAC system for use with the third operator's console and other remote-area data links.

Development work continued on the CAMAC IEEE/ASCII interface bus system for the third console. This system will provide a standard and easily expanded method by which devices can be interfaced to computer-controlled consoles such as exist in CCR, HRS, WNR, and the Biomedical Facility.

A design was completed for an automatic bus analyzer which will allow extensive checkout of the prototype microprocessor ASCII bus controller as well as other future devices. All mechanical work on the analyzer was finished. The electronic circuits were wire wrapped and checked out.

The function button panel, to be coupled to the ASCII interface, is nearly complete. Checkout of this device will begin next quarter.

A message structure to allow microcomputer-driven console devices on the ASCII bus to exchange information with tasks in the central control computer was designed. A general communications protocol was adopted to permit interface hardware and software between the device and an application task to be very general. Such a design should minimize the effort required to add new console devices or modify old ones in response to future needs.

Several Burroughs SELF-SCAN bar graph displays were purchased in order to evaluate their possible use as a programmable panel meter for console use. Bar graph displays are flat panel indicators that provide an analog signal representation with digital accuracy.

The modification package to allow Tektronix Model 611 display scopes to be used in multiplex mode with a Tektronix Model 4610 hardcopy unit received some effort this quarter. The modification drawings were completed, and fabrication of the wire-wrap boards and the necessary mechanical brackets were started. Until debugging is complete, only two units will be modified.

Preliminary software and interface hardware were assembled to operate a remote logging terminal (Data Terminal Communications-300) for the Experimental Area Managers' Office (AMO). The terminal will be driven from a serial-data CAMAC module located in the CCR CAMAC system via cable to the AMO.

Master Timer

The projected operational requirements for a facility with three ion sources and the expanding need for timing signals in the experimental areas prompted a design study for a new master timer.

Logical design of the second-generation master timer, based upon an Intel 8080 microprocessor, is 95% complete. Drawings have been submitted to the LASL Electronics Division for wire list programming and chassis wiring. A basic set of timing algorithms will be assembled, and microprocessor software development can begin next quarter.

Printed-circuit boards and front panels for two prototype timing modules were manufactured, assembled, and bench-checked. One of these units is shown in Fig. VI-1. Twenty-three such modules may be inserted into a modified CAMAC crate, each producing a timing signal under the control of the microprocessor. When all spaces are used up in the first crate, another crate can be installed and the expansion continued. Each crate will be linked to the microprocessor chassis through a separate module occupying two spaces in the crate. The front panel for the microprocessor chassis will contain manual control switches and information readouts.

Fig. VI-1.
Module to produce timing signal in new master timer.

Interface Hardware

Two dual-cassette TI Silent 700 terminals, with acoustic couplers, were fitted with modifications to allow binary format and ASCII recording. The units are used on PDP-11/05 and NOVA laboratory computers, an 8080 microprocessor development machine, and the LASL CCF network. An automatic search control and 1200-baud tape option make the units a favored replacement for the mechanical teletypewriter.

A code translator for the Data Products line printer was fabricated and installed in the Terminal PDP-11/45 system. The translator corrected a reversed "," and "+" on the printer which has caused a great deal of confusion during software development. Construction of the translator obviated the need to purchase a new \$2000 print roller.

A CPU/Memory board was designed for the Intel 8080A, utilizing Intel's latest integrated circuit components. The unit is designed to be used in a CAMAC module, but is suitable for other package configurations. Memory capacity is 2k of PROM and 256 bytes of RAM. In order to avoid using a double-width CAMAC module, as is necessary when using wire-wrap interconnections, the unit is being built on a pc board. Layout and taping are complete, and negatives have been sent out for pc fabrication. All parts have been ordered. Modularity was one of the overriding design concepts to facilitate faster and easier redesign in the event of future microprocessor improvements. For this reason, a minimum usable configuration was designed. Input/Output, interrupt structure, and additional memory requirements must be provided on companion boards.

An I/O and interrupt unit was designed as a companion board for the CPU/Memory unit. An eight-level interrupt system and a multiport, programmable I/O structure was chosen. Since the present design may be too general, a more modular layout will be considered before the design is committed to pc boards.

Software is being developed for a complete diagnostic test of the 256 bytes of RAM and the entire instruction set of the 8080A microprocessor. When completed and debugged, this program will allow the CPU/Memory board and other 8080 systems to be tested quickly.

An immediate use for the new 8080 CPU board is foreseen for the microcontrolled data-link modules and the ASCII controller module. Production units

will necessarily be fabricated with printed-circuit techniques instead of wire-wrap techniques used in the prototype version. The minimal capability CPU board allows an easy implementation of our current philosophy in use of microprocessor technology; i.e., a direct replacement for large blocks of random IC logic elements as opposed to the central element of a homemade minicomputer.

The development of software for microprocessor-implemented instrumentation can best be done through the use of cross-assemblers and compilers running on large computer systems (such as a CDC-6000 or a PDP-11/45). The development of hardware is speeded through the use of a small RAM-based (rather than PROM) development machine using the selected microprocessor. Such a machine was acquired for use with the ongoing microprocessor projects, and is shown in Fig. VI-2. A hexadecimal display of current address and eight-bit data, plus a number of machine states, was added for greater versatility. This machine allows PROM elements to be programmed, and it supports the running and debugging of software prior to committing it to an actual instrument.

Fig. VI-2.

Control logic microprocessor development machine.

Accelerator Interface System

Several people from the group worked with the Operations staff in repairing faulty accelerator DACT components during the quarter. Almost 200 boards, chassis, and power supplies were repaired, validated, and returned to the spares pool. A total of 160 DACT receiver cards, using a new technique to receive and decode the data stream, have been fabricated and turned over to the Operations staff. These cards will replace older, less reliable receivers in each LAMPF DACT.

Interface hardware for the polarized injector control system was completed and partially debugged. NOVA computer software to include the third injector was completed and will be integrated into the system next quarter.

A thermal protection unit was added to the ICR NOVA power supply to shut the computer off if the cooling fans should slow or stop entirely. Past experience with such a problem indicated that catastrophic failure of the supply could occur.

A prototype remote bootstrap and down-line loader board was tested in the FWSS PDP-11/10. The unit will allow remote restart and load from CCR through a DACT binary command closure.

Computer System Software

A modest effort continues in maintaining and improving the SEL 840 system software. Some of it involves the correction of faults discovered; some involves changes necessary to support new devices such as the remote consoles at HRS and WNR; some derives from new or improved capabilities deemed necessary or desirable in view of our operating experience.

Among the items completed during the reporting period were the following:

- The operator note display software was modified so that operator notes are sent to the remote consoles as well as the CCR consoles.
- An additional facility was provided for monitoring the status and performance of the computer system by providing for the display of peripheral device reservation status on a Tektronix 611 display.
- The default delay timer for reading data which is synchronized with the H^- beam pulse had to be

- A new console operator command to permit an operator to schedule a task on a periodic basis was added.

When the accelerator control system was designed, it was assumed that the accelerator would operate in a steady state, in which successive pulses were identical, at least from the point of view of the control computer. Recently, requirements developed at three secondary beam lines (EPICS, Biomed, and WNR) for special timing signals to modulate or

The Run-Permit diagnostic software, described in the last quarterly report, was put into operation. However, some work remains to be done to bring its data base into conformance with the Run-Permit hardware and the accelerator channel tables. Programs were added to help manage this information, which suffers a steady trickle of changes.

An on-line update facility for the fast wire-scanners data base was also developed and put into operation.

The program which acquires digital voltmeter data and displays it on the storage tube display units was modified to operate on the remote consoles at HRS and WNR.

A program was written to print the contents of the master timer registers on the line printer.

The harps control software was enhanced by the addition of features to permit the recording of harp data on disk for use in later calculations of beam-quality measurements and to compensate for broken wires in the harps. The computer is able to test each device for broken or shorted wires and then ignore data from faulty wires in subsequent processing.

A program for recording the integrated beam current at the current monitor toroids in the main beam lines was designed and written but has not yet been put into operation. Since the current monitors are shared by the beam current displays, the transmission monitor software, and the recording program, a carefully integrated design is required.

Experimental Area Controls and Instrumentation

Most of the equipment along the primary beam lines is operated through the central control computer or one of the satellite control computers. The equipment along the secondary beam lines is controlled from the associated experimental area computer.

Switchyard

Light maintenance and minor corrections on the controls in the SY were made this quarter. The controls for a new phosphor (LA-TV-02) located at the wire scanner LA-WS-09 were installed. The controls for the two turbopumps in the downstream end of Line A were repaired. A third turbopump was modified to be a spare for the others. It can also be used at the A-1 target in Area A. Work was initiated to replace all 11 of the magnet bypass dynamic shunts in the SY as part of a program to upgrade equipment for more stable performance and ease of maintenance. Control wiring for two racks of equipment is involved in this effort. The circuit for the Line D Run Permit was incorporated into the SY

Run-Permit system. A file system was set up to contain the schematic drawings and wire installation books for the SY.

The PDP-11/10 software for reading toroid current monitors was installed in the Switchyard PDP-11/10 so that current monitor signals can be read via both the Area A and Switchyard PDP-11s. The program to display this information on the operator's console in CCR was completed last quarter.

Area A

Prior to the start of operations in Area A, work was concentrated on the completion of controls and instrumentation for Line A. The remainder of the RM-16 radiation monitors were installed and checked. The last of the thermocouple temperature sensors were installed and connected. The timing distribution system was augmented to satisfy the requirements of some new instruments.

Since the start of operations in Area A, a modest effort has gone into the maintenance and modification of equipment. The A-1 target motion detector was improved with the addition of another control box and associated electronics. The vacuum threshold detectors were found to have a failure mode which rendered them useless in protecting the beam line. To remedy this situation, a new type of vacuum gauge was installed and connected to the Run-Permit system.

A major effort during the quarter went toward the installation and checkout of the transmission monitor software, which forms a major part of the system protecting Line A from damage due to misdirected beam. The work required the collaboration of a half-dozen people in three groups. The approach taken in the software implementation has been to provide initially all necessary facilities for complete operator control of this critical system and then to introduce gradually the degree of automation which is deemed appropriate as operating experience accumulates. By the end of the quarter, the primary goal had been achieved, and a more highly automated implementation had been designed and was under active development.

A console programmable button card was designed and implemented to aid in the control of the Areas A and A-East magnets.

A storage scope display for the beam-spill monitors in Areas A and A-East was developed.

EPICS

During the shutdown to reinforce the EPICS floor, a number of improvements were made in the controls and instrumentation for the area. Two new racks and associated junction box were installed in the EPICS counting house. The racks will hold the ADS and the cable delay systems. Three cable delay systems were built and installed; a fourth system is on order. Each system consumed 914 m of RG-213 and 305 m of RG-223 cable. A dozen fans were installed at various locations in the counting house racks to improve the cooling of electronic equipment. The NIM power distribution system was modified for more stability. A ground-fault detector was designed and built for use with regulator rack and raw power supplies. Numerous items were repaired or modified in preparation for the next run cycle.

The software for the EPICS computer received its share of attention. The RSX-11D operating system on the EPICS PDP-11/45 was regenerated to accommodate it to the memory expansion on that computer. It is now at the maximum of 124k. A program was written to record the EPICS beam-line status on the data tapes written by the data-acquisition program Q. Work was begun on a more highly automated magnet control program for the EPICS beam line. This program is intended to provide a subset of the facilities currently available on the central control computer for magnet control.

Work began on a new and comprehensive control system for the EPICS separator. The present system was adequate to establish the feasibility of the separator but not adequate for the experimental program. As a first step in the development effort, the designs of the present control system and a comparable one from the Princeton-Penn accelerator were analyzed with computer-aided design techniques. The insights gained from this analysis plus suggestions from other controls engineers led to a design which should provide optimum control of the C-W output voltage under normal loads. The design features regulation on both current and voltage with a crossover network that will smooth the transition between regulating modes. This crossover network was breadboarded. While the design will accommodate servo inputs from voltage, current, and power regulators, a tentative decision was made to concentrate on the voltage and current regulators and to regulate on power only if the need is

demonstrated. The basic voltage-regulating loop was constructed, installed, and tested. The deviations from theoretical performance of this unit are being studied because the underlying reasons may affect the final design of the control system.

Stopped Muon Channel

Several improvements were made on the SMC in preparation for resuming the experimental program. A 24-V distribution system was installed in eight new racks. A junction box in which to terminate new CAMAC equipment was attached to the end rack. The layout for a new CAMAC crate was completed and documented; interconnecting cables were ordered and the associated channel list was issued.

The installation of cabling continued in support of the conversion of magnet power regulators. The magnet interlocks were moved from inside Cave A to racks outside; the wiring for this move was designed, installed, and documented. The existing magnet controller chassis was repaired. The magnet control program which had been used at the SMC during the last run period was updated to accommodate hardware changes made during the shutdown.

Low-Energy Pion Channel

A trunk line cable package, containing 170 cables from the LEP counting house to the cave, was designed and installed. Several small changes were made to the hardware associated with the personnel safety system.

P³-East and -West

The key release system was checked and other miscellaneous support was given to the teams getting ready to use these channels. The wiring on the A-2 collimator and P³ was modified to accommodate a new device.

Biomedical Facility

The data-acquisition program Q was installed and made operational on the Biomed PDP-11/45. The

principal difficulty of this task was the merging of the MBD (programmable CAMAC interface) programs which are necessary to normal Biomed operation with those which are needed by Q.

WNR Facility

The SEL 840 software was modified to accept a larger number of beam position monitors in Line D.

Beam-Stop Area

The A-6 beam stop was installed and tested along with the counter/comparator which was fabricated to measure beam-stop position. The digital readout of position was not consistent initially, but a diode and switch debouncer improved the repeatability to $<2/3$ cm. Cables and wiring were installed to make the location readout available in CCR via the computer data-acquisition system.

The control concepts in the RADIP evolved to such an extent that substantial changes in the wiring plant were necessary. These changes are being implemented on a time scale consistent with operation of the RADIP area during cycle 3.

Modifications were made to the Neutrino Area NOVA Branch Driver (CAMAC) to improve interface with JORWAY 72A Visual Display unit. CAMAC Branch Highway multiple-controller-sharing logic, similar to that used in the PDP-11 MBD controller, was installed.

Lines B and EPB

The neutron detector system for Line B/EPB was made operational during the last quarter. Six of the seven detectors are now in the Run-Permit system, and analog data from these detectors are transmitted to CCR through the ADS system.

A 24-V-dc, 125-A power supply was acquired from surplus and will be installed on the wall of Equipment Room B to supply power primarily for the Line B wire-scanner motors. This will release several 50-A power supplies for use elsewhere.

The controls for the turbopump located in the Nuclear Chemistry Cave were designed and the information given to the crafts and technicians who

will complete the installation early next quarter. These controls will provide remote control of the pump from a rack in Equipment Room B.

A file system was set up in Equipment Room B to hold the current drawings and installation books for this area.

The wiring required for Exp. 269 was installed in the Nuclear Chemistry Cave. This experiment will be controlled from Aisle D.

Line C and HRS

Considerable progress was made last quarter in anticipation of beam in Line C next quarter. The controls for LC-BM04/05 HT windings and the LC-MU01 multipole magnet were checked out and made operational during the past quarter. These controls use three power supplies of ± 1000 A-dc to supply power of ± 60 A or ± 250 A to 28 different magnet windings. Figure VI-4 shows the two racks housing the controls. The shunts are inside the righthand rack along with the water-cooled heat sinks. The regulator electronics are contained on pc cards mounted for ease of maintenance in a front-opening panel in the lefthand rack. A ground-fault detector circuit, that will shut the system off when any one or

Fig. VI-4.
Magnet current regulator rack for 28 Line C H_z windings and multipole magnet.

more magnets are shorted to ground, was constructed and installed. A similar system for the HRS bending magnets, H_z windings, and multipole magnet was designed. This system will be fabricated next quarter. Installation books for the system were prepared.

The quad magnets located in Line C were checked out and recalibrated. Several minor problems were found and corrected in the shunt controls and data polarity information. Checkout of all devices in Line C will continue up until beam time.

The vacuum curtain and rod transfer mechanism controls for the scattering chamber and spectrometer interface were fabricated and checked out. These controls will be duplicated for the spectrometer frame.

The design and installation of the wiring plant was a major activity. Installation books were issued for the wiring required for the four shaft encoders for the Line C target. Another motor required for the target table was added to this system. The 120/208-V outlets required for the center pit area of the dome were designed, and a drawing was prepared for the crafts. Installation books were prepared and issued for six detector scanner mechanisms on the HRS frame. The wiring for the HRS water system was installed, and the ac distribution system required on the HRS frame was partially installed.

A wire schedule was issued to crafts for the installation of the wiring required for interfacing Equipment Room B to the CCH. This included the interlocking of the spectrometer motion to the vacuum system, Run Permit, remoting the Line C target controls to CCH, and the RM-16 neutron detector. A new bin of controls was fabricated and installed in the counting house.

A design was started for the control system to operate the TOF telescoping buggy mechanism.

A Versatec controller was installed that provides the capability for a standard Versatec matrix printer/plotter to accept data from a Tektronix storage-tube display or from the PDP-11/45 computer. This enables a hardcopy to be obtained from the storage-tube display. The controller will accept inputs from up to four separate storage tubes. Currently, three of the four inputs are being used at HRS.

The HRS interim program button panel was fabricated, checked out, and installed. This button panel has a switch encoder and a PROM which gives sequential numbers for the buttons that are pushed.

The button panel is interfaced to a CAMAC input module.

Duplicate operating manuals, schematics, etc., have been ordered to provide complete documentation in the HRS counting house for equipment that is used in HRS.

A new RSX operating system was generated for the HRS PDP-11 to take advantage of the computer's expansion to 124k of core memory. The HRS remote console development continued and was brought to a high level of compatibility with CCR consoles. Both control knobs (shaft encoders interpreted by the computer to generate pulses to pulse motors) and programmable button cards were made operational on this console during the quarter. Programs for data acquisition and display for the ISICs in Line C were designed and written. They are presently in the checkout state.

Communications

The CCR line provides voice communications with each of the 250 stations sprinkled around LAMPF. The weak volume of this line has been a long-standing problem. A study of the problem this quarter suggested two modifications to improve the operational capability of the line: 1) replace all of the on-line, low-impedance monitors with high-impedance models, and 2) divide the CCR line into two systems and put a two-way amplifier between them. Orders were written for equipment to implement these two improvements.

Seven universal stations were ordered for installation as required. These stations provide the capability to page all channels, not just those in a given area.

A communications line was pulled to the A-4 target area, and the station in the maze was terminated. The communications systems to two experimenter trailers were installed.

A program of preventive maintenance and periodic testing of the interphone and paging system stations was instituted.

Experimental Data-Acquisition System

The LAMPF experimental data-acquisition system includes computers, software, CAMAC

modules and interfaces, data links, and an equipment pool, all for the purpose of acquiring and reducing data from nuclear physics experiments.

Experimental Area Computers

In order to satisfy the needs of experimenters, the PDP-11/20 CPU, which at one time served as the Terminal Computer and had been intended to serve as a maintenance device and spare for the accelerator control systems, was pressed into service as a data-acquisition computer. A disk unit was diverted from its intended destination and other peripherals and memory provided from various sources to create a viable computer operating under the Disk Operating System.

Slow delivery by the vendor of the disk systems delayed the commissioning of the two PDP-11/45s ordered for LEEP and assigned to the SMC and P³-East. One of the two disks was finally delivered by the middle of the quarter, but the other had not yet been shipped at the end of the quarter. All other components of the systems have arrived.

The Terminal Computer was expanded to 124k of core memory. The two telephone lines were installed and checked out early in the quarter. The system is now able to support three users at local terminals simultaneously with two users who have dialed in from remote locations.

PDP-11 System Software

The PDP-11 data-acquisition systems operate under the control of vendor-supplied system software. In addition, a variety of software items of general use at LAMPF, besides the general data-acquisition system, are provided and maintained by LAMPF personnel.

A library of various subroutines which have been created at LAMPF over the past two years and which are considered to be generally useful was created. This library provides a user with a single source from which he can incorporate these subroutines into his programs. Two versions were created, one for each of the FORTRAN compilers now in use.

The magnetic tape handler for the CAMAC-based IBM 729 tape controller was modified to handle file-structured tapes. Files were not supported on

magnetic tape in RSX at the time it was first written.

A new version of RSX-11D, version 6B, has been in hand for some months. Discussions with users at other sites, however, have indicated that this version is not sufficiently reliable, with respect to the new features, to be worth the effort to change. The standard FORTRAN compiler in this release is an improvement, however, with some bugs fixed and some incompatibilities corrected. Consequently, the compiler was extracted and installed in the version 6A systems now in use at LAMPF.

Data-Acquisition Software

The conversion of the existing modules of the general data-acquisition program Q to RSX-11D version 6A was completed.

A formal distribution disk pack was created, first for systems running under the FORTRAN IV Plus Compiler, and subsequently for the standard RSX (FOR) compiler. The former compiler creates much higher performance code for PDP-11/45s or PDP-11/70s with floating point hardware, but the latter is required by PDP-11/40s and other models without floating point. As a part of the process of setting up a formal distribution, much effort went into the definition and testing of semiautomatic procedures for the installation of Q on individual computer systems which vary in size and capability. The start-up and shutdown procedures were also improved and simplified.

In consultation with active and near-term users of program Q, priorities were set for subsequent enhancements and modifications to the package. As a result, the following items were completed: A facility was added for making simple tests on bit patterns in the event data. The tests are made in the MBD (programmable CAMAC interface) and can be used to select which data words are read subsequent to the test or to abort the reading of data for an event. An unconditional branch command was added to the event definition language, permitting more flexibility in specifying event acquisition. Certain timing problems associated with the distribution of events to user-supplied analysis code were studied, and the time to distribute an event was reduced from 2500 to 500 μ s. The general-purpose MBD code which resides in the MBD along with the specialized data-acquisition code was modified to be

more compatible with some of the modules used in control applications on some beam lines. In particular, a different response to a module not generating the X (command accepted) signal was required.

In order to make the software usable at the LEP Channel, MBD code dedicated to the support of the CAMAC IBM-729 magnetic tape controller was merged into the MBD code module.

As is normal for a software system of this size, usage turned up a certain number of faults, which were traced and corrected, and suggested further improvements in organization of the modules. A trouble report form was designed and distributed to help in communications between users and support personnel.

The Q program was installed on the Terminal Computer, where it is available for testing, software development, and data analysis.

Interface Hardware and Nuclear Instrumentation

A number of new CAMAC power supplies and blower/metering units were acquired to replace existing units in satellite computer systems throughout the experimental area. The units are mounted on slides, thus making removal for repair or replacement easier and faster. Existing power supplies, while constructed with pc board technology, fail in such a manner that complete removal of the unit is required. Although the failures are rare, when they do occur, at least one-half day is required to effect a repair. The older supplies and blower/metering units will be used in experimental physics interface systems that are transient by nature and much easier to repair than dedicated control installations with rear connector wiring and cable assemblies that block removal.

A total of 25 event trigger modules have been completed and turned over to LEEP. A complete test and diagnostic package written in the BASIC language is available to repair technicians in LEEP.

An ADC to PDP-11 interface for nuclear chemistry at LAMPF has been 75% designed. The unit will incorporate an LSI-11 microcomputer to provide independent and parallel data handling with the PDP-11 computer. Final coupling between the two processors will be via an existing CAMAC interface.

An automatic search, 1200-baud, binary/ASCII keyboard terminal was added to the LEEP NOVA computer used for testing and repair. The terminal is also used through the LASI computing facility for data-base management.

A five-day course was conducted for technicians on the CAMAC interface technique. The course will be repeated at intervals, as the need arises.

A proposal for automatic control of the four existing (and three to four proposed) liquid hydrogen refrigerator units used in experimental physics target systems was generated this quarter. Automatic startup, run, and shutdown of the units are proposed, thereby reducing the manpower required to bring the systems on-line. It is expected that more firm requirements and a time schedule for design and fabrication will be set down next quarter.

A beam gate splitter/controller for all experimental area CAMAC-satellite computer systems was designed and is being fabricated. The unit will provide H^+ or H^- beam gate, as desired, to various beam-line monitoring instrumentation under control of the CCR-FWSS computer systems.

A priority arbitration scheme for processor-based auxiliary CAMAC controllers was modeled and tested with a CAMAC Serial Crate Controller Type L-1. Auxiliary controllers residing on a common CAMAC Dataway can share the Dataway, provided an arbitration policy is followed by each controller. The use of auxiliary controllers in CAMAC systems allows parallel peripheral processing to be accomplished, thereby increasing the ultimate throughput of a data-acquisition or control system.

LAMPF Electronics Equipment Pool

Usage of LEEP equipment and services has been very high during the past quarter. The pool is currently supporting 25-30 experiments, which is just about the limit of its capability. Some reallocation of equipment was necessary just prior to the start of cycle 1; if all users would return equipment not in use, this would not be such a problem. Equipment availability for the next report period, which includes run cycles 2, 3, and 4, appears good. Conflicts for equipment in the past have been resolved either by the involved parties or by the Scheduling Committee, with input from the LEEP Committee.

The LEEP is supplying disk packs (manufactured by the 3M Co.) to users for use on PDP-11 computers.

An order for 13 rack-mounted digital printers was placed last quarter. These printers, in conjunction with printout options purchased for the Northern Scientific multichannel analyzers, will provide a hardcopy of data which the users have requested.

It has definitely been determined that the fixed delay boxes, fabricated by LEEP personnel, are filling a gap. All 20 are presently in use, and the demand is on the increase. Components for an additional 20 units have been ordered and will be fabricated next quarter.

An order was placed for 20 rack-mounted fans to help cool experimental electronics racks in various experiments. The heat load problem will become worse as summer weather approaches.

Recently, there has been increased interest in equipment with 200-MHz capability. Most NIM and CAMAC modules in LEEP are limited to ~100 MHz. Several 200-MHz items were purchased for evaluation, including CAMAC scalars, NIM prescalers, coincidence units, and amplifiers.

Shifting of the inventory control data base to S2k is complete. Improvements in efficiency and versatility have already been realized. This can be attributed both to the new system and to the TI terminal recently installed. The computer maintenance data base is presently being added to S2k and should be completed early in the next quarter.

Signal Noise Problems

The beam halo measurement problem through the accelerator requires high-gain wire-scanner amplifiers. With the high gain comes an increase in noise on the data channels read in CCR. Modules 8, 9, and 11 were found to be much more noisy than the other 805-area modules. The problems in these modules were located and repaired. A test was conducted in which the noise was monitored on each wire-scanner amplifier while the stepping motor was driven. On several modules (~1/3 of them), there was a noticeable increase in high-frequency noise while running the motor. The recommendation is to not take data while the motor is running when at high gain. The alternate approach would be to

systematically revise the grounding on each module — a job that could take about one day per module.

The decision to try to put the optics of the TR under computer control placed certain noise limits upon the data. Several of the bending magnet current measurements via the ADS were unusable because of the noise level, and one was unusable because of a high-common-mode-voltage component. These problems were corrected by the addition of filters on certain of the ADS channels and the addition of high-common-mode-rejection (CMR) narrow-band amplifiers on other channels.

CMR Shunt Amplifiers

A number of amplifiers are in use at LAMPF that were originally designed specifically to reduce high-common-mode voltages (up to 300 V) and to amplify small differential-mode voltages. These are frequently used as "shunt" amplifiers for high-current power supplies, both as servo inputs and over-current detectors. Experience has shown that they tend to drift. A new shunt amplifier was designed around an optically coupled linear amplifier and a high isolation dc-to-dc converter (for power). If tests prove the validity of this approach, the circuit will be committed to a general-purpose pc card.

Magnet-Mapper Electronics

A circuit design analysis was performed on the magnet-mapping integrator used in field studies of bending and focusing magnets. This study resulted in several recommendations which should lead to better system performance. These modifications included the addition of a resistor in series with the integrating capacitor, use of a better power supply, operation within a temperature-controlled chamber, change to a polycarbonate capacitor, and new offset adjusting scheme.

LH₂ Refrigerator Temperature-Control Systems

Several rather elementary temperature-control systems were fabricated as an interim solution to a problem presented by the experimenters. These

bang-bang controllers measure the pressure of the liquid hydrogen in the refrigerators and add heat via a resistive heating element to maintain that pressure. Thus, the temperature of the LH_2 is controlled.

Plans are in progress for a more elaborate control system using an analog controller (as opposed to the bang-bang controller). This system will provide adjustable alarms and BCD outputs proportional to LH_2 pressure. It is anticipated that five or six of these systems will be put into operation next quarter on the small 10-W refrigerators as well as on the large 300-W system.

Remote-Handling Manipulator System

A control system for the PAR and Remotion manipulators is being designed and packaged. Included will be controls for TV (monitors, pan, tilt, zoom, and lights for cameras), HAP (leveling, extension, swing, raise, etc.), hydraulic pumps, stem raise and lower, and winch.

Sharing of LAMPF Technology

Two members of the staff attended the NIM-CAMAC Working Group meetings on interface and software standards.

One member of the staff was appointed a member of the USERDA NIM committee's Advanced System Study Group (ASSG). This is a committee of eleven members — five physicists, four electrical engineers, and two software specialists, from SLAC,

LBL, FNAL, BNL, and LASL — which is studying the problem of high-data-rate experiments to see whether a common approach, possibly a new standard to supplement CAMAC and NIM, is feasible or desirable. Special emphasis is being given to the use of very fast logic (emitter-coupled logic) now available, large solid-state buffers, and front-end filtering with either hardwired logic or microprocessors. The goal of the group is to define the general problems and to outline an acceptable common approach. The group expects to have definite recommendations early in 1977. If the conclusion is that work toward a new standard system is warranted, a multilaboratory group will be formed to work out the details.

Electronics Perspectives Seminars

The problem of keeping the technical staff abreast of the latest technology was attacked by organizing a series of seminars. Thirty sessions, ranging from basic to advanced, have been scheduled for presentation through October 1976. Typical of the response was a two-session seminar titled "The M6800 Microprocessor Family — An Introduction" which was attended by nearly 100 people. A presentation by Motorola featuring their latest equipment has been scheduled as a follow-up seminar.

In an effort to upgrade beginning technicians with little or no formal electronics training, a course titled "An Introduction to Electronics" was organized. It features lectures augmented by demonstrations and hands-on training.

VII. ACCELERATOR OPERATIONS

General

The accelerator was in continuous operation throughout the quarter for a total of 270 shifts. Of the total, 59 shifts were scheduled for facility development, 24 for maintenance, 35 for tuning production (research) beams, and 152 for research.

With the completion of the renovation of Experimental Areas A and A-East late in the quarter, H^+ and H^- beams were used simultaneously for research for the first time. All research beam delivered to Areas A and A-East in 1974 involved accelerating only H^- beam and then stripping a portion of the H^- beam to these areas.

Machine availability during research shifts averaged 83% for the H^- beam throughout the quarter, and 86% for the H^+ beam during the three-week period it was in use.

Experimental Program

Because upgrading of Experimental Areas A and A-East was still in progress during much of the quarter, research beams were initially limited to Lines B and EPB, with the machine operating at average currents ranging from 0.1 to 2 μA of H^- . On April 5, Areas A and A-East were brought on-line, marking the start of cycle 1 of dual-beam operation with 10 μA of H^+ going to Area A in addition to the

low-intensity H^- beam to Lines B and EPB. Cycle 2 of dual-beam operation began April 26 with 20 μA of H^+ going to Area A. Cycle 3 is scheduled to start May 16 with 35 μA of H^+ in Area A.

Research-quality proton beam currents to Area A totalled 4450 μA -h as measured at the A-1 target station. An additional 380 μA -h of H^- went to Area B. Eighteen experiments received beam during the quarter as shown in Table VII-I. This tabulation does not include parasite use of beam during production runs or the beam used in facility development or tuneup activities.

Facility Development

Much of the time allotted for facility development was used for checkout of beam optics and diagnostic systems in the beam switchyard and Experimental Areas A and A-East. The harps and profile monitors worked very well, and the beam optics results were as expected. Shielding surveys detected some penetrations which needed to be plugged, but general radiation levels were as expected. A computerized beam-transmission monitor employing beam-current monitors and a PDP-11 computer was checked out successfully and constitutes the first part of a burnout protection system. Two new operating modes were checked out and employed: a one-in-ten mode in which the amplitude of every tenth beam pulse is attenuated by a factor of several hundred to permit measurements of secondary beam-line particle distribution, and a second mode

TABLE VII-I

QUARTERLY REPORT OF BEAM PROVIDED FOR EXPERIMENTS

Experiment No.	Channel	Shifts (8 h)	μA -h	Experiment No.	Channel	Shifts (8 h)	μA -h
2	LEP	50.0	4310	176	EPB	16.0	----
7	SMC	13.5	1600	179	LB	103.5	368
31	Neutrino	27.5	1720	193	AB Neutron	27.5	110
60	SMC	10.5	775	195/214	Biomed	3.0	275
80	P ³	14.5	1670	195/214	P ³	27.5	2020
81	EPB	93.5	----	270	Biomed	18.0	385
86	TTA	11.5	860	271	Biomed	23.5	1440
105	AB Nucchem	1.0	13	272	Biomed	1.0	----
142	SMC	23.0	1690	273	Biomed	5.5	295

in which selected H^- beam pulses are suppressed while the corresponding H^+ beam pulse is routed into the WNR beam line.

Methods were explored for measuring beam halos in the accelerator with wire scanners, employing both secondary emission and beam spill detection techniques.

A mechanism was developed for degrading the risetime of the proton pulse in the ion source in an effort to reduce the effects of beam-loading transients in the accelerator cavities. With a 10-90% risetime of 30 μs , the amplitude controllers on the 805-MHz systems were able to maintain cavity fields within tolerance for peak beam currents of at least 8 mA. An apparent reduction in the frequency of high-voltage arcs in the H^+ accelerating column was a welcome side effect.

Development was started on a computerized control vector for the TR. If it is successful, the operator will be able to make one-knob adjustments of beam position, angle, and phase.

Operating Experience and Downtime Accounting

Machine operation was again more reliable and stable than at any time in the past. A significant decrease in downtime of 201-MHz rf systems can probably be attributed to a new preventive maintenance program.

A summary of the machine downtime is given in Table VII-II. A major portion occurred during machine startup following scheduled maintenance days.

TABLE VII-II
QUARTERLY SUMMARY OF MACHINE DOWNTIME

Category	Downtime (h)	Percent of Total
201-MHz amplifiers and transmission lines	73	21
805-MHz amplifier systems	57	17
Vacuum	48	14
Magnets and magnet power supplies	34	10
Interlocks	30	9
Injectors	28	8
Water	25	7
Computer control and data acquisition	13	4
Reference source	3	1
Beam stops, plugs, targets, strippers, scrapers	3	1
Beam diagnostics	2	1
Timing distribution systems	2	1
Miscellaneous (utilities, etc.)	21	6
TOTAL	386	

VIII. EXPERIMENTAL AREAS

Secondary Beam Lines

The major activity of this section during the last quarter has been to run first beam down the secondary beam lines in Area A, check out the beam lines, and turn the beam lines over to experimenters for production running of experiments. Meanwhile, despite problems with the LD₂ target in Area B, Lines B and EPB have been running regularly.

Significant activities have been:

1. Building of the experimental caves for SMC, LEP, P³, and the test channel has been completed, personnel safety systems have been installed, and checkout and documentation of the personnel safety systems are complete.

2. Vacuum window guards for SMC exit windows have been built and installed; repairs have been made to beam plugs on both output legs.

3. The two quads for the SMC-East beam line have been hooked up and powered. Preliminary checkout of the line was carried out during cycle 2.

4. A dc power jumper for an LEP bending magnet shorted and was repaired. This jumper repair interrupted cycle 1 and required that the shield doors be moved over target cell A-1.

5. Repairs were carried out on two sets of beam jaws on the P³ channel and cycle 1. The shield doors over target cell A-2 had to be moved for these repairs.

6. The SMC, LEP, P³, and test channels were checked out with beam and are now in use by experimenters on a production basis. In all cases the channels are performing at least as well as they were before the great shutdown began.

7. Two new TV phosphors were installed in Line EPB.

8. Vacuum leaks were found in the transfer lines in the movable center part of the LD₂ neutron-production target in Area B. Initial attempts to repair the leaks failed. The target assembly was removed and the center part is being rebuilt. The Univ. of New Mexico group made a new LD₂ target and center plug to be used with a refrigerator system acquired from LBL. It, too, leaks, but it will be used as a solid target holder while the regular LASL target is repaired.

9. In Area B, Exp. 81 was completed, and support was given to the Exp. 176/219 run. Also, support on a continuing basis was given to Exps. 179 and 193.

10. In Area A, extensive support was given in setting up Exps. 2 and 164 in LEP and Exp. 80 in P³. Extensive support was also given to the users from Cal Tech who did the preliminary checkout of SMC-East.

Shielding

The installation of the mass shielding along Line A and the secondary channels in Area A was completed in this past quarter. Also completed was the installation of experimental caves for initial experiments at the end of LEP, EPICS, the test channel, SMC, and P³.

At target station A-1, the in-cell steel shielding above the target from the 2.7- to 3.7-m level was designed, fabricated, and installed. The Merrimac door 1A was fabricated in place at the west end of the 1A opening, doors 1B and 1C were closed to meet it, and the 10 concrete battery plates were installed at the east end of the door opening.

Concrete shielding was stacked between the LEP counting house and the process water valve caves for A-1. The concrete blocks were arranged to form a maze access to the valve caves. An added layer of concrete blocks was stacked on the EPICS face of A-1 mass shielding.

At target station A-2 some additional steel shielding was installed between beam-line elevation and the bottom of the doors. All A-2 Merrimac doors were completed and closed. Stacked concrete blocks were installed behind door 2A, and steel and concrete battery plates were placed behind 2B and 2D. Key blocks and cover blocks were set to complete the A-2 doors.

Concrete blocks were set to cover the A-2 process-water valve caves and the profile-monitor shield plug. A design was completed to provide a shield for the exposed part of the A-2 target mechanism.

Additional lead and concrete fill was placed in the utility penetration to the A-3 station. Fabrication work is still under way on the steel covers for the power service and instrumentation trenches at the top of the shield mass. Installation of these covers within the next few weeks will complete the main beam-line shield mass through Area A and provide uniform roadway to A-East.

At A-East, iron counterweights were installed above A-4 station to form a level roadway at the top

of the shield. All water-cooled steel shielding was installed near A-5 target and A-6 beam stop. Additional steel was placed above the beam line in both areas.

At A-5, steel shielding was stacked around the biomed-line first triplet and start of the first bending magnet. Concrete blocks were placed in front of A-5 process-water valve cave and the access walkway under door G was reworked.

The A-5 and A-6 Merrimac doors were closed, special key plug blocks installed, and both areas made ready for beam.

Extensive radiation surveys were carried out with beam on and production targets inserted. Hot spots were found behind the LEP counting house, on the SMC power supply platform, and a few other places. These radiation leaks have been corrected and the shielding looks good for at least 100 μ A.

Facility Operations

With the end of the great shutdown, extensive work has been accomplished to clean up and organize the Experimental Area buildings and service yards.

In Area A, the steel-cutting operation has been moved out of the building eliminating the source of much of the dirt in the area. The associated oxygen tanks and piping on the south side of the building have been removed, providing additional space near the experimental floor for users' trailers.

Much residue from the shutdown activities has been gathered up and disposed of through LASL salvage and waste disposal channels, including the radioactive solid waste, temporarily stored in secure areas at the site.

Concrete and steel shielding, not installed in the mass shielding and experimental caves, has been gathered up from throughout the service area and experimental buildings and is now being consolidated in a shielding supply yard at the east end of the area.

The two large bridge cranes in Area A have undergone major maintenance and a thorough cleaning. Mechanical and electrical systems have been serviced, repaired, and replaced as needed. Complete load tests were carried out and the two cranes recertified for full service.

The Area Manager's Office has been set up to provide facility management and user support on an extended time basis. The office is now manned from

0600 to 2400 Monday through Friday and 0800 to 1630 on Saturday and Sunday. Support at other times is available from standby or on-call personnel.

Experimental Area Cooling-Water Systems

The five radioactive water systems (X02-X08) operated continuously during this period. As of April 30, 1976, the water specific resistivity for each of these systems was as follows:

X02	~10.3 M Ω -cm
X03	~ 5.9 M Ω -cm
X04; -06	~14.3 M Ω -cm
X05	~ 4.1 M Ω -cm
X07; -08	~13.1 M Ω -cm

Installation and checkout of the three new cooling systems for EPICS, HRS, and Area A are nearing completion. The pump-heat exchanger package for the HRS has been checked out. The piping to the spectrometer magnets is almost complete.

The EPICS spectrometer pump-heat exchanger-package installation is complete. Checkout of the system has begun.

The Area A pump-heat exchanger package (Rover) has been installed, and checkout is nearly complete. This system will be used to supply cooling water to the experimental magnets in the Area A experimental caves. Experiments 37, 99, and 80 will be the initial users of this system.

Efforts continued on the CCR system to permit the remote printout of water system data in the Area Manager's Office. Most of the transducers for the X02-X08 systems are installed and the long lines to the CCR are complete. The software is being checked out and programming has begun.

The design effort was started on the wiring of the high/low flow alarms on the valve cave flowmeters. These signals will eventually be routed to the CCR and back to the AMO through the system described above. The low-flow alarm will assist in detecting water leaks, and the high-flow alarm will assist in the management of the water systems.

Remote Handling Equipment

Remotion Co. delivered the hydraulic unilateral servomanipulator system for which the slave arm (Servoarm) is on loan from the U.S. Navy. The

system was tested successfully and is now ready for assembly on Monitor. The system will benefit from some further improvements which will be made in cooperation with the manufacturer.

Tests with the manipulator showed that the servomanipulator is very much faster than a rate-controlled manipulator. However, because of the high speed, the lack of force reflection also becomes very noticeable. The operator has to be very careful not to damage equipment and/or the slave arm itself.

A shoulder assembly was designed and installed at the end of the Monitor hydraulic boom. The left arm on the assembly is the P.A.R. #3500, as originally installed. The right arm will be Remotion Co.'s hydraulic Servoarm.

A control station, serving all Monitor subsystems including the Servoarm master, was designed with due consideration for human engineering. Details for the control system wiring are being worked out and rewiring of the system has started.

A second remote control vehicle, Tele-arms, (or third, including Merrimac) has been designed to accommodate the force-reflecting servomanipulator being built by TeleOperator Systems Corp. (TOS). The design leans heavily on experience gained with Monitor.

The truck loader is identical to the one used on Monitor. The supporting frame is somewhat heavier, and to save cost lacks the wheels. It can be handled by crane and by forklift. The order for the unit has been placed.

The shoulder assembly, including the leveling drive, has been designed for low backlash and much stronger torques. The appearance will also be more compatible with the TOS manipulator, with a minimum of gears, motors, and cables exposed.

The conceptual design of the remote-handling unit, including its master station, is complete. Detail design will begin soon.

The TOS accepted the order for a two-arm force-reflecting servomanipulator system on March 18. This fixes the contractual delivery date for the first arm at January 20, and for the second arm on May 12, 1977. The company is making good progress with shop drawings and placing long delivery orders.

All major components of the remote-handling mock-up have been placed in the "plywood" target cell, located near the hot cells. The assembly is ready for installation of electrical, water, and vacuum connections.

A questionnaire on remote-handling tools and tooling fixtures was sent to those who were involved with beam-line equipment design. Five questionnaires were returned, containing valuable suggestions, particularly with regard to tools to be used with manipulators. Detail design and procurement of some of these tools are ready to start.

Polarized Proton Target Development

The polarized target cryostat was tested in the first part of this quarter, after it was reassembled for the new ^4He pump.

The target cryostat functioned much better with the new ^4He bath pump. The normal operating pressure was 1.1 to 2.5 mm, depending on the heat load. The improved instrumentation showed agreement of the ^4He bath temperature as measured by a resistance thermometer and by the bath vapor pressure. The 1-l, ^4He reservoir ran typically at 1.35°K under load corresponding to 35 mm ^3He condenser pressure.

Steady-state operation of the refrigerator was achieved under the above-mentioned conditions. The ^3He space was pumped by two WS-250s in tandem, backed by a Welch 1397 forepump. The system achieved a stable 150- μ working pressure, which is equivalent to 1°K for ^4He under its own heat load.

A series of heat load vs vapor pressure measurements was made, and the plotted results are attached. The current pumping system can sustain 100-mW steady power load at ~700- to 800- μ pressure, corresponding to 0.62 to 0.64°K ^3He equivalent temperature. These temperature limits were pump-limited, and will improve when all the planned pumping systems are connected. The 100-mW refrigerator capacity significantly exceeds the 10-mW design value.

After the ^4He working-fluid test, the Edwards 9B4 booster pump was inserted between the cryostat and the Roots blowers to increase pumping speed at lower pressure. This improvement was necessitated by the larger mass rate of flow when ^3He is used as the working fluid.

A successful run using ^3He as the working fluid was carried out during the last part of the quarter. Steady-state operation was observed at a ^3He vapor pressure of ~30 μ , corresponding to 0.4°K temperature. At 0.4°K, the adjustment of ^3He flow

was critical and sensitive. A very long cool-down time was also observed. Both conditions were probably due to the lower latent heat of ^3He and much smaller volume of gas available.

No refrigeration capacity could be measured because of the small amount of liquid available

($\sim 15 \text{ cm}^3$) in a large reservoir. After the cryostat is modified for polarized target applications, another attempt will be made on the refrigeration capacity of the cryostat.

IX. BEAM LINE DEVELOPMENT

Beam Line A

The magnet and instrumentation components of the main beam line were installed, checked out, and operated satisfactorily during the run-up to production beam operation. The proton beam itself was used during the preliminary "R" cycle to perform an operational check of the beam transport and beam diagnostic systems. The checkout revealed only minor problems and is a tribute to the care taken in construction, installation, and debugging of these devices.

Collimators were also added during the shutdown to provide protection for the magnets, harp circuit boards, and current monitors from primary beam halos as well as from scattered radiation.

During the checkout "zero" cycle, when H^+ beam was transported through to the A-6 beam stop, the same checks were completed at A-5 and A-6, with the same satisfactory results. Production beams of $10\text{-}\mu\text{A}$ average in cycle 1 and $20\text{-}\mu\text{A}$ average in cycle 2 were successfully transported through the target cells, and the transmission monitor was commissioned (see below for description). Transport tunes calculated from the measured H^+ phase-space properties have been implanted for production proton beams of 10- and $20\text{-}\mu\text{A}$ average current. Targets in use have usually been 1 cm of graphite at A-1, 6 cm of graphite at A-2, and 8 cm of graphite at A-5. Only minimal empirical adjustment of quadrupoles has been necessary to produce the operating tunes from the calculated tunes.

Calculated beam-transport tunes are available for the most likely combinations of targets in the three target cells, which take into account the limitations on quadrupole excitation imposed by the existing power supply allocation. The starting emittance for these tunes has been determined by measurements in the SY. The values are less than the previously used $\pi/30$ mr-cm, and are different in x and y (see below).

The spot size at target A-1 has been approximately 5 mm (vertical) by 11 mm (horizontal). This vertical size will be reduced to 1.0 mm when the vacuum-protect window at LASV05 at the end of the SY is removed. The A-2 spot size has been about

6 mm (vertical) by 8 mm (horizontal), and at A-6 the size is about 8 by 8 mm.

A test run of $50\text{-}\mu\text{A}$ average for 1 h has been accomplished, producing acceptably small beam spills with all targets in place.

Beam Lines X, B, C, and EPB

For all of this period, H^- beams were delivered to Areas B and EPB as required by experimenters. Standard procedures were used by the MP-2 operators to provide the beam tuning required, but MP-13 personnel made a start on tuning Line X to give a beam that would meet the stringent Line C requirements. These are quite different from the Line B-EPB specifications which have been used since startup. Checks of H^- beam emittance have also been made using three wire scanners at the end of Line X.

Television-viewed phosphors, which are useful tuning aids in these low-intensity beam lines, are now independent of the wire-scanner mechanisms. The phosphors have their own pneumatic actuators, and, in addition, console-operated illumination is provided to allow viewing of the fiducial marks with an external light and then switching to a dark field to enhance the beam-spot visibility.

Switchyard

Beam Measurements and Analysis

The phase-space parameters of the H^+ beam have been measured using the four wire scanners in Line A-Direct at peak currents between 17 and $1700\text{ }\mu\text{A}$. The measurements are consistent over a period of several weeks for fixed source current and low-energy jaw (collimator) settings. The emittances measured at $1700\text{-}\mu\text{A}$ peak were $E_x = 0.020\text{ mr-cm}$, and $E_y = 0.012\text{ mr-cm}$ where the area of the phase-space ellipse for 40% of the beam is given by πE . The source current used to achieve this peak current was 10-mA peak.

At the beginning of this year we started to clear up the transverse-emittance determination using the existing wire scanners in the SY. We sought optical conditions (for fixed locations of the hardware)

which gave the minimum error on emittance assuming statistical errors on the measurements. These considerations showed that the best conditions occurred in Line A-Direct using the four wire scanners there with the triplet (LAQT01;02;03) turned off and the doublet at the end of the linac tuned to produce a waist midway down Line A-Direct. Experimental studies with H^+ beam showed consistent results at the 5-10% level of reproducibility.

Hardware Improvements

Accumulation of spares for magnets and instruments is now an active project. Some improvements are being incorporated in the hardware at the same time, e.g., Fig. IX-1 shows a SY quadrupole coil which has been cast in solder by LASL Group CMB-6 to provide improved heat transfer from the conductors to the indirect water-cooling passages. Further improvements in m.i. cable production are being implemented in cooperation with the manufacturer, (Pyrotenax). Cable is now being made with thinner magnesium-oxide insulation, and consequently increased copper cross section, giving both lower power dissipation in the coil and better heat transfer to the cooling water. This technique may enable high-power coils to be indirectly cooled, for instance, in

Fig. IX-1.

A switchyard quadrupole coil which has been cast in solder to improve heat-transfer characteristics.

the target-cell triplet quadrupoles, eliminating worries about ceramic water insulators.

Instrumentation Development

Guard Rings

Prototype amplifiers have been constructed and tested by connection to a four-segment secondary emission guard-ring monitor downstream of a 6-cm graphite target with 20- μ A average current incident upon it. A very clean signal was obtained from all four quadrants of the guard ring. Nine of these devices are installed in collimators in the target cells and promise to be quite useful in detecting abnormal spills.

High-Level Dosimetry

The SY, target cells, and beam stop have high-level dosimeter packages installed near components expected to be radiation-sensitive, e.g., stepping motors. The packages, made with the cooperation of Group H-1, contain a Kodak M-rad film, using a self-developing tetrazolium salt and several silver-phosphate glass rods. This gives a range of 50 R to 50 MR, and it is intended to correlate these exposures with component failure lifetimes.

Drawings showing the locations of these dosimeters, and the area-protect and loss-monitor scintillators have been prepared.

Harps

The harp system is now essentially complete, and the system configuration is shown in Fig. IX-2. The harp system can be divided into three areas: the harp and cables, the multiplexer and isolator chassis, and the computer interface, which contains various CAMAC modules. The harp is schematically represented by a crosshatch on the top of the figure (the wires are actually vertical and horizontal). The secondary emission current charges up each cable to a potential proportional to the amount of beam that intercepted the harp wire. The charge remains stored in the cable until a read command is issued by the computer interface to the multiplexer.

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A read command causes the computer interface to issue the harp select command to the multiplexer. The multiplexer selects the harp, and then by the advance command, serially switches the analog signal on each harp wire, x and y in parallel, to the input of the ADC module in the computer interface. The ADC digitizes the analog signal and stores the result in the PDP-11 memory. When the analog signals on all of the wires have been digitized, the multiplexer receives another harp select signal from the interface and repeats the above process for the new harp. This continues until all selected harps have been read out. The reset module in the computer interface resets the harps by issuing a command to the multiplexer that causes all of the switches to discharge all of the cables to ground.

The isolating gates and differential line drivers in the MUX to CAMAC isolator serve to minimize ground loops between the MUX rack and the module 65 racks.

Fig. IX-3.
Line A harp profiles.

Software provides for taking a "background" signal from each harp, with the beam off. This background can then be subtracted from the beam-on signal. Software provisions further reduce noise and provide the capability to sum a number of sequential beam pulses on each wire, "analog sum", up to 64 before reading the stored voltage, and then to average the data (in digital form, "data average") after analog-to-digital conversion further reduce noise. The expected interference from magnet power supply SCR spikes has been greatly reduced by filtering and is presently only at a level of 1-2 counts in a full-scale range of 500 counts.

Some typical Line A harp profiles are shown in Fig. IX-3.

Development of improved hardware has included the production of two monolithic harp boards, 508-mm square by 10-mm thick, having an x-profile on one side and the y-profile on the other (see Figs. IX-4 and IX-5). These 99.5% pure alumina substrates were silk screened with EMCA 2031, a palladium-silver ink, and fired to 900°C at Sandia Laboratories in Albuquerque. These represent the largest ceramic pc boards produced by that laboratory.

Beam-Current and Transmission Monitors

The beam-current monitor (BCM) system provides direct readout of the beam intensity in all beam lines except EPB. This system uses toroidal transformers, coaxial with the beam line, to produce a signal proportional to the H^+ or H^- macropulse current (within some bandwidth limitation). To minimize noise pickup and line resistance, each BCM has a preamplifier located as close as possible, for example, near the beam pipe in the SY. The preamplifier has remote gain ranging through four levels to provide 10-V, full-scale output for beam pulses of 0.2, 1, 5, and 20 mA peak current.

The signal is subsequently processed through an elaborate system, providing several outputs for various purposes, as shown in Fig. IX-6. The amplified signal is sent to a "signal processor" in one of five equipment bins for gating, baseline restoration, and 60-Hz hum bucking. An ac-coupled output goes to a line driver to provide a "video" signal for CCR and experimenters. A dc-coupled output (e.g., free of signal-dependent baseline shift) goes to the RICE

Fig. IX-4.

Monolithic alumina harp board, x-profile side.

Fig. IX-5.

Monolithic alumina harp board, y-profile side.

ADS for waveform sampling and to the current integrator logic.

A calibration system provides the capability for conversion of the toroid signal to absolute current units. A single-turn calibrate winding passes through each toroid and carries a standard current pulse following each beam pulse for calibration. The calibrate gate width is matched to beam gate width to equalize pulse droop error, and the calibrate pulse amplitude is kept within a factor of 2 of the beam peak current to minimize linearity error. The H^+ calibrate line is continuous from the SY (LACM02) to the main beam stop (6ACM02) to minimize the relative error among toroids. At present, Lines X and B each have isolated calibrators to minimize ground currents, seen as a major noise source on the low H^- BCM signals.

As shown in Fig. IX-6, the preamplifier gains are controlled from CCR via the CAMAC satellites, and the calibrate amplitudes (Lines A and X) are controlled by the RICE data system.

The characteristics of the current integration system may be of particular interest to users. The

heart of the integrator is a voltage-to-frequency (V/F) converter which produces a pulse train at a rate proportional to the instantaneous voltage from the signal processor, with a maximum rate of 1 MHz/10 V. The pulse train may be accumulated with a scaler to yield a number giving total beam charge or average current over the integration interval.

There are two V/F converters on those toroids whose signals are needed by experimenters, to permit CCR and the experimenters to calibrate without mutual interference. The experimenter may switch his V/F converter into calibrate gate time by means of a switch in the equipment racks.

Calibration must be made carefully to realize the maximum accuracy. First, calibration should be taken at the same duty factor (repetition rate and beam gate width) as will be used during the beam run because the background will change with these factors. There is a particularly large background shift from 120 Hz to lower repetition rates, due to residual 60-Hz hum. Second, background data should be taken for both beam gate and calibrate

computer program uses only the central range to display the shorter strokes.

Other facilities provided in the programs include background subtraction, data averaging, and the ability to switch from "fly" to "step" scan mode if the beam repetition rate is too low to produce the operator-selected scan density. A significant improvement in operator-machine interaction has resulted from these changes.

Stopped Muon Channel

The SMC is now back in routine operation, and channel downtime is <1%. Major improvements installed during the great shutdown include: 1) a vacuum system for the beam transport, 2) new regulators for a quarter of the power supplies, and 3) two quadrupoles and shielding for the new "east leg" of the beam line.

Tuning for the routine modes of operation is now complete. The results of this tuning are summarized in Table IX-I. Compared to the best results before the shutdown, the normalized (to 1 μ A) muon rates

are a factor of 2 higher at 130 MeV/c increasing to 10 times higher at 65 MeV/c. Despite the fact that the original muon channel report (LA-4474-MS) contained several optimistic assumptions which were not realized in the final design, the present measured rates exceed those of the original calculations.

Magnet Measurements

The following magnets were measured during this period:

- 1) The β Gdl and harmonic content of a 12Q4 quadrupole for WNR;
- 2) Two 30.5-cm bore steering magnets (Line A standard and 5A-SM-2X,Y);
- 3) Hall probe measurements on three injector quadrupole triplets;
- 4) Magnetic field maps of the Bicentennial magnet.

A Line A-Line X magnet data book has been assembled. Copies of the measured data and the polynomial fits are stored in MAGSET for the magnets in Lines A and X.

TABLE IX-I

NEGATIVE MUON FLUXES

P_μ (MeV/c)	Rate (kHz/ μ A-gm/cm ²)	Total Rate (kHz/ μ A)	Electron Contamination (%)
55	3	1	0.5
70	5	5	1.0
80	12	12	0.5
90	12	18	0.5
110	11	30	0.3
130	13	40	0.5
140	12	40	0.2
132	25	90 (Calculated rates)	

P_μ is the muon momentum.

Rate is the stopping rate in kHz for a 1- μ A beam (6-cm carbon target)/gm/cm² (~150-cm² target area).

Total Rate is the total flux in this area for the same conditions.

Electron Contamination is the upper limit of the electron contamination of the beam.

Computing Efforts

Calculations of beam emittance in Line A-Direct continued. A new 840 program, AD1133, will use the data from three or four wire scanners in Line A-Direct and calculate the emittance at the linac.

A new "low-field" Line A transport tune was obtained which sets the 2A-QT-01,02,03 and 2A-QT-04,05,06 quadrupoles to appreciably lower fields than the earlier "Line A-Standard" tune.

The computer program SHUNT, which calculates the shunt voltages for magnets in P⁸, was modified to include the polarity setting (normal or reverse) of the power supply. The input was simplified and the program adapted so it could be run easily from a keyboard terminal.

Shock Tube Tests

The shock tube facility has been outfitted with access ports and instrumentation to measure the velocity of the disturbance which breaks harp wires or other windows. Results to date show that the fragments, from a 0.0127-mm aluminum window rupture, travel at about Mach 1 and are capable of breaking a 0.0127-mm aluminum window ~20-m downstream.

A fragment-free rupture diaphragm has been found. Tests using a fragment-free rush of air from rupture of this diaphragm show that the harp-breaking disturbance propagates at about Mach 3.5.

Future tests will include measuring the response time of a variety of sensors being considered for use as fast-closing valve triggers.

X. LARGE-SPECTROMETER SYSTEMS

Channel Tuneup

Installation of Floor and Pivot Plate

It was necessary to replace the existing 15-cm unreinforced floor with a new 60-cm-thick heavily reinforced floor in the area of travel of the spectrometer. The existing floor was removed, the reinforcing in the adjacent 2.4-m-thick slab was exposed, reinforcing was installed which was welded to the exposed reinforcing, and the new floor was poured. The total interruption of use of the channel was four weeks, and no significant problems for other Area A users were caused by this work.

Spectrometer Assembly

During the past quarter, it was possible to make the first full-time effort on construction of the spectrometer. We were able to fit the vacuum chamber to the poles and weld the vacuum seals to the poles. The NMR drives were assembled and fit to the vacuum chamber, and pole plugs were fabricated to fill the holes which were drilled to allow assembly of the magnet in the frame. These have now been hand finished to give a smooth surface. The rework on the coils for the first magnet (EA-BM-05) has been completed, and the first coil has been installed.

The first pions in the EPICS channel were observed early in March. For these tests, detection apparatus was set up consisting of three external delay line chambers, three dE/dX scintillators, a 15-cm E scintillator, a propane Cerenkov counter, and two ion chambers. This apparatus was sufficient to separate pions from protons, muons, and electrons, and to measure the phase space of the beam. To date, pion energies of 67.5, 151, and 225 MeV have been studied. At 67.5 MeV, the E counter nicely separates the particles. Time-of-flight is also available using the 200-MHz rf structure of the beam and the 15.25 m of the beam line as a flight path. The EPICS channel is not isochronous. Therefore, it is necessary to measure the angle of the trajectory of each event and correct the TOF for path length differences. Time resolution of 500 ps FWHM was obtained, which was sufficient to separate pions from background at all three energies. The beam intensity and contamination observed are given in Table X-I. The chamber information was used to give beam profile and divergence information. All results to date are consistent with performance of the optics as designed.

The separator was used in the tuneup work, and a rejection factor of >100:1 for protons was observed. Although we were able to make the separator run for the tests, we have problems with the power supply.

TABLE X-I

PRELIMINARY DATA ON PERFORMANCE OF EPICS PION CHANNEL WITH SEPARATOR ON

Energy (MeV)	Polarity	Count Rate (Scaled to 1-mA and 3-cm target)	Fraction of Beam			
			π	μ	e	p
67.5	+	2.1×10^7 /s	0.60	0.25	0.16	0.01
151.0	+	1.2×10^8	0.71	0.08	0.11	0.03
255.0	+	2.5×10^8	0.78	0.09	0.05	0.05
67.5	-	7.8×10^8	0.44	0.17	0.25	--
151.0	-	2.7×10^7	0.78	0.05	0.14	--
55.0	-	1.6×10^7				

There are frequent tripoffs due to electronics problems, and the regulator has not been able to operate without causing frequent faults. Because of these problems, we have decided to procure a new commercial high-voltage supply which should be delivered in the fall of 1976.

A major accomplishment of the tuneup was the use of the software which will later be used with the spectrometer. Program Q (which does the CAMAC handling), ALLTEST (which does fast logical tests), WORKER (which does histogram and display manipulation), and an event analyzer were used together for the first time. This worked extremely well, and no major changes are needed to take data for any of the experiments which are planned with the spectrometer. During most of the tune-up runs, 40 spectra were simultaneously acquired, and since each run was on the average of a half hour, a great quantity of data which specifies the operation of the channel is available.

We have now begun plans to handle the large quantities of data that will be acquired with the spectrometer. The immediate problem to be solved is handling the large number of tapes required, estimated to exceed 5000/year. We are considering purchasing a nine-track tape drive capable of writing at a density of either 1600 or 6250 bits per inch. Such a tape drive would reduce the number of tapes required by a factor of 4 or 16 depending on which density is selected. The EPICS users are being consulted for their advice on this matter and a decision is expected in midsummer.

High-Resolution Proton Spectrometer

Following completion of the rigging of the spectrometer dipoles in late January, the quadrupole was installed and preparations begun for alignment of the system. The alignment required fixtures for transferring the load of each dipole from its support bearings as well as fixtures for their subsequent repositioning. The initial rigging of the dipoles achieved locations to better than 2 cm, and the final alignment of the system met typical positional tolerances of ± 0.125 mm and angular tolerances of ± 0.5 mr for the various degrees of freedom of both dipoles.

A variety of installation work was also carried out during this period. The pivot-point platform which rotates with the spectrometer was finished. A con-

siderable amount of work was spent on the catwalk structure, including floors for the second and third levels. The stairway and frame elevator for the top two levels have been installed and are now operable. The 2-ton spectrometer jib crane was installed on the third level together with the outer TOF support structure. The drive and the interlock system for the outer TOF detectors has been run, and all signal and high-voltage cables have been installed.

The remote positioning and support structure for the inner TOF system has been built and delivered by the Univ. of Texas. It has been installed on the exit side of the MWPC box. The detector box has been surveyed, and 0.0254-mm Kapton windows have been made and installed at both entrance and exit to contain the helium gas atmosphere. The vacuum-to-air interface at the end of the spectrometer occurs right in front of the detector box and consists of a dacron/Kapton combination window having thicknesses varying from ~ 30 -50 mg/cm². Two such windows are currently being fabricated at UCLA. This window is followed by a thin section of air of about 5-cm thickness before the entrance window of the detector box. This thin section serves as an additional level of protection for the chambers during operation and also allows a mechanical shutter to be inserted for further protection against vacuum failure when beam is not being run into the spectrometer. Final vacuum tests on the spectrometer can begin as soon as this window is built and tested to hold 50 psi.

The spectrometer cable bridge, which routes all dc power cable from the supplies in the B/C equipment building to the magnets, has been installed and terminations made at the magnets. A considerable amount of control and interlock wiring remains to be done, however. The spectrometer pump and heat-exchanger package is installed and has been checked. We have run this package with the spectrometer, excluding H₂s, and the system is now leak tight at full operating pressure. We expect to power the spectrometer by mid-June and finish supply calibrations thereafter.

Area C and Beam Line

The Area C shield door was installed at the end of this quarter and is now in routine operation. Because this weighs in excess of 85 metric tons, a 600 CFM air compressor is currently being used to operate it until the spectrometer air system becomes available. Following installation of the shield door, beam was

run into the area for the first time since the great shutdown for one shift during cycle 2. This time was spent in reestablishing what we had accomplished previously with the exception that the complete run-permit chain could be made up. Initial insertion of the stripper at the end of Line X resulted in a beam which was centered in both x and y at the end of the twister section. Use of the new stripper configuration in Line X showed a significant improvement in the ease with which pencil beams could be created as well as in their time stability. The largest time variation in the current in the pencil was due to the momentum stripper where there was a rather characteristic oscillation observed. Current levels going into Line C without a stripper were high enough that coarse beam tuning was possible without a stripper. The high background level from Line X could result from the tune or obstructions in the SY such as partially inserted wire-scanners. For a 100-nA average current in Line X, the average background going through Line C at 800 MeV was measured to be ≤ 1 nA. Related modifications such as an additional beam plug at the beginning of Line C are in progress.

The spectrometer drive control and interlock system has been built and is currently being used to run the tests on the sliding-seal curtain and curtain rod transfer mechanism on the scattering chamber. A forming die and welding fixture for fabricating the 0.25- to 0.40-mm stainless curtains has also been designed and built. Vacuum tests on the scattering chamber using these windows have shown no leaks although, so far, the current effective vacuum loads have not allowed us to move the curtains.

The first complete Line C ISIC has been built and tested with the final electronics and software. The system is designated LC-II-02 and has a 15 by 5-cm sensitive area ($x \times y$) based on 100 wires with a 2-mm spacing. Figure X-1 shows a plot taken using a 10-mCi ^{90}Sr source and the chamber filled with argon. Because of the windows and the distance to the source, the profiles are broad with the vertical having a somewhat higher peak intensity because it is in front of the horizontal. The repeated traces show the reproducibility in the raw minus the background data taken with the HRS PDP-11/45 system using individual wire integration times of a few seconds. The rising data at the extremes of the horizontal profile are due to charging of wires adjacent which are neither read nor reset to ground. This effect was eliminated in the vertical trace by shorting the five adjacent wires on either side of the active wires.

Work has been completed on the 16-channel, remotely programmable delay unit and its CAMAC control module shown in Fig. X-2. Each of the 16 independent logic-delay channels provides up to 101 ns of delay for NIM pulses in steps of 1 ns. Each of these delays can be set locally at the delay unit or remotely using the CAMAC unit which allows front panel manual or computer selection of any delay channel and setting of its delay. Individual delay settings over the full range show $< \pm 1$ -ns maximum accumulated error from their nominal settings for typical NIM pulse widths down to 6 ns FWHM and instantaneous repetition rates up to 50 MHz. Pulse-width variations between input and output vary less than ± 1 ns for the same pulse widths and rates. The unit will pass pulses down to ≤ 4 ns FWHM and instantaneous repetition rates > 100 MHz. These characteristics compare very well with conventional cable-delay boxes as illustrated in Fig. X-3.

A target-thickness gauge has been designed and constructed in collaboration with the Univ. of Texas to measure the uniformity of large-area targets to better than 0.1% (Fig. X-4). The technique employs the nearly perfect exponential dependence on target thickness of the transmission of the total beta spectrum of ^{147}Pm for target thicknesses between 1 and 30 mg/cm². The apparatus consists of a target mounted on the arm of a standard HRS beam-line scanner sandwiched between a 1-mCi point source (1-mm diam) and a 3.8-cm-diam, 0.32-cm-thick piece of NE111 mounted on a photomultiplier tube. The scanner and counting electronics may be operated manually or via the HRS PDP-11/10 computer. The figure shows the results of some measurements made

Fig. X-1.

ISIC plot for a 75 by 25 wire system having a 2-mm wire spacing. A 10-mCi ^{90}Sr source was used with argon gas in the chambers.

with a 11.4-mg/cm² target of pyrolytic graphite (¹²C) of transverse dimensions 4.4 by 11.4 cm supplied by Pfizer, Inc. Plotted is μ m for three scans across the target in the long dimension. The quantity μ is the mass absorption coefficient (~ 0.155 cm²/mg), and m

is the target thickness (mg/cm²). It is apparent from the figure that the device is ideal for mapping local thickness fluctuations for extended area targets having thicknesses typical of those to be used for the HRS.

Fig. X-2.

Remotely programmable delay unit and control cable with 26 twisted pair and CAMAC module with memory and delay cards for one channel.

Fig. X-3.

Oscilloscope traces for:

- (A) LRS 621 discriminator output pulse (minimum width) and delay unit output (flat-top pulse) for this input. Delay setting is 99 ns.*
- (B) LRS 621 output pulse and pulse from commercial cable delay for that input. Delay setting is again 99 ns.*
- (C) Trace A with a continuous pulse train separation of ~25 ns for the same delay setting.*
- (D) Trace B with a continuous pulse train separation of ~25 ns for the same delay setting.*

Fig. X-4.
 Target thickness as a function of position for
 three different vertical positions.

XI. RESEARCH

Tests, Data Runs, and Analyses of Experiments

Breakup of Few-Nucleon Systems and Nuclei (Exp. 42)

(LASL, Univ. of Southern California, Univ. of California at Santa Barbara)

This experiment studied the break-up reactions ${}^m\text{Li}(p, \text{pd})\text{X}$, $m = 6$ and 7 , $y = p, d$, and t . Subsidiary studies of p - p , p - d , and p - t elastic scattering using CH_2 , CD_2 , and titanium-tritide targets were also made. Protons were detected by a magnetic spectrometer using four helical-wire proportional chambers. Heavy particles were detected in a conjugate telescope using a single helical-wire proportional chamber for position and an eight-element intrinsic germanium telescope for energy measurements. Appropriate scintillator trigger logic constituted the signature of the event.

Data taking was completed in January 1976. The activities of this quarter centered around the data reduction of the ${}^6\text{Li}(p, \text{pd})$ measurement at two quasi-free scattering angle pairs. Related analyses on the "free" p - d elastic-scattering data and a ${}^6\text{Li}(p, \text{pd})$ measurement at a nonquasi-free angle-pair were also performed.

A number of constraints designed to select the events for which protons were bent through the spectrometer and deuterons were stopped in the germanium telescope were applied to the raw data. One of the more time-consuming parts of the analysis to date has been the rejection of events involving multiple scattering or nuclear interactions in the germanium telescope. For the preliminary results given below, all such events have been rejected except those where relatively small quantities of energy are not properly collected in the germanium telescope.

Figure XI-1 illustrates a typical missing energy spectrum for the ${}^6\text{Li}(p, \text{pd})\text{X}$ reaction at the quasi-free scattering angle pair $\theta_p = 30^\circ$, $\theta_d = -62^\circ$. The dominant feature of the spectrum is a peak centered at 1.5 MeV which corresponds to X representing a ${}^4\text{He}$ nucleus in its ground state. The 1.5-MeV shift corresponds to the binding energy of an α - d cluster in ${}^6\text{Li}$ (Ref. 1). Of course, this binding energy is unique, the width of the peak in the missing energy

Fig. XI-1.

Missing energy spectrum for the ${}^6\text{Li}(p, \text{pd})$ reaction at $\theta_p = 30^\circ$, $\theta_d = -62^\circ$.

spectrum arising largely from the momentum resolution ($\sim 1\%$) of the magnetic spectrometer.

The smaller peak centered at 32 MeV corresponds to X representing a ${}^4\text{He}$ nucleus with ~ 30 -MeV excitation. Since the ${}^4\text{He}$ binding energy is ~ 20 MeV, one expects to observe a continuum of events extending in missing energy from ~ 22 MeV on up corresponding to breakup of the ${}^4\text{He}$ nucleus during the reaction process. Apparently, contributions to the spectrum from this source are very small. Preliminary analysis of the ${}^6\text{Li}(p, \text{pd})$ reaction for the nonquasi-free angle-pair ($\theta_p = 40^\circ$, $\theta_d = -59^\circ$) yields a missing energy spectrum in which the areas under the ground-state and excited-state peaks are roughly equal. This is in agreement with the work of other investigators² in their studies of $(\pi^+, 2p)$ and $(\pi^-, 2n)$, as well as other quasi-free knockout reactions.

The momentum distribution of recoil ${}^4\text{He}(\text{g.s.})$ particles obtained from the data at the $\theta_p = 30^\circ$, $\theta_d = -62^\circ$ angle-pair is shown in Fig. XI-2. A preliminary

fit to the recoil momentum distribution with a Gaussian yielded a FWHM of 100 MeV/c in plane-wave impulse approximation (PWIA). This value can be compared to the recent results at 590 MeV (120 MeV/c, PWIA) from SREL³ and 100 MeV (72 MeV/c, DWIA) from Maryland.⁴ The extraction of the α -d spectroscopic factor awaits careful normalization of the differential cross-section data.

Study of Neutron-Proton and Proton-Proton Coincidence Spectra from $pd \rightarrow npp$ Reaction (Exp. 81)

(Rice Univ., Univ. of Houston)

The analysis of the data taken for Exp. 81 in 1974 is now complete, and the results are either published

or in final preparation for publication as shown in the previous progress report.

While the first phase of Exp. 81, performed during 1974, emphasized proton-induced deuteron break-up reactions, preliminary data were obtained for pion production from hydrogen and deuterium.^{5,6} These data illustrated the significance of the study of pion-production processes and the feasibility of our experimental technique for such a study at LAMPF. As a result, the second phase of Exp. 81, starting January 1976, was devoted to a systematic investigation of reaction mechanisms for π^+ and π^- production from light elements ($\leq {}^6\text{Li}$). The experimental apparatus was basically the same as before,⁵ but with some modifications so that certain phase-space regions of interest could be reached. The 18D40 spectrometer was placed in "C" configuration, which enabled the magnet arm to be set at more forward angles (smallest angle 14°). This is crucial for measuring reactions (2) and (3) (below), and pion production from deuterium and ${}^6\text{Li}$. There was also an improvement made in the MWPC system. A third wire-plane coordinate rotated 45° was added to the standard x-y MWPC in front of the spectrometer. This additional coordinate made it possible to identify uniquely two charged particles passing through the spectrometer, simultaneously, and with low relative momentum.

Pion Production from Hydrogen.

The primary goal of the present experiment was to complete the study of pion production from hydrogen, which began in 1974, and proceed with pion production from other more complex nuclei. The previous data⁵ show that at 800-MeV incident energy, the following reaction mechanisms for production of positively charged pions in proton-proton collision have a high probability.

where Δ^{++} is the $3/2, 3/2$ (1236) isobar, and d^* is the neutron-proton system with low relative energy.

In order to provide a more stringent test of theoretical models for pion production from

Fig. XI-2.

Recoil momentum distribution for the reaction ${}^6\text{Li}(p,pd){}^4\text{He}$ at $\theta_p = 30^\circ$, $\theta_d = -62^\circ$.

hydrogen, reaction (1) was studied in detail at kinematical conditions which allowed observation of the Δ^{++} resonance isolated from contributions of other reaction mechanisms. The differential cross section for Δ^{++} production was measured at six $p-\pi^+$ angle-pairs by detecting the proton in the magnet ($15^\circ - 58^\circ$) and the pion in the TOF arm. The Δ^{++} decay was observed via $p-\pi^+$ and $n-\pi^+$ coincidence measurements with the π^+ passing through the spectrometer and the proton and neutron detected in the TOF arms. One additional measurement was undertaken at an angle-pair ($\theta_p = 20^\circ, \theta_\pi = 22^\circ$) where the center of the Δ^{++} ($3/2, 3/2$) resonance overlaps with the Δ^+ ($3/2, 1/2$) resonance so that possible interference between these two resonances can be investigated.

The study of the two-body reaction $pp \rightarrow d\pi^+$ is of particular interest due to its importance in testing fundamental principles of particle physics; this reaction also represents one of the highly probable reaction mechanisms for pion production on hydrogen and, as our data show, has a significant role in explaining pion production from other nuclei (deuterium and ^6Li). The angular distribution of deuterons from the reaction $pp \rightarrow d\pi^+$ was measured over the entire angular region allowed by the geometry of the experiment (Table XI-I). The deuteron momentum was determined by the magnetic spectrometer, while the TOF of the pions was measured in the straight arm. It would be more desirable to detect the pions in the magnet since they have a larger angular spread than the deuterons. However, this is not possible because, in that case, reaction (2) could not be distinguished from reaction (3). Therefore, the production of d^*

was measured at the same conditions as the $pp \rightarrow d\pi^+$ reaction, only the magnetic field of the spectrometer was reduced to allow detection of the lower momentum protons coming from the decay of d^* . Some preliminary results are shown in Fig. XI-3, where the measured proton momentum distribution has been divided by the experimental momentum acceptance. The enhancement of the cross section occurs at the minimum of the $n-p$ relative energy (dashed curve), confirming the occurrence of a d^* . The broad peak next to the d^* enhancement represents the Δ^{++} resonance which is present at all five angle-pairs, but is separated well enough to observe the isolated d^* .

To obtain more complete information about the pion production via the nucleon-nucleon final-state interaction [reaction (3)], data were also taken for the reaction

The momentum distribution of the singlet "diproton" was determined by the spectrometer at 14° . Figure XI-4 shows the missing mass of the reaction which corresponds to the mass of the neutral pion.

Fig. XI-3.

Proton momentum distribution from the reaction $pp \rightarrow p\pi^+n$.

TABLE XI-I

ANGULAR DISTRIBUTION OF DEUTERONS FROM THE REACTION $pp \rightarrow d\pi^+$

Deuterons (degrees)	Positive Pions (degrees)
11.5	20.8
12.8	25.0
13.8	30.0
14.7	40.0
14.4	50.0

Fig. XI-4.
Missing mass distribution.

The experimental investigation of pion-production mechanisms from hydrogen was completed by performing a "single-arm" experiment in which only the π^+ momentum was determined by magnetic analysis from 15° to 58° in the lab. These data contain all the three reaction mechanisms described above, with reaction (1) producing a broad peak, and reactions (2) and (3) being represented by one narrow peak at the maximum pion momentum (Fig. X-8, LA-6195-PR, p. 57).

An attempt to measure double pion production from hydrogen was made by measuring the π^- angular distribution in the spectrometer arm. The preliminary results indicate that the yield is higher than predicted in the literature.⁷ Due to limited time, the angular distribution is not complete and the statistics are low.

Pion Production from Deuterium.

Besides the fundamental interest in understanding the mechanisms of pion production, pion production from deuterium is particularly interesting

because at 720 MeV (Ref. 8) the inclusive pion-production cross section is less than the sum of inclusive pion-production cross sections from proton-proton and neutron-proton collisions.

Under the assumption that positive pions are produced mainly as a proton-proton interaction through the two-body reaction $pp \rightarrow d\pi^+$, leaving the neutron in the target deuteron as a spectator, the reaction

was measured at the same kinematical conditions as the ones given in Table XI-I. In addition, data were taken at $d-\pi^+$ angle-pairs where the neutron is no longer at rest but removes momentum from the reaction. The preliminary analysis of the data indicates that this reaction mechanism is very strong and probably accounts for a large fraction of the total pion production from deuterium at 800 MeV.

Angular distributions of both π^+ and π^- from deuterium were measured in an inclusive "single-arm" experiment from 15° to 58° . The π^+ results of this measurement will be compared with reaction (5) to observe whether the reaction mechanism described above is the dominant mechanism for pion production from deuterium at 800 MeV.

Pion Production on ^6Li .

The fact that the wavelength of an 800-MeV proton is much smaller than the radius of the simplest nucleus, deuterium, leads to the idea that pion production from ^6Li (and possibly other light nuclei) can also be explained as proceeding via the reaction $pp \rightarrow d\pi^+$ leaving the rest of the ^6Li nucleus as a spectator in the lab (Fig. XI-5). In order to test this

Fig. XI-5.
Feynman diagram for the reaction
 $^6\text{Li}(p, d\pi^+) ^5\text{He}$ or $^6\text{Li}(p, d\pi^-) ^5\text{Li}$.

idea, the deuteron angular distribution from the reactions

and

was measured by detecting deuterons in coincidence with pions at the same conditions as in Table XI-I. Some preliminary results are given in Fig. XI-6 where the measured deuteron momentum spectrum is divided by the experimental momentum acceptance of the system. A strong enhancement in the cross section occurs at the minimum of the "spectator" mass five systems as expected. The broad structure under this peak could be caused by four-body breakup reactions and phase-space effects. Figure XI-7 represents the momentum distribution of the "spectator" itself, with a maximum at its lowest value. This spectrum has also been corrected for the solid angle.

Reactions (5) and (6) are almost kinematically identical and cannot be distinguished in the present experiment, since the charge of the pion cannot be determined by measuring only its TOF. Furthermore, excited states of ${}^5\text{He}$ and ${}^5\text{Li}$ are also kinematically allowed, but our momentum resolution ($\sim 1.2\%$) is not sufficient to separate their contribution.

Fig. XI-6.

Momentum distribution of the "spectator" ${}^5\text{He}$ in the reaction ${}^6\text{Li}(p, d\pi^+){}^5\text{He}$, ${}^6\text{Li}(p, d\pi^-){}^5\text{Li}$.

Inclusive pion production of both π^+ and π^- from ${}^6\text{Li}$ was measured with the magnetic spectrometer, in an angular range of 15° to 58° .

Quasi-free Reaction on ${}^6\text{Li}$.

The favorable characteristics of the 800-MeV proton beam at LAMPF, its high energy and angular resolution, and its short wavelength were also used to investigate the quasi-free reaction on ${}^6\text{Li}$. A large amount of data exploring the structure of ${}^6\text{Li}$ by measuring various quasi-free reactions exists in the literature at other incident energies. Although most of the data confirms the validity of the (α -d) cluster model of ${}^6\text{Li}$ (Ref. 9), some of the data seriously disagree with simple shell-model predictions.¹⁰

We have measured the proton-proton and deuteron-proton quasi-free scattering reactions

and

by measuring p-p and d-p coincidences at five angle-pairs.

Fig. XI-7.

Measured deuteron momentum distribution in the reaction ${}^6\text{Li}(p, d\pi^+){}^5\text{He}$, ${}^6\text{Li}(p, d\pi^-){}^5\text{Li}$.

The cross sections for p-p and p-d elastic scattering necessary for the analysis of the present data were measured by our group in the first phase of Exp. 81 in 1974, and are in preparation for publication.

Low-Energy π -p Elastic Scattering (Exp. 96) (LASL, Arizona State Univ.)

We are continuing the analysis of the data from the last run of Exp. 96. Data with π^- of 50-MeV kinetic energy has been examined. Approximately 10 000 events consistent with $\pi^- p \rightarrow \pi^- p$ remain after all cuts. Detailed examination shows that, for this condition, the 15% correction for MWPC inefficiency and multiple-track solutions can be made to better than the 10% level of the correction (i.e., to 1.5% overall uncertainty). The elimination of non-pion events from the target region on the basis of pulse height in energy loss and total energy counters may be cutting into the pion signal at the ~5% level. We are presently trying to reduce our uncertainty of this correction.

The Monte Carlo program which simulates the geometry of our acceptance has been reworked. The largest change has gone into the simulation of $\pi \rightarrow \mu$ decays from scattered pions. Now π s are allowed to decay anywhere along their path, and the resulting μ s are traced through the chambers and counters to get the numbers which would be accepted. This correction can be at the 8% level for 70-MeV incident pion energy.

Studies of the beam composition and pion flux have been continuing. Examination of the composition monitor data as a function of momentum bite of the channel gives the pion flux after pileup correction. At 40 MeV, the uncertainty of the pion flux is estimated to be 2%. The biggest problem that remains now is the determination of the density of the H_2 gas in the pressurized, cold target vessel.

We are currently building the apparatus for the next phase of the experiment. Each scattering arm will consist of four wire chambers with two coordinate delay line readouts each and packages of energy loss and total-energy counters. The design of the counters is optimized for 30 MeV. An additional total-energy counter will be added for higher energies.

Two designs for the liquid H_2 target are under study. One design, a cylindrical flask 3-cm long and 5 cm in diameter, minimizes all uncertainties with respect to beam divergences but puts non- H_2 material very close to the beam. The other design, 2-cm long and 15 cm in diameter, rotated at 45° with respect to the beam, has little non- H_2 material near the beam but requires accurate knowledge of the rotation angle of the target and a good measurement of the beam centroid and divergences. Both target designs incorporate a liquid H_2 flask with parallel ends suspended inside a 1-atm gas H_2 flask.

Measurement of the Cross Section for $\pi^- + p \rightarrow \pi^- + \pi^+ + n$ with a Magnetic Spectrometer (Exp. 99)

(Colorado Coll., Univ. of Virginia, LASL,
Massachusetts Inst. of Tech., Univ. of Wyoming)

The new preamps and amplifiers are complete, tuned, and ready to go. Counters for four beam-monitoring telescopes are finished. Frames to support them are being built. A support structure for the ion chamber and upstream beam-profile monitor is under construction. Both beam-profile monitors are ready.

Programming work has been held up waiting for a disk system for our computer, but has, with the arrival of the needed equipment, just this week been started again.

Proton- and Pion-Induced Fission of Medium-Mass Nuclides (Exp. 104) (Simon Fraser Univ.)

Progress on this project was interrupted by the absence of the graduate student, but is now resumed.

Scanning is under way of micas exposed to fragments produced in the proton-bombardment of silver, gold, and uranium targets at 500 and 800 MeV. Two experimental configurations were employed — the target sandwiched between two mica sheets (necessitating three-dimensional scanning) and the micas deployed around the periphery of a scattering chamber (for which the easier two-dimensional scanning is satisfactory).

Problems encountered with three-dimensional scanning, namely extraction of erroneous fissioning-system mass and erroneously high center-of-mass energies, have been traced to mechanical stress of the mica sandwiches during scanning, and to the need for additional calibration data for the response of mica detectors to ions heavier than silver. Accordingly measures have been adopted to counter the stress effect, by weighting down the sandwiches on the microscope stage; in addition, bombardments have been conducted at Chalk River Nuclear Laboratories, Ontario, of mica detectors with ^{127}I and ^{197}Au ions in the energy range of interest, via previously established techniques.¹¹ These micas are now being scanned.

Two-dimensional scanning of the micas from the "scattering chamber" experiments involving gold and uranium targets are almost complete, and exploratory analysis of the data is proceeding with a view to extracting fission energies, center-of-mass motions, and moments of inertia.¹² The results of calculations performed at LAMPF (and supplied through the courtesy of CNC-11) for the distributions in nuclear charge, mass, and angular momentum at the end of the prompt cascade from 500-MeV protons plus gold target nuclei are employed in this analysis.

Comparison is proceeding of the above results from mica measurements at LAMPF with results from conventional Si(Li) detectors for fission of gold and uranium with 500-MeV protons at TRIUMF. This is intended to verify the mica scanning and analysis techniques before the tedious scanning of the micas from the (more important) silver fission experiments is undertaken.

These latter data will be completely reduced before pion bombardments at LAMPF are requested. Results of the LAMPF prompt cascade calculations indicate that higher average angular momenta are populated by the interaction of 500-MeV π^+ with gold target nuclei; the effect of this on parameters of fission reactions induced by such projectiles should prove interesting.

Nuclear Spectroscopy of Proton-Induced Spallation Products (Exp. 105) (Idaho National Engineering Lab., LASL)

Decay of ^{131}Ba . Our study of the decay of (^{131}Ba , 11.7-d) has been completed. The ^{131}Ba samples were

produced by proton bombardment of praseodymium-metal foils in the Area B Nuclear Chemistry Irradiation Facility of LAMPF. Following irradiation, the active foils were shipped to INEL, where chemical and isotopic separation was carried out to produce samples of pure ^{131}Ba . Extensive γ -singles and γ - γ coincidence experiments were carried out.

As a result of the present investigation, a number of previously unreported γ rays have been identified, and the existence of additional energy levels at 919, 1170, and 1341 keV has been established. These data help to clear up a previously unresolved question concerning the Q-value of the ^{131}Ba decay. The only reported measurement of this decay energy gave the value 1165 ± 15 keV (Ref. 13). However, in their 1971 Atomic Mass Evaluation, Wapstra and Gove¹⁴ point out that this value is ~ 200 keV lower than that computed from other mass-related information. Our observation of the 1341-keV state clearly indicates that the Q-value must be at least this large and thus sets a lower limit on it. To obtain a value for this decay energy, we have measured the electron capture to positron intensity ratio for the strong ($\sim 20\%$) transition to the 216-keV level, this ratio being quite sensitive to transition energy in this energy region. This was done by looking for 511-keV annihilation radiation in the spectrum of γ radiation in coincidence with the 216-keV γ ray. From these data, we deduce a value of $(4.7 \pm 2.3) \times 10^4$ for the e.-c./ β^+ ratio for this transition. From the tables of Gove and Martin,¹⁵ this corresponds to a β^+ endpoint energy of 134^{+10}_{-20} keV. This gives a Q-value for the ^{131}Ba decay of 1372^{+10}_{-20} keV. Recent work by Firestone *et al.*¹⁶ suggests that the experimental e.-c./ β^+ ratios differ from those calculated theoretically, sometimes by rather large factors. If it is assumed that such effects are present in the ^{131}Ba decay and that they are of the magnitude predicted in Ref. 16, a crude estimate suggests that the deduced Q-value given above may be low by ~ 100 keV.

The features of the ^{131}Cs level scheme deduced from these data are being compared with the predictions of a quasi-particle-phonon coupling model. These model calculations were carried out by G. J. Mathews¹⁷ of the Univ. of Maryland. Although this analysis is not yet completed, one of the features which has thus far emerged is that the well-known states at 133 and 216 keV are not accounted for in these calculations, suggesting that they may arise

from a mechanism other than that considered in the model.

**Measurements of "P," "R," and "A"
Parameters in $\pi^{\pm}$ -p Elastic**

**Scattering/Measurements of "D," "R," and
"A" Parameters in p-p Elastic Scattering**
(Exp. 132/160)

(LASL, Virginia Polytech. Inst. and State
Univ., State Univ. of New York at Geneseo,
Texas A&M Univ.)

These two experiments propose to measure the Wolfenstein triple-scattering parameters "R" and "A" for $\pi^{\pm}$ -p and p-p elastic scattering respectively. The magnetic spectrometer planned for these two experiments was used as a part of Exp. 42, "Breakup of Few-Nucleon Systems and Light Nuclei." The p-p, p-d, and p-t elastic-scattering results from Exp. 42 permit the evaluation of the performance of the spectrometer. One set of p-d results ($\theta_p = 44^\circ$, $\theta_d = 51.1^\circ$) has been fully analyzed. The spectrometer, mounted on the pivot arm, showed an angular acceptance of ± 25 mr as defined by the deuteron counter. For all particles included in the entire 50 mr of acceptance, the momentum spread as measured by the spectrometer was 1.2% FWHM. In a scatter plot of particle entrance angle to the magnet vs momentum, the momentum resolution was determined to be 0.8% FWHM.

A single-arm analysis awaits the absolute calibration of the shunt which measured the magnet current. However, with the constraint of the deuteron angle, it was possible to calculate the deuteron energy from the proton arm results and compare it with that observed in the germanium detector on the conjugate arm. These two ways to extract deuteron energy agreed exceedingly well.

To further sharpen the momentum resolution of the spectrometer, a pair of field clamps will be designed, fabricated, and installed for the 18D40 magnet. An improved method of impedance matching for all cathodes of the helical chambers in the spectrometer is under investigation.

The polarized target cryostat for this experiment has been tested using ^4He gas in the recirculation loop. The lowest temperature reached and refrigeration capacity for the cryostat were measured. The results, when properly interpreted in terms of ^3He in

the recirculation loop, were found to be equal to or better than the design values. A more detailed report on the cryostat is contained in the MP-7 progress report.

**Precision Measurement of the Decay Rate for
the Dalitz Decay Mode of the π^0 Meson**
(Exp. 221/222)
(LASL)

All of the long lead-time items for Exp. 221 (π^0 Dalitz decay) and Exp. 222 ($\pi^0 \rightarrow e^+e^-$) have been designed. The depleted uranium beam stop for Exp. 222 has been completed. The hydrogen target design is now final, and construction is ready to begin. The MWPCs, converters, and muon shielding are undergoing final design considerations.

We are presently designing a system of Cerenkov counters for Exp. 222 to eliminate accidental triggers from elastic π -p scattering. The Cerenkov counters now seem to be essential for good lepton discrimination. The hodoscope magnet to be used in both Exps. 221 and 222 is scheduled to be tested and mapped during the latter part of May.

Direct Lepton Production at LAMPF Energies
(Exp. 241)
(LASL, Temple Univ.)

The purpose of this experiment is to measure positron production in p-p collisions at 800 and 256 MeV to determine if a threshold exists for direct lepton production. We have completed the analysis of part of the 800-MeV data and of all of the 256-MeV data. A paper describing these results has been submitted to Phys. Rev. Lett.

Figure XI-8 shows the apparatus which was located in EPB. The apparatus was discussed in some detail in the last progress report.

At 800 MeV the major sources of positrons are Dalitz decays of π^0 decay photons. To determine the contribution from pair conversions in the material intrinsic to the apparatus, M_0 data were taken with one, two, and four radiators of 0.613-g/cm²-thick Mylar placed between the target and counter A. The positron yield in each momentum bin, after correction for empty target rates, dE/dx , and radiative

Fig. XI-8.
Plan view of the apparatus.

losses fits well to straight lines as a function of extra radiator.

The contribution from Dalitz decay is similar to the conversion of 5.85×10^{-4} of the photons; a Monte Carlo calculation which simulates the apparatus acceptance and the details of Dalitz decay and pair production is used to determine η , the relative detection efficiency for positrons from these two processes. The positron yield in excess of that due to π^0 decay is given by

$$N_{e^+} = N_0 - \Delta N / \Delta M \cdot M_0$$

$$[1 + \eta/2 \cdot \Gamma(\pi^0 \rightarrow e^+e^-\gamma) / \Gamma(\pi^0 \rightarrow \gamma\gamma)],$$

where N_0 is the positron yield with no radiators added, and $\Delta N / \Delta M$ is the positron yield increase per radiator.

The results of this calculation are shown in Fig. XI-9. The error bars represent the statistical errors and the uncertainties in the radiative corrections. Combining all of the data from $p_1 = 175$ to 310 MeV/c into a single point yields an invariant cross section of

$$E(d^2\sigma)/(dp^2) = (-14 \pm 12) \\ \times 10^{-22} \text{ cm}^2/\text{sr}(\text{GeV}/c)^2.$$

There are, in addition, systematic errors due to uncertainties in the amount of material available for photon conversion, in the value of the Dalitz ratio

Fig. XI-9.
Direct positron yields at 800 MeV as a function of the positron momentum. The inset shows the yields at 256 MeV.

and the pair cross section, and in η . The systematic errors contribute an uncertainty of $\pm 10 \times 10^{-22} \text{ cm}^2/\text{sr}(\text{GeV}/c)^2$; there is also an overall normalization uncertainty of $\sim 20\%$.

The 256-MeV data were taken well below the threshold for pion production in p-p collisions, so the only known production mechanism is via p-p bremsstrahlung. The photon yield was measured directly at 110° using the lead-glass counter and has been extrapolated to 60° using the expected angular distribution of p-p bremsstrahlung. The internal conversion coefficient for these photons is calculated using the prescription of Kroll and Wada. The net direct positron cross section is obtained by subtracting the bremsstrahlung yield from the data, corrected for conversions in the hydrogen. The results are shown in the inset of Fig. XI-9. The momentum range included is from 65 MeV/c (the lower limit of the spectrometer acceptance) to 136 MeV/c (the kinematic limit at this energy). The weighted average invariant cross section is

$$E (d^3\sigma)/(dp^3) = (-3 \pm 2) \times 10^{-32} \text{ cm}^2/(\text{GeV}/c)^2.$$

The 256- and 800-MeV data are thus consistent with no direct lepton production. Even though we explicitly assume that, at 800 MeV, all photons come from π^0 decay, the analysis technique will subtract out positrons originating from any photon source as long as the internal conversion coefficient is similar. Thus, we are not able to exclude anomalously large production of photons. In fact, at 256 MeV, the observed photon flux at 110° is three times the calculated bremsstrahlung flux. In Fig. XI-10, the 95% confidence level cross-section limits are compared with the previous data. The high-energy data fall on a universal curve as a function of $p_\perp$, while our data fall well below that curve. We obtain $e^+/\pi^+ < 2.3 \times 10^{-6}$ (95% confidence) at

Fig. XI-10.

The invariant cross section for direct lepton production as a function of $p_\perp$. The results from this experiment (95% confidence level upper limits) at both 256 and 800 MeV are also plotted.

800 MeV. Since the production mechanism for pions differs at this energy from those dominant at higher energies, the value of e/π might not be expected to be a useful way of comparing data. Nevertheless, Fig. XI-11 shows that the π^+ cross section at 800 MeV fits smoothly onto the higher energy data when plotted vs $p_\perp$, so the e^+/π^+ ratio may in fact provide a useful comparison.

The results of this experiment are substantially smaller than high-energy results and indicate a threshold for direct lepton production. This information will be extremely useful in trying to understand this unknown phenomenon.

General Research Projects

Beam-Profile Monitors

Beam-profile monitors have played an important role in the tuning of both LEP and P². One was tried at the μ channel as well, but some modifications to

Fig. XI-11.

The invariant cross section for inclusive π^+ production in p - p collisions at 90° in the center of mass.

the electronics (see below) will be needed to make the device useful there. Several more monitors have been requested with a variety of chamber configurations. Several configurations could use the same electronics. We have managed to organize their construction so that most of the work is now done by job shops.

A study of the efficacy of different integrating and memory time constants is under way. The μ channel will clearly benefit from a longer storage time, which would produce a less "jumpy" display when the number of particles per wires is small. However, not everyone would want a long storage time; had it been in use at LEP, the wobble of the target wheel might not have been discovered as easily.

Beam-on-Target Monitors

The beam-on-target monitors have been tested. They work. With the 6-cm ^{12}C target in place, the digitized output from the A-2 monitor is about 1 Hz/ μA (1 count = 10^{-10}). The 3-cm target at A-1 produces 2.5-3 Hz/ μA on the same scale. (The geometries and effective absorbers in the two setups are not alike.) A bias potential of 50 V is well onto the plateau region for these radiation levels. The chambers can be run at up to 1 kV.

The electronics needed to produce these digitized signals is simple: 1) an Ortec Current Digitizer, and 2) a bias supply — a 300-V "B" battery will do nicely. Further equipment needed to integrate these signals into the fast-protect system can now be designed.

Programming for Experiments

The off-line analysis program for Exp. 179 was completed on the terminal computer under DOS and converted later for use under the RSX operating system. The program decodes data tapes written by the MBD and produces histograms and scatterplots of variables with cuts applied to them; also produced are spectrum plots of the various isotopes which the program identifies. As the program was used, various modifications were made to include additional variables, enlarge the number of plots and cuts, and to add new latches. The program was also set up to run under DOS on the 11/20 at the site of the experiment.

The P9 program XFP9 was used to decode the first data tapes produced by Exp. 137A at the Van de Graaff. A code was then written to pick off the scalars and DVMs, scale them, produce scatterplots, and compute means and errors. A modified code allows the user to combine runs.

The analysis program for the ZGS parity experiment (137B) was extensively modified for the May 1976 run. A routine was written to decode the new tape format, new counters and variables were added, the regression was generalized, the ability to make variable cuts was added, and several variables were recomputed after regression. The program was converted to standard FORTRAN for use on the IBM370/195 at Argonne during the May run.

Some preliminary testing was done on SUPERFISH, a new rf cavity code produced in P-11, which combines a lattice technique with a tridiagonalization process for matrix inversion to solve directly for the frequency instead of using over-relaxation. Several cell geometries were set up and tested on the lattice generator and SUPERFISH. The plotting program used with the magnet POISSON code was modified to plot rf lines. A preliminary subroutine was written to compute transit time factors.

Theory

Determination of Pion-Nucleon Form Factor from Pion-Nucleon Elastic Scattering

The pion-nucleon form factor in the static Chew-Low model of pion-nucleon scattering was determined from the elastic pion-nucleon data. Crossing symmetry and the effect of the inelastic pion production channels were included. The form factor was determined up to a momentum of $k \approx 10 m_\pi$ by adjusting it to fit the pion-nucleon data. The result is shown in Fig. XI-12, denoted E-J. Also shown are the determinations by Salzman and Salzman¹⁸ and by Carter *et al.*¹⁹ Figure XI-13 shows our fit to the experimental data.

Improved Analysis of Coulomb-Nuclear Interference Experiment for Pions on ^{16}O

We developed a new procedure for analyzing Coulomb-nuclear interference experiments, in which

Fig. XI-12.

Our form factor (E-J) compared to the Salzman-Chew-Low and the Carter *et al.* determinations.

the elastic-scattering angular distribution of projectiles on nuclei is measured in the angular region where Coulomb and nuclear amplitudes are comparable in size. In contrast to conventional procedure, detailed dynamical assumptions are not required in order to extract both the Bethe phase and the forward nuclear amplitude from the data. We tested the new scheme by applying it to the ^{16}O data of Mutchler *et al.*²⁰ who provide good quality angular distributions over the angular range $5^\circ \leq \theta \leq 11^\circ$ for π^+ and π^- incident at energies near the (3-3) resonance. Our basic results are: 1) the real part of the π - ^{16}O forward nuclear amplitude vanishes at $T_\pi = 178 \pm 4$ MeV, a result substantially higher in energy than previously reported,²⁰ and 2) the extracted Bethe phase is in accord with the prediction of West and Yennie.²¹

2S State of Muonic Hydrogen

The computer code written to describe Stark mixing in mesonic hydrogen in a fully quantum-mechanical coupled-channel model has been used to investigate collisional quenching of the metastable 2S state of muonic hydrogen. Cross sections as a function of energy were computed for $2S \rightarrow 2P$ transitions (above threshold) and $2S \rightarrow 1S + \gamma$ (near and below threshold). The latter agree surprisingly well with the much cruder calculations of Mueller *et al.*²² The precise treatment of the dipole potential near the origin, where it is highly singular, remains a problem.

Fig. XI-13.

Fit to experimental results. The δ_{33} is a modified phase shift which includes some effect of inelasticities above pion production threshold.

Collisional quenching of the 2S state of muonic hydrogen will be measured in Exp. 206.

Data on the pionic x-ray experiments (Exps. 195 and 214) were taken during April. In Exp. 195, a large nuclear resonance effect has been seen in pionic ^{110}Pd , which will give significant information on the high-Z p-wave π -nucleus interaction.

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XII. NUCLEAR CHEMISTRY

Nuclear Chemistry Laboratory

Counting Room Equipment

Two additional counters have been made operational this quarter. These are heavily shielded, low-background β counters with NaI(Tl) crystal "umbrellas" operating in anticoincidence with a β -proportional counter to reduce cosmic-ray background. Background in these counters are typically as low as 1 to 3 counts per min.

New electronic components have been ordered and some received for use in a new dual-parameter Ge(Li)-Ge(Li), γ - γ coincidence system. The NIM bins, a Canberra Time-to-Amplitude converter, a pair of Canberra 8060 ACDs, and a pair of snap-off discriminators are now on hand. The heart of the system, a PDP-11/03-AA microcomputer, is expected in a month or so and will enable spectral data to be transmitted to the DAS via a CAMAC interface. The microprocessor module will accomplish all the software control for the ADC readout system (direct memory addressing for the mode, selected address increment, vectored interrupts for data readout, and local data manipulation) thereby relieving the main computer of that task. In addition to the dual-parameter function, the system will be usable as a pair of separate 4096-channel pulse-height analyzers (PHA) or a single 8192-channel PHA.

Data-Acquisition System (DAS)

Hardware problems are still plaguing several of the counting room CRT terminals. The primary cause of the problems appears to be inadequate cooling. New, higher capacity fans are on order for all the terminals.

The software development for the DAS is proceeding rapidly now that operating system RSX-11D, version 6A, and program Q6A have been installed. Programs written for version 4 have been revised to be compatible with version 6A. The installation of program Q6A required a large amount of effort due in part to the nonavailability of FORTRAN 4P for the PDP-11/40 computer. Data-acquisition programs for Exps. 67 and 150 are being

written as a beginning of a generalized operating system.

Pure Water System

Two of the three stills which have been used to produce pure water for the chemistry laboratories failed during this quarter. Because of the high cost of maintenance and high power consumption of these stills, an alternate air-free reverse-osmosis/demineralizer system purportedly capable of producing higher quality water was proposed and accepted. The components for this system have been received and will be installed early next quarter. The capability of reverting back to the still system will be retained.

Pneumatic "Rabbit" System

Considerable efforts were made to bring the "rabbit" system closer to operational status. The vastly improved 9-position diverter, the main switch gear for the system, was reinstalled in the Hot Cell and rewired for proper control from the operating console. All four receiving terminals, which were removed for modifications to their microswitch sensors, have been reinstalled and appear to be functioning properly. Larger air cylinders and position-sensing microswitches have been installed on the main air-shifters.

Much work was done to complete the line to the Energetic Neutron Station at the main beam stop. Water and mud had to be removed from the switchpit through which this line runs and a rain-proof cover was installed over the pit. Waterproof joints were installed on the air-tube segment in the pit. Before reinstalling this segment, steel plugs of graded outer diameters were drawn with a steel cable through the air tube between the switchpit and the end of the line beyond the beam stop to remove dents and other obstructing features. A slightly undersized plastic carrier was successfully blown from the Hot Cell terminal to the end of the line beyond the beam stop. The check valves and air-filter holder for the end of the line have been installed. A drive mechanism was fabricated for controlling the insertion distance of the "snake," which determines the

location of the "rabbit" carrier relative to the beam-stop source of neutrons. Also, a radiation-resistant switch to sense the arrival of the carrier at the beam-stop station was designed, fabricated, and installed on the end of the "snake." These latter items will soon be installed to make the Energetic Neutron Station operational.

To position activation targets next to the WNR facility neutron-emitting target, a "J" tube assembly has been designed, detailed, and sent out for cost estimates. This assembly will operate through the steel cover of the target crypt and be adjustable up and down and rotatable from a storage position to an irradiation position. A remotely-removable head, which will become highly radioactive, has been designed for the assembly, and the hydraulic power supply for moving the assembly has also been designed.

Theoretical Support

The VEGAS Intranuclear Cascade Program

Pion absorption for pions incident on nuclei is treated in the VEGAS program¹ by a two-step mechanism. First, the pion and target nucleon form an isobar, Δ , (excited nucleon with angular momentum and isospin 3/2):

The isobar can then scatter from another target nucleon into two nucleons:

Thus, step (1) followed by step (2) gives a simple pion-absorption mechanism. Originally the cross section for (2) above was taken to be that given by a static one-pion exchange model with a form factor of

unity. A simple experimental test of this model is the inverse reaction which leads to a model for pion production in two-nucleon collisions:

This calculated cross section is a factor of 2 greater than the observed pion-production cross section. However, by introducing a phenomenological form factor² which keeps the two nucleons apart, as they should be, the magnitude and energy dependence can be reproduced with one parameter. This improved isobar absorption cross section has been incorporated into the VEGAS program.

A sensitive test of this improved pion-absorption mechanism is given by the nucleon spectrum at 90° for pion-induced reactions on nuclei. The high-energy part of the spectrum can be produced only by the pion-absorption part of the reaction. A VEGAS calculation of the proton spectrum at 90° for 235-MeV π^+ on nickel using the old pion-absorption model gives too large a cross section of energetic protons (>100 MeV) compared to the experimental results.³ However, using the new pion-absorption model, the high-energy proton spectrum is reduced, and the calculated yield compares favorably with the experimental results.

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XIII. PRACTICAL APPLICATIONS OF LAMPE

(Summarizes work being performed under the auspices of USERDA Division of Research, USERDA Division of Biomedical and Environmental Research, and the National Cancer Institute.)

Pion Biomedical Program

Biomedical Facility

During the past quarter a number of improvements have been incorporated in the biomedical pion channel and control system. A new target mechanism has been installed and checked out, and provisions have been made for positioning the target with the computer which permit rapid target scans of the proton beam to be made. This beam profile information is useful for determining target alignment and proton beam quality. The magnet controllers have been modified for better response, and the software for setting magnet currents, cycling magnets, and displaying magnet status has been improved. Both slit systems are now installed in the channel, and control software has been written. About 80% of the channel contains a helium atmosphere. The 40-cm beam monitor at the channel exit has been reworked and reinstalled, and the dynamic range shifter for spreading the depth-dose distribution is operating. A demineralized water supply system is now available for the tissue culture laboratory and the control room humidifiers.

Experimental pion beams have been available since April 1976. The overall control system is working well, and modifications are continually being implemented to simplify operation and improve reliability.

Beam Development

One technique for flattening the pion flux profiles for therapy beams involves the use of combinations of scattering foils and collimators. A computer program BEAMFIX was written to aid in designing optimum configurations of foils and collimators. With BEAMFIX, the effect on a beam of any com-

bination of foils, collimators, and drifts can be studied.

Channel tuning studies have been directed toward developing therapeutically useful beams with emphasis on first obtaining a pion dose distribution which is flat throughout a volume 4 cm in diameter and 4 cm deep. This is a coordinated effort requiring computer code development, multiwire proportional counter measurements, and dosimetry.

Dosimetry Program

The dosimetry three-dimensional scanner is now under complete computer control (motion and data acquisition). The electrometers have been checked out and are working. Rails have been installed in the treatment room for rapidly moving and accurately positioning the scanner and phantom.

In collaboration with members of MP-9 and MP-12, the dynamic range shifter was completed and used for dosimetry experiments. The range shifter consists of a fluid-filled piston with a programmable, time-dependent motion. The motion of the piston (i.e., changing absorber thickness) alters the residual range of the pions and thus produces a depth-dose distribution different from that of the original beam. Computer codes have been written which calculate the desired piston motion needed to convert a known input beam to the desired output beam.

The dynamic range shifter has been used to produce depth-dose distributions which are flat over a range in depth of up to 10 cm. Figure XIII-1 shows three such depth-dose curves. Work is continuing on using the range shifter for other beam tunes (including input beams which are already broadened to some degree) and also for producing depth-dose distributions which flatten "biological effect" instead of physical dose.

A prototype of a TE proportional counter has been built in which the bias will be pulsed in coincidence with the 1-in-10, low-intensity beam pulses. Tests with alpha particles have begun. The system is comparable to the previous systems in terms of resolution and noise when operated in the dc mode. Initial measurements with the bias pulsed 120 times a second with a pulse width of 3 ms show reasonably shaped pulses from the preamplifier. The noise level and resolution in the pulsed mode are not yet known.

Fig. XIII-1.

Depth-dose curves produced using computer codes to calculate. Curve A is the unmodified, nearly monoenergetic input beam. Curves B and C are depth-dose curves, produced with the range shifter, which are flat ($\pm 5\%$) over 5 and 10 cm, respectively.

Dose Model Calculations

The program BUCKET has been used to determine dose distributions resulting from trial beams generated by transport calculations. Now that LAMPF is again operational, comparisons are being made with experimental dose distributions obtained with beams using the calculated channel settings. In addition, calculations have been made for range-shifted beams, which are designed to spread the treatment dose in depth over 5- and 10-cm intervals, thus providing input for experiments using the hydraulic range shifter. In the coming months, the use of BUCKET should provide an important calculational tool, in conjunction with experimental dosimetry and microdosimetry, for the development of therapeutically useful beams.

BUCKET may also be used as an integral part of a treatment-planning code, performing the dose calculations needed to generate isodose contour graphs. To this end, three features have been incorporated in the code which are necessary for treatment planning: 1) inhomogeneities in the treatment volume are included; 2) range-shifter thickness dis-

tributions to flatten the dose in depth are calculated; and 3) collimations of the beam, including edge effects, is included. Comparison with experimental data has begun for item (2) and is planned for future runs for items (1) and (3).

Further comparisons have been made with the ORNL Monte Carlo code PION, which has been modified to the rectangular coordinate system used in BUCKET. It appears that both codes calculate doses which are too high in the peak region by $\sim 25\%$. However, a comparison with new experimental data will be made to verify this. Except for a somewhat higher plateau dose obtained with PION, the two programs are in substantial agreement for the one small-field beam which has been tried to date. Collaboration with H. Wright and R. Hamm of ORNL will continue in order to provide an optimum program for inclusion in a treatment-planning code.

Treatment Planning

The computer program PIPLAN was the primary focus of treatment-planning development during this quarter. Several minor coding errors were corrected, and coding was completed to convert anatomy contour data into a three-dimensional density matrix to interface with the BUCKET dose model. To obtain high resolution with small array sizes, tissue densities were converted into 3-bit density codes, representing air, lung, fat, muscle, soft bone, hard bone, and bolus. The code is general to allow a different number of densities or a different computer wordlength by changing just two constants.

Test runs for a typical deep tumor case established several input/output changes required for clinical compatibility, for example, specification of patient position relative to the pion beam, and prompting clues to the planner during parameter input. The first of these changes was completed.

Equipment was ordered and received to modify an existing computer terminal to allow switch-selectable access to either the Biomed computer via cable or the CCF via acoustic modem.

Plans for next quarter are to install and debug the dose model and to implement the interactive version of PIPLAN.

Practical Applications Experiments

Tissue Analysis with Muonic X-Rays (Exp. 100)

Additional samples have been obtained for study with muonic x rays. Three samples of dog tissue, two simulated bone samples, and two human liver samples will be studied during the next series of experiments.

Chemical Effects in the Capture of Negative Mesons in Matter (Exp. 60)

Experiment 60 was resumed in cycle 1. Targets irradiated included sodium, aluminum, potassium, calcium, titanium, manganese, cobalt, zinc, and selenium. The metal target series has now been completed, except for chromium, which may possibly be run during cycle 3. These targets were chosen to provide comparative spectra to our 1974 metal oxide series as well as to investigate the variation with Z of the K-series intensities observed in metals with stopped kaons. Tentative plans for cycle 3 are to irradiate a series of low- Z targets, including some organic materials.

Technology Transfer

Biomedical Engineering

The treatment of spontaneous animal tumors at the Univ. of New Mexico School of Medicine has been expanded from heat (LCF) alone to combination radiation/heat therapy, in collaboration with the Univ. of New Mexico Cancer Research and Treatment Center (CRTC) personnel. Three malignant animal tumors have been treated with the combined approach; two of these have exhibited significant regression. Most of the future animal referrals

will probably receive combination treatment rather than LCF heating alone.

One human case with squamous-cell carcinoma in the base of the mouth received LCF treatments for palliation during March and April at the CRTC.

Apparatus for simultaneous hot-water heating of several transplanted mouse tumors has been constructed and supplied to the CRTC for combination radiation/heat experiments. The unit allows controlled heating of about 10 tumors on mouse feet coincident with radiation exposure.

Construction of a portable LCF generator for treatment of squamous-cell carcinoma of the eye and eyelid in beef cattle is almost completed. This unit, which is operated from a standard 12-V automobile battery, is intended for use by ranchers and veterinarians at remote locations. Tests on cattle with this type of cancer are planned for the summer.

Improved thawing techniques are needed to allow cryopreservation of kidneys and other of the larger organs. Experiments in the use of low-frequency electrical currents to thaw frozen kidneys are progressing. Best results to date have been the warming of 60-g canine kidneys from -40°C to 0°C in ~ 100 s with approximately uniform temperatures. (Microwave thawing techniques normally thaw the surface, but leave the center of the organ frozen for 5 to 8 min.) Discussions have begun with CRTC personnel concerning the possibility of testing the viability of kidneys which have been thawed with this technique.

Proton Radiography

The theory of multiple coulomb scattering for low- Z elements has been examined in detail after mistakes were uncovered in earlier published analyses. The appropriate atomic form factors have been integrated for input to Moliere theory. Atomic binding energy effects are being investigated. Differences in the effects of normal and tumor tissues on both proton and x-ray attenuations have been calculated.

XIV. MANAGEMENT

Budget and Personnel Levels

The ERDA financial plan for FY 1976, allocating \$18.5M for LAMPF, was received late in February.

Total operating costs to date essentially agreed with the budget forecast. About 85% of the capital equipment allocation has been obligated. The average number of full-time-equivalent employees chargeable to the medium-energy/physics program is 346, slightly less than forecast.

Experimental Program

From start-up of accelerator through this report period, 28 experiments have received beam. To date, the following experiments have been completed:

- 26 "Neutron Time-of-Flight Experiment at Beam Stop"
L. R. Veaser, Spokesman
- 34 "Elastic Scattering of π^+ on Deuterons"
R. C. Minehart, Spokesman
- 42 "Break-up of Few Nucleon Systems and Nuclei"
R. K. Cole, Spokesman
- 79 "Calibration of the Pion Beam Transport Systems and a Pion Beam Monitor"
G. C. Phillips, Spokesman
- 84 "Quality of Meson Radiation Fields"
G. C. Phillips, Spokesman
- 102 "Excitation Functions and Angular Distribution Recoil Studies of Simple Pion Induced Nuclear Reactions"
S. S. Markowitz, Spokesman
- 125 "Elastic Neutron-Proton Back Angle Differential Cross-Section Measurements 300-800 MeV"
B. D. Dieterle, Spokesman
- 128 "WNR Storage Ring Stripper Experiment"
T. D. Hayward, Spokesman
- 129 "Pion Production in Neutron Proton Collisions"
D. M. Wolfe, Spokesman
- 143 "Study of the Radiobiological Properties of Negative Pions"
M. M. Kligerman and E. A. Knapp, Spokesmen
- 148 "Neutrino Electron Elastic Scattering at LAMPF (A Feasibility Study)"
F. Reines, Spokesman
- 153 "Investigation of Nuclear Gamma-Rays Resulting from In-Flight Pion and Proton Reactions"
R. A. Eisenstein, Spokesman
- 162 "Studies of the (π^+, π^+) Reaction on Light Elements"
A. I. Yavin and J. Alster, Spokesmen
- 163 "Investigation of Changes in Charge Distributions for Nuclei near $Z = 28$ by Electron Scattering and Muonic X-Rays"
R. B. Perkins and E. B. Shera, Spokesmen
- 165 "Muonium Formation in Helium and Other Rare Gases"
V. W. Hughes, Spokesman
- 167 "Heavy Fragment Formation Following the Absorption of Negative Pions in ^{12}C "
K. O. H. Ziach, Spokesman
- 169 "Proton Irradiations for Project JUMPer"
C. J. Orth and J. E. Sattizahn, Spokesmen
- 170 "Study of the Reaction $^{12}\text{C}(\pi^+, \pi^+)^{12}\text{N}$ (Ground State)"
J. Alster, Spokesman
- 175 "Search for the Formation of Muonic Helium (μHe)"
V. W. Hughes, Spokesman

189 "Search for Condensed Nuclear States and Study of High q^2 Low v Nuclear Interactions"
O. B. Van Dyck, Spokesman

192 "Measurement of the Emittance Growth in H Stripping"
T. D. Hayward, Spokesman

198 "Effects of Pions on DNA of Nondividing Cell Systems"
G. E. Powers, Spokesman

207 "Measurement of Neutron Spectrum and Intensity Resulting from π Capture in Water Phantom and Human Tissue"
J. C. Allred and J. N. Bradbury, Spokesmen

209 "Pion Interactions in Nuclear Emulsions"
J. C. Allred and J. N. Bradbury, Spokesmen

210 "Isotope Production Facility Irradiation: Vanadium, Molybdenum, and Lanthanum Targets"
H. A. O'Brien, Spokesman

211 "Neutron Irradiation of Copper Single Crystals"
V. W. Green, Spokesman

241 "Direct Lepton Production at LAMPF Energies"
C. M. Hoffman and R. E. Mischke, Spokesmen

255 "Measurement of $\sigma(\theta)$ for n-p Elastic Scattering at 460 MeV"
L. C. Northcliffe, Spokesman

Safety

Group H-3 has assigned a safety engineer to assist the LAMPF Health & Safety Office (HSO) on a half-time basis. Group H-5 will soon provide personnel to staff LAMPF for industrial hygiene problems on a full-time basis.

Radiological Safety

Individual as well as total man-rem exposures continued at acceptable levels. Excluding craft workers, 186 LAMPF-associated personnel received 26 man-rem during January, February, and March. The maximum individual exposure was 1.25 rem. Craft personnel were not included in this figure because many received exposures at areas other than LAMPF.

Twenty-six operational plans for work involving radiation were reviewed and approved this quarter.

Recent site surveys showed a larger-than-expected number of untagged radioactive items (e.g., nuts, bolts, scrap metal). Several measures were taken to correct this situation, as well as to minimize the possibility of such items leaving the site as clean material. By means of safety meetings and memorandums, site personnel were reminded of the proper procedures for handling radioactive material. Certain waste containers, used for disposal of clean refuse, were locked; all material is monitored before placing it in these dumpsters. Monthly site surveys were continued.

Discussions were held with Group R-2 personnel concerning the installation of a sensitive gamma detector system to monitor vehicles as they leave the LAMPF site. Preliminary tests show that a 25-mR/h source can be detected in a vehicle traveling up to 40 mph (64 km/h) at a distance of ~3.5 m. For additional sensitivity, the crystal will be mounted beneath the road surface. A signal from the unit will provide an alarm in the guard station and actuate a stop light.

Procedures

The following safety procedures were updated and distributed:

- 1) General Lock and Tag Procedures;
- 2) Procedures for the Control and Handling of Induced Sources, Research Sources, and Irradiated Materials;
- 3) Procedures for Packaging, Transfer, and Shipment of Radioactive Materials;
- 4) LAMPF Radiological Safety Procedures;
- 5) Summary of Safety Rules and Procedures.

A temporary procedure for operation of the RADIP facility was prepared.

Safety Committee Meetings

The following safety committee meetings were held this quarter:

LAMPF Safety Committee — Major topics covered were: radioactive material control, tours for visitors, hard-hat areas, group safety meetings, and gate entry procedures.

Group Safety Officers — Guest speakers discussed control of radioactive material and safeguards in handling and use of hydrogen.

Safety Review of Experiments

Safety reviews were conducted for 24 experiments. Safety information forms are being sent to experiment spokesmen prior to their experiment engineering reviews. These forms identify certain areas of safety the experimenters are to evaluate in relation to their experiments.

Inspections

Seven site inspections were conducted by the LAMPF Health & Safety Office this quarter. Deficiencies were reported to the proper groups for corrective action.

Accidents

Twelve accidents resulting in injuries were reported this quarter. Eleven of these were minor, consisting of lacerations, strains, abrasions, and foreign bodies in the eyes; they did not result in any significant loss-of-work time. The remaining accident involved an individual who fell from a 1.8-m-high wall and sprained his arm, resulting in loss-of-work time of three days.

LAMPF Users Group, Inc.

User Activities

An HRS Working Group meeting was held in Washington, DC on April 29, 1976, with George J. Igo (Univ. of California, Los Angeles) chairing the

meeting. The following agenda items were featured: Beam Line Tuning by James E. Spencer (LASL); Computer-Controlled Delay Lines by John C. Pratt (LASL) and James E. Spencer; Handling Charpak Plane Data by Thomas Kozlowski (BNL); Status of HRS Scattering Chamber by Nobuyuki Tanaka (LASL); Additional Tasks that Users Can Help With at HRS by George J. Igo; and Status of Tune-Up Experiment by James E. Spencer. Minutes of this meeting will be mailed to all members of the HRS Working Group in the near future.

Liaison Office

In conjunction with the Board of Directors, LAMPF management are actively working on several projects that should prove beneficial to the users at LAMPF. A summer program of seminars, lectures, and colloquiums has been planned. The program is designed primarily with the graduate student in mind. A series of seminars, meeting twice a week, will start in late May. The first series will be an introduction to detectors and experimental techniques used at LAMPF and coordinated by Peter Gram (LASL). From mid-June to mid-July, Charles Critchfield (LASL) will give a series of lectures on scattering theory. The latter part of the summer will feature seminars in basic electronics and its applications to the physical sciences, with Jan Studebaker (LASL) coordinating this effort. Throughout the summer, talks will be presented on topics in the physical sciences, with emphasis on informing the nonexpert.

John Allred (Univ. of Houston/LASL), Harvey Willard (Case Western Reserve Univ.), and Hillard Howard (LASL) are acting as ombudsmen for graduate students. Several rather critical problems have been found and ways to alleviate the situations are being initiated. In particular, the cost of living at Los Alamos and the shortage of low-cost rentals for graduate students have been of major concern. It has become apparent that graduate students are being sent to Los Alamos without adequate support money. In addition, a second income is sometimes lost by the relocation. An attempt is therefore being made to establish a basic living cost for graduate students and make this information available to the advisors. In order to help alleviate the problem, LAMPF Director Louis Rosen has agreed to make up

to 40 hours per month of part-time work available to graduate students to assist MP-Division staff in the experimental areas. A letter was sent to all LAMPF experiment spokesmen outlining this program (see Appendix B). In addition, the Board of Directors has directly contacted local builders and apartment complex owners about housing that graduate students can afford. Several possibilities are being discussed.

Plans are being made for several outdoor activities throughout the summer for families, as well as hikes, bicycle trips, and visits to local peaks for the hardier individuals.

The Nominating Committee for the upcoming election of officers for the LAMPF Users Group, Inc. was appointed and consists of Chairman Vernon W. Hughes (Yale Univ.), Peter D. Barnes (Carnegie-Mellon Univ.), Bruce J. Dropesky (LASL), Sherman Frankel (Univ. of Pennsylvania), George J. Igo (UCLA), and Glen A. Rebka, Jr. (Univ. of Wyoming).

The February Newsletter was mailed to the entire membership of the LAMPF Users Group, Inc. on March 30, 1976. The May Newsletter was prepared and sent to the printer. Distribution will be made in mid-May.

Board of Directors and Technical Advisory Panel

The Board of Directors is currently negotiating with ERDA to obtain funds to provide accident and major medical insurance for graduate students while they are at LAMPF. At present, a plan is being considered that would allow coverage for dependents for an additional premium to be paid by the individual. The policy has excellent coverage for very reasonable premiums.

The next meeting of the TAP is scheduled for July 27, 1976 in Los Alamos. The agenda for this meeting is not available as of this writing.

LAMPF Visitors Center

Housing

Exclusive of the "casual" visitors this quarter, there were more than 200 research guests at LAMPF

working on LAMPF-related problems, or preparing for or participating in experiments (see Appendix A). Visitors Center personnel checked in 147 guests this quarter, with 134 guests checking out.

As of this writing all of the available LASL/LAMPF-administered housing has been assigned through the summer, with 11 requests remaining to be filled.

Tours

Organized tours of the LAMPF were conducted by LASL personnel for the following organizations:

- 2/ 7 - LASL families tour
- 2/10 - New Mexico State Legislators
- 2/12 - Univ. of New Mexico engineering students
- 2/18 - Western Regional Commissioner of the National Archives
- 2/25 - Albuquerque, NM Technical Vocation Institute
- 2/25 - ERDA officials
- 2/26 - Adams State Coll. (Colorado) chemistry students
- 3/ 6 - LASL families tour
- 3/10 - International Energy Agency Coordinating Committees
- 3/11 - ERDA Conf. on Surface Studies attendees
- 3/11 - Univ. of Central Arkansas Society of Physics Students
- 3/17 - Hays State Coll. (Nebraska) premedical chemistry students
- 3/19 - Cameron Univ. (Oklahoma) Society of Physics Students
- 3/29 - Consul of the Netherlands
- 3/30 - Coll. of Santa Fe (New Mexico) students
- 4/ 1 - Coll. of Santa Fe (New Mexico) science students
- 4/ 2 - Naval Reserve (Albuquerque, NM) electronic engineers
- 4/ 2 - Amer. Nuclear Soc. students meeting (ERDA-sponsored)
- 4/ 9 - Texas Tech. chemistry students
- 4/10 - LASL families tour
- 4/28 - Amer. Orthopedic Assoc. of Traveling Fellows
- 4/30 - Nurses' Workshop
- 4/30 - National Labs. Plant Facility Managers

APPENDIX A

RESEARCH GUESTS AT LAMPF DURING PERIOD FEBRUARY 1, 1976 - APRIL 30, 1976

John C. Allred	Univ. of Houston	Borge Espensen	Brookhaven National Lab.
John R. Allred	Univ. of Texas	Yuriy K. Fatkulin	Inst. for Nucl. Res., USSR
James F. Amann	Carnegie-Mellon Univ.	Richard D. Felder	Rice Univ.
Bryon D. Anderson	Kent State Univ.	Edward L. Fireman	Center for Astrophysics
Leonard B. Auerbach	Temple Univ.	Thornton R. Fisher	Lockheed Missiles/Space Co.
Thomas J. Baird	Rensselaer Poly. Inst.	John C. Fong	UC, Los Angeles
Robert L. Barnard	UNM Cancer Center	Rudolf Frei	L. Hartmann, Switzerland
Peter D. Barnes	Carnegie-Mellon Univ.	Jozica Gabitzsch	Rice Univ.
Stephen M. Bart	Univ. of Houston	Shalev Gilad	Tel-Aviv Univ.
John A. Becker	Lockheed Missiles/Space Co.	George Glass	Texas A&M Univ.
Fred E. Bertrand	Oak Ridge National Lab.	Gary A. Glatzmaier	Univ. of New Mexico
Hans A. Bethe	Cornell Univ.	Paul F. Glodis	UC, Los Angeles
Philip R. Bevington	Case Western Reserve Univ.	Joyce A. Goldstone	State Univ. of NY, Stony Brook
Christopher W. Bjork	Univ. of Wyoming	David E. Good	Univ. of Illinois
Gary S. Blaupied	Univ. of Texas	Kazuo Gotow	Virginia Poly. Inst.
Stewart D. Bloom	Lawrence Livermore Lab.	Nancy E. Greene	Univ. of Colorado
Felix H. Boehm	California Inst. of Tech.	Steven J. Greene	Univ. of Colorado
Joseph E. Bolger	Univ. of Texas	Mark B. Greenfield	Florida A&M Univ.
Kenneth Boyer	Univ. of Texas	Chilton E. Gregory	Univ. of New Mexico
Wilfred J. Braithwaite	Univ. of Texas	Edward E. Gross	Oak Ridge National Lab.
Hubert Brandle	UC, Los Angeles	Roy P. Haddock	UC, Los Angeles
Robert J. Broughton	Yale Univ.	Alan A. Hahn	California Inst. of Tech.
James A. Buchanan	Rice Univ.	Klaus Halbach	Lawrence Berkeley Lab.
Joseph J. Burgerjon	TRIUMF	Robert L. Hall	Univ. of Houston
George R. Burleson	Univ. of New Mexico	Isaac Halpern	Univ. of Washington
Roger D. Carlini	Univ. of New Mexico	Virgil L. Highland	Temple Univ.
Donald E. Casperson	Yale Univ.	Nathaniel W. Hill	Oak Ridge National Lab.
Constantine Cassapakis	Science Applications, Inc.	Norton M. Hintz	Univ. of Minnesota
David T. Chiang	Univ. of Washington	Martha V. Hoehn	Florida State Univ.
John M. Clement	Rice Univ.	Gerald W. Hoffmann	Univ. of Texas
Josefino C. Comiso	Univ. of Virginia	John H. Hoftiezer	Rice Univ.
Joseph N. Craig	Carnegie-Mellon Univ.	Kenneth R. Hogstrom	Rice Univ.
Thomas W. Crane	Yale Univ.	David B. Holtkamp	Univ. of Texas
Dorothy M. Crawford	UNM Cancer Center	Vernon W. Hughes	Yale Univ.
Frank N. Cverna	Case Western Reserve Univ.	Ed V. Hungerford	Univ. of Houston
Peter G. Debrunner	Univ. of Illinois	Homer B. Hupf	Mount Sinai Medical Center
Arthur B. Denison	Univ. of Wyoming	George J. Igo	UC, Los Angeles
Byron D. Dieterle	Univ. of New Mexico	Harvey Israel	LASL
Madhu S. Dixit	Carleton Univ.	Steven G. Iversen	Northwestern Univ.
Joey B. Donahue	Univ. of New Mexico	Mahavir Jain	Texas A&M Univ.
Mohan Doss	Carnegie-Mellon Univ.	Mark J. Jakobson	Univ. of Montana
William H. Dragoset	Rice Univ.	David A. Jenkins	Virginia Poly. Inst.
Steven A. Dytman	Carnegie-Mellon Univ.	Randolph H. Jeppesen	Univ. of Montana
Patrick C. Egan	Yale Univ.	Kenneth F. Johnson	Temple Univ.

William Johnson	Univ. of Rochester	O. Harry Otteson	Utah State Univ.
Jan Källne	Univ. of Uppsala	Alden T. Oyer	Univ. of Wyoming
Joseph X. Kallcor	Univ. of Houston	Gerald C. Phillips	Rice Univ.
Brad Keister	Carnegie-Mellon Univ.	Lawrence S. Pinsky	Univ. of Houston
Charles A. Kelsey	UNM Cancer Center	Franz Plasil	Oak Ridge National Lab.
Arthur K. Kerman	Massachusetts Inst. of Tech.	Hans S. Plendl	Florida State Univ.
Nicholas S. P. King	UC, Davis	Arthur M. Poskanzer	Lawrence Berkeley Lab.
Thomas R. King	Univ. of Wyoming	Richard J. Powers	California Inst. of Tech.
Lynn D. Knutson	Univ. of Washington	Barry M. Preedom	Univ. of South Carolina
Kenneth L. Koester	Univ. of Houston	Glen A. Rehka	Univ. of Wyoming
I. G. Kostoulas	UC, Los Angeles	James J. Reidy	Univ. of Mississippi
Thomas Kozlowski	Brookhaven National Lab.	Hans-Walter Reist	Univ. of Berne
Kenneth S. Krane	Oregon State Univ.	Louis P. Reznberg	Brookhaven National Lab.
Raymond Kunselman	Univ. of Wyoming	Robert J. Ridge	UC, Los Angeles
Gary Kyle	Univ. of Minnesota	Peter J. Riley	Univ. of Texas
Wing Chee Lam	Virginia Poly. Inst.	Robert M. Rolfe	UC, Los Angeles
Richard G. Lane	UNM Cancer Center	Isaac I. Rosen	Univ. of New Mexico
Phillip M. Lang	Northwestern Univ.	Ted D. Rupp	Univ. of New Mexico
Malcolm A. LeCompte	Univ. of Wyoming	Marvin Sachs	Univ. of New Mexico
Christopher P. Leavitt	Univ. of New Mexico	Mark A. Schardt	Arizona State Univ.
L. Y. Lee	Univ. of Houston	Wolf-Udo Schroeder	Univ. of Rochester
Rodger P. Liljestrand	Univ. of Texas	Carol A. Selheimer	UNM Cancer Center
V. Gordon Lind	Utah State Univ.	Valeriy L. Serov	Inst. for Nucl. Res., USSR
Joseph W. Lo	Univ. of Houston	Hasan Sharifian	Univ. of New Mexico
Chris E. Long	Florida A&M Univ.	Tilak C. Sharma	Oregon State Univ.
Steven C. Luckstead	Washington State Univ.	Joseph D. Sherman	Carnegie-Mellon Univ.
Donald J. Malbrough	Univ. of South Carolina	Donald G. Shirk	Iowa State Univ.
Thomas Marks, Jr.	Univ. of South Carolina	Frank T. Shively	Lawrence Berkeley Lab.
Roscoe E. Marrs	California Inst. of Tech.	Donald C. Slater	Univ. of Virginia
Nina Marsh	UNM Cancer Center	Alfred R. Smith	UNM Cancer Center
Bill W. Mayes	Univ. of Houston	Lester E. Smith	Univ. of Texas
Robert E. McAdams	Utah State Univ.	Stanley E. Sobottka	Univ. of Virginia
W. Kenneth McFarlane	Temple Univ.	Larry B. Sorensen	Univ. of Illinois
M. W. McNaughton	Case Western Reserve Univ.	Paul A. Souder	Yale Univ.
Hans O. Meyer	Univ. of Basel	Rolf M. Steffen	Purdue Univ.
James P. Miller	California Inst. of Tech.	Marcus D. Stevens	UNM Cancer Center
Murray A. Moinester	Tel-Aviv Univ.	Richard J. Sutter	Brookhaven National Lab.
C. Fred Moore	Univ. of Texas	L. Wayne Swenson	Oregon State Univ.
C. L. Morris	Univ. of Virginia	Willard Thomas	Univ. of New Mexico
Zvonko Mozetic	J. Stefan Inst.	James D. Thomasson	Univ. of Houston
Donald W. Mueller	LASL	Hossein Tootoonchi	Univ. of New Mexico
Gordon S. Muellner	Rice Univ.	Georgui M. Vagradov	Inst. for Nucl. Res., USSR
Robert A. Naumann	Princeton Univ.	James K. Valentine	Temple Univ.
B. M. K. Nefkens	UC, Los Angeles	Philip Varghese	Univ. of Oregon
Peter Nemethy	Yale Univ.	Stephen L. Verbeck	New Mexico State Univ.
Charles Newsom	Univ. of Texas	Jean-Luc Vuilleumier	California Inst. of Tech.
Lee C. Northcliffe	Texas A&M Univ.	E. Alan Wadlinger	Univ. of Virginia
Andrew W. Obst	Northwestern Univ.	Louis K. Wagner	Florida State Univ.
Michael A. Oothoudt	Univ. of Minnesota	Sheldon S. Wald	Texas Tech. Univ.
Herbert Orth	Universitat Heidelberg	John B. Walter	Univ. of Wyoming

Keh-Chung Wang California Inst. of Tech.
 Michael L. Warneke Univ. of Houston
 Bruce A. Watson . . Lockheed Missiles/Space Co.
 Charles A. Whitten UC, Los Angeles
 Harvey B. Willard . . Case Western Reserve Univ.
 Thomas M. Williams Rice Univ.
 Suzanne Willis Yale Univ.
 Kentner B. Wilson Remotion Co.

Nord F. Winnan UC, Los Angeles
 David M. Wolfe Univ. of New Mexico
 James Worthington . . . Argonne National Lab.
 Yoshishige Yamazaki Florida State Univ.
 Mary Ann Yates Carnegie-Mellon Univ.
 Sergey K. Yessin . . . Inst. for Nucl. Res., USSR
 Alex Zehnder California Inst. of Tech.
 Klaus O. H. Ziock Univ. of Virginia

APPENDIX B

PART-TIME EMPLOYMENT OPPORTUNITIES FOR GRADUATE STUDENTS AT LAMPF

The following letter was sent to all thesis advisors for graduate students at LAMPF. Information announced in the May issue of the LAMPF Users Newsletter is also included:

... we are initiating an experiment to determine the utility, feasibility, and desirability of offering part-time employment to graduate students at LAMPF. The objec-

tives of this program, and the procedures for implementing same, are described in the above newsletter.

We have now identified 23 jobs, list attached, which could be filled by graduate students on a part-time basis. If you have at LAMPF a student who could benefit from this program, and you wish him to participate, please let us know.

Enclosure:

Part-time Employment Opportunities for Graduate Students at LAMPF

In accordance with a proposal which was introduced during the 1975 LAMPF Users Meeting by L. Rosen, and on the recommendation of the Chairman and Chairman-elect of the LAMPF Users Group, Inc., and after much deliberation, the following opportunity will be offered to graduate students at LAMPF on a trial basis.

A number of jobs, normally filled by casual or part-time employees will be reserved for graduate students who may work up to 40 hours per month. Arrangements for subject jobs will be made on the basis of the skills and interests of the graduate students and the needs of the various groups which have responsibilities for the operation, maintenance, development, and safety of LAMPF. Job assignments will be made only with the approval of the thesis advisor and their university, and upon application of the graduate student for a specific job. Job listings and descriptions will be published periodically. The objectives of the above are to:

- 1) offer a wide range of laboratory experience to thesis students,
- 2) increase the familiarity of students with the operation of a large accelerator facility, especially with safety considerations, and
- 3) provide an opportunity for a modest amount of supplemental income.

Tom Putnam will coordinate job assignments to all groups. All applications should be sent to Eleanor Dunn, Head of Administrative Services, for implementation. Administratively the commitment to hire a specified individual will be made by means of a letter of understanding with the individual's university. Remuneration will be at the rate of \$240 per month, corresponding to a work schedule of 40 hours per month.