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GLOSSARY OF TERMS USED IN THIS REPORT

ADC	- Analog Digital Converter	LEEP	- LAMPF Electronics and Equipment Pool
ADS	- Analog Data System	LET	- Linear-Energy Transfer
AMO	- Area Manager's Office	LM	- Loss Monitor
AP	- Activation-Protect	LTSS	- Livermore Time-Sharing System
APF	- Alternating Phase-Focusing	LUGI	- LAMPF Users Group, Inc.
APL	- A Programming Language	MBD	- Microprogrammed Branch Driver
ASCII	- American Standard Code for Information Interchange	MG Set	- Motor-Generator-Set
bpi	- Bytes Per Inch	m.i.	- Mineral Insulated
BPM	- Beam-Position Monitor	MIG	- Metal Inert Gas
CCF	- LASL Central Computer Facility	MPU	- Microprocessing Unit
CCT	- Color Character Terminal	MSSC	- Multistrip Scintillation Chamber
CCR	- Computer Control Room	MTBF	- Mean Time Between Failures
CCTV	- Closed-Circuit Television	MWPC	- Multiwire Proportional Chamber
CIU	- Console-Interface Unit	NCL	- Nuclear Chemistry Laboratory
CPU	- Central Processing Unit	NIM	- Nuclear Instrumentation Module
CRT	- Cathode Ray Tube	NMR	- Nuclear Magnetic Resonance
cw	- Continuous Wave	OER	- Oxygen Enhancement Ratio
C-W	- Cockcroft-Walton	pc	- Printed Circuit
DACT	- Data-Acquisition and Control Terminal	PHA	- Pulse-Height Analyzer
dpa	- Displacement Per Atom	PIGMI	- Pion Generator for Medical Irradiations
DPM	- Digital Panel Meter	PIP	- Proton Irradiation Port
DVM	- Digital Volt Meter	PLI	- Procedural Language Interface
EFB	- Effective Field Boundary	PMT	- Photomultiplier Tube
EPA	- Electron Prototype Accelerator	RAM	- Random Access Memory
ETL	- Equipment Test Laboratory	RBE	- Relative Biological Effectiveness
FET	- Field-Effect Transistor	RGB	- Red-Green-Blue
fh	- Filament Hours	RICE	- Remote Information and Control Equipment (remote data terminal)
FSI	- Final-State Interaction	RIU	- RICE Interface Unit
FWSS	- Fast-Wire-Scanner System	ROM	- Read-Only Memory
hfs	- Hyperfine Structure	S2K	- System 2000 (a large software package for information storage and retrieval)
hvh	- High-Voltage Hours	SCC	- Serial Crate Controller
IC	- Integrated Circuit	SCR	- Silicon Control Rectifier
ICR	- Injector Control Room	SM	- Sweeping Magnet
IDS	- Information Display System	SSD	- Serial System Driver
IEC	- International Electrotechnical Commission	SY	- Switchyard
IFA	- Interface Amplifier	TDC	- Time-to-Digital Converter
I/O	- Input/Output	TDI	- Temperature Difference Integrator
ISIC	- Insertable-Strip Ion Chambers	TIG	- Tungsten Inert Gas
IVR	- Induction Volt Regulator	Tm	- Absolute Melting Temperature
LAM	- Look-at-Me Interrupt	TOF	- Time of Flight
LAMPF	- Clinton P. Anderson Meson Physics Facility	TR	- Transition Region
LCF	- Localized Current Fields	VSWR	- Voltage Standing-Wave Ratio
LED	- Light-Emitting Diode		

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
- ISORAD - Isotope Production and Radiation Damage

LEP - Low-Energy Pion Channel

Neutrino A

P³ - High-Energy Pion Channel

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, 1977

I. SUMMARY

Accelerator Operations

The accelerator was in nearly continuous operation throughout the quarter, with 47 days allotted to research and the remaining 42 days used for facility development and routine maintenance. A new 5-week structure to the operating cycles has been adopted, with 23 1/2 days scheduled for research.

H⁺ beam intensity was increased by 50% over the previous quarter to 150 μ A, and the machine ran routinely at that level, with as much as 6 μ A of H⁻ in simultaneous operation. Machine availability during research shifts averaged 84% for the H⁺ beam and 81% for the H⁻ beam.

Research-quality proton beams to Area A totaled 142 000 μ A-h during the quarter, as measured at the A-1 target station. An additional 1070 μ A-h of H⁻ was delivered to Area B. The first polarized proton beam was accelerated to 800 MeV and measured in Area B. Thirty-five experiments received beam.

During machine time allotted for accelerator development, emphasis was placed on the improvement of beam-tuning procedures. Work continued on the determination of magnetic and physical misalignments in the beam transport, 201-MHz linac, and the transition region.

Machine operation continued to be reliable and stable at 150 μ A. Difficulties continued to be encountered during tuneup for production beam and the restart after a maintenance period.

The beam-loss monitor and activation-protection systems were improved by the installation of additional detectors.

Injector Systems

Both H⁺ and H⁻ injectors operated almost continuously this quarter at 30 mA_p and 0.5 mA_p, respectively. The polarized ion injector was run for the first time this quarter. Polarized H⁻ beam was accelerated to 800 MeV, and measurements showed 76% polarization with ~ 20 pA_A on target in EPB.

Several problems were encountered in the early operation of the C-W high-voltage generator in the polarized injector. After making several modifications, the generator was operated up to 803 kV.

The prototype transistorized arc-pulse modulator is now ready for initial tests on the H⁺ injector. This modulator employs a fast controller on the arc current with a wide dynamic range and is expected to reduce some of the variations in injector beam caused by fast-protect transients.

Work has started on the PIGMI injector. A converging Pierce-geometry design has been developed and construction of some electrodes has started. This design will require high accelerating gradients to meet the brightness requirements needed for this application.

Accelerator Systems Development

A new general-purpose computer program, named PANDIRA, for solving two-dimensional, cylindrically symmetric, anisotropic magnetostatic problems, was completed. This code is able to handle permanent-magnet material; it is the only code in the country known to us which has this capability in a general way, and promises to have wide applicability.

Transverse dynamics studies are receiving the major effort in the beam dynamics work. Several

simulations are under way for analyzing and understanding experimental data being accumulated on the transverse behavior of simultaneous H^+ and H^- beams in LAMPF. Some experience was also obtained during the quarter on controlling the horizontal oscillations which appear in the drift-tube linac. Longitudinal dynamics studies included investigation of a possible bead-size effect previously unaccounted for in the Tank 1 field distribution data and evaluation of methods for using extensions of the Δt theory and other measurements to cross-check or improve the longitudinal tuning.

Continued progress was made on the evaluation of space charge effects. The properties of the equilibrium phase-space distributions were related to actual machine parameters, and a set of PAR-MILA runs was completed to explore a range of pertinent parameters. In general, the two methods agreed. These studies were effective in pointing out directions where improved techniques are needed for modeling multidimensional particle distributions.

Instrumentation development work on a wide variety of applications was carried out, including modifications to the multigain wire-scanner system.

Work on a streamlined operations/maintenance equipment data base was completed and the new version was put into operation.

Design work on a project to test the rf properties of cavities cooled to liquid hydrogen temperatures was completed. Development of the new Biomed range-shifter and hydraulic servo arm was continued, and design of a servo-controlled Biomed collimator is well under way.

Accelerator Support

The reliability studies over the past year indicate an improvement in the availability of the accelerator equipment, a payoff due in part to the extensive preventive maintenance and repair activities.

Modifications to the 201-MHz test stand for 4664 operation were completed and three 4664s were processed for spares. The test stand can now be used to

test and process all tubes used in the 201-MHz rf systems.

Maintenance of the standard ACI, ACII, BCI, BCII, MOE, IND, Relay, and Meter NIM modules is now the responsibility of the 805-MHz section.

Final modifications to the 805-MHz resonance controllers have begun. The present power supplies are being replaced with precision power supplies that will improve interchangeability and stability. The resistors in the temperature-sensing circuit are being replaced with resistors that have a temperature coefficient of ± 1 ppm per Celsius degree. An out-of-tolerance temperature alarm circuit is being added.

The prototype 805-MHz solid-state IFA has been extensively tested and has either equalled or outperformed the tube-type IFA in all respects. Feedthrough power between pulses and phase shift with changes in output power is much lower. A comparison of reliability, the big problem with the tube-type units, will be made by constructing five more solid-state IFAs and retrofitting one sector with these units.

The 12-MHz timing signal has been provided to several new experimental locations for use with chopped beam operation.

Resonance problems in the 201-MHz tanks have prompted the development of a tuning slug resonance control system. A prototype system has been built to obtain temperature response information on the 201-MHz tanks which will be used in the design of the final system.

A wide assortment of beam diagnostic hardware was reviewed and many new parts were fabricated or are in the process of fabrication. A new prototype actuator is being designed as a replacement for existing units. A new method for the storage and labeling of beam diagnostics spare parts has been devised and implementation of the system is in progress.

The dual-Acme power supplies have been rebuilt and converted to use the LAMPF-standard regulator and standard control and metering chassis.

All installation work on Line 1L of the WNR facility is complete. Six power supply systems and four by-pass shunt systems were installed and checkout of the units is under way.

Engineering Support

Over 1.17 million filament operating hours have been accumulated on the klystrons to date. One klystron has logged over 33 000 fh, and LAMPF rebuilt units have now exceeded 14 000 rh. Three klystrons were rebuilt, and fifty-five triodes were reprocessed. Eight of the ten klystrons ordered have been received.

Components of the EPICS spectrometer system installed last quarter were aligned, and the detector frame assembly is nearing completion in preparation for installation on the spectrometer structure.

Continued engineering support was provided the PIGMI program in the areas of rf power systems, PIGLET, fabrication, drift-tube plating, and permanent-magnet quadrupole development.

The LAMPF experimental programs continued to receive a major portion of the group effort this quarter. Significant support was given 21 experiments. The stockpile of devices that can be used in experimental setups has increased substantially, and we can now handle even the more complicated experiments on a routine basis.

Electronic Instrumentation and Computer Systems

The new disk system for the SEL-840 control computer moved a step nearer completion with the delivery and installation of the remaining two disk drives.

The interface electronics for the new operator's console in CCR were installed for test and evaluation along with the first device, a function-button panel.

The new microprocessor-based Master Timer was completed and checked out. The unit is ready for integration into the accelerator control system.

Several programs were written to help diagnose problems both in the control computer hardware and in the accelerator control equipment. New options and features were added to a variety of control programs.

A major effort was mounted to complete the controls for the EPICS spectrometer before the May test.

Despite the heavy schedule of operations, a substantial number of modifications and additions were made to the instrumentation and controls in the experimental area.

A purchase request was submitted for a LAMPF-standard PDP-11/34 to be used for systems development, thereby relieving the Terminal computer of this load.

Several new enhancements were added to program Q, the general data-acquisition software. The documentation for the system was improved with the release of three new manuals.

A pc card was developed for the Tektronix 4010 terminals to reduce the wear on the CRT face.

All but one of the Berkeley synchronizers were replaced with KS-90 magnetic-tape-drive controllers for greater reliability.

A capability for renovating disk cartridges was demonstrated by LEEP personnel, who reconditioned the first 20 cartridges at a cost of half the price for new disks.

User feedback concerning the support received for their data-acquisition systems was collected in a series of debriefing meetings.

A radiation detector was put into operation to monitor the exit gate at LAMPF for any radioactive materials leaving the site in a vehicle.

Beam Line Development

Three-hundred microamperes of beam were transported to A6 for 2 h during a heat run. The SY and Experimental Area transport performed efficiently.

The thin uranium target at AT-TW-01 was accidentally destroyed, resulting in distribution of α -active fragments about the SY. The contamination has been adequately removed but the thin target station is not yet back in operation.

Polarized H^- beam was delivered to EP for a short time, marking the third type of beam available from the LAMPF linac.

A program of improving the H^- beam diagnostics was begun. Computer processing of toroid data has been implemented. New improved 2-jaw stripper mechanisms have been designed. A counter telescope and electronics for diagnosing the tune of the H^- chopper were constructed and placed in

operation. The EP ion chamber has been rebuilt, and an MWPC with integrating readout has been installed in EP and tested with beam. Design work is proceeding on new secondary-emission monitors and insertable MWPCs to add to the H⁻ beam lines. A polarimeter capable of measuring vertical and horizontal transverse polarization is now in operation in EP.

Beam line protection instrumentation has received considerable attention. The Transmission Monitor has been improved, activation-protect (AP) spill monitor station units have been modified, and a prototype electronics circuit for use with the secondary-emission guard rings has been constructed and tested.

Encouraging stopping- π^- flux in SMC and an exciting number of 28-MeV/c μ^+ from the surface of the A2 target were observed during work on secondary beam line development. Measurements in the P³ line confirmed that extrapolations of previous small solid-angle fluxes are valid for full solid-angle beams and that the central momentum of the channel may indeed be lower than calculated; checks will continue. New data on muon and electron contamination were obtained at several momenta.

Experimental Areas

A new facility for high-current proton radiation-damage studies has been constructed and placed into operation. The facility, which has been named the Proton Irradiation Port (PIP), allows thin samples to be remotely inserted into the LAMPF 800-MeV proton beam where spot sizes as small as ~ 1 by 2 mm are available.

All pion production target systems are being upgraded. Good results have been obtained with a solid-disk graphite wheel, and a new spin-drive mechanism is nearing completion. Minor changes have been made in the A-5 target that fractured during the 300- μ A beam test.

A consulting structural engineering firm has been named for the Area A-East service structure. A new building will be erected to serve the crafts; the present craft building near Area A will be converted into a cryogenic laboratory and a small assembly area.

Several improvements in the shielding have been made. Radiation surveys taken during the 300- μ A

beam test show good results for the open areas and the counting houses in Area A.

Progress has been made on the spare pump/heat-exchanger system and the tritiated water-disposal system. The EPICS spectrometer magnet cooling system is operational. Improvements in the water interlock systems are being planned.

Substantial progress has been made in the development of techniques for bonding graphite to copper cooling tubes. Tests carried out in an induction heating rig have shown that large heat fluxes can be passed through the bond. The most successful bond to date passed 625 W/cm². The bonds can be cycled repeatedly without loss of performance.

A vacuum system has been built for SMC-West. A new target box has been installed in the nuclear chemistry cave in Area B.

A complete hydrogen/tritium target system containing 80 000 Ci of tritium was assembled and run for Exp. 50. In addition, the Cryogenics Section built and installed a number of other targets for experiments. Modifications and improvements have been made to existing cryogenic pool equipment. A new refrigerator system has been ordered.

A nuclear magnetic resonance detection system has been successfully fabricated for use with the polarized target facility. Auxiliary ³He, ⁴He, microwave, and vacuum systems are in progress.

Large-Spectrometer Systems

Energetic Pion Channel and Spectrometers

Experiment 245 was completed on the EPICS channel. One running cycle was then devoted to beam composition studies. In April, the channel was shut down for installation of the spectrometer.

High-Resolution Proton Spectrometer

Run cycles during this quarter were used primarily for continuation of Exp. 139 and completion of Exp. 4, with a small fraction of time devoted to HRS development. Between cycles, modifications and improvements to the Line C HRS operating system continued.

Practical Applications of LAMPF

In the pion biomedical program, several new therapy beams were developed for patients in Cycles 13 and 14. Also, a fan-shaped beam was developed for future use with a scanning treatment couch. New improved dynamic range-shifter functions were designed and evaluated. An extensive catalog of beams with different dimensions, dose rates, and depth-dose distributions is now available at the Biomedical channel.

Dosimetry studies have been made to ascertain the effect of inhomogeneities on pion dose distributions. Significant effects were discovered for inhomogeneities oriented parallel and perpendicular to the beam direction. Radiobiology experiments to investigate tissue-bone interface effects were also performed. In another experiment, microdosimetric spectra were obtained for a broad beam used for patients. A series of experiments was initiated to check the feasibility of using long-lived residual activation induced by negative pions to monitor the dose. Such techniques might be useful for *in vivo* dosimetry.

Practical applications experiments in progress during the past quarter included radioisotope production, proton-induced radiation damage, and studies dealing with chemical and structural effects in the capture of negative muons in matter. Several muon spin rotation studies were performed as a function of temperature using several targets. The feasibility of efficiently performing such studies at LAMPF was conclusively demonstrated.

In the area of technology transfer, localized current field (LCF) units have been loaned to individuals and institutions for use in hyperthermia studies including the treatment of the "cancer-eye" condition in cattle. LASL's evaluation of the equipment for cattle treatment is essentially complete. An effort is under way to develop an LCF technique for the generation of heat at depth in the cornea. This technique might prove useful in altering the shape of the cornea to correct refractive errors of the eye.

Linac Technology

A computer algorithm for determining the geometric properties of the alternating-phase-

cused (APF) linac structures has been developed. Two-dimensional arrays of acceleration gap-to-cell-length ratios and transit time factors are collected from SUPERFISH outputs over the array of geometries of interest and organized for use by PARMILA in the generation of the geometrical and dynamical properties of the structures.

PIGLET, the six-cell, 45-MeV drift-tube geometry, field-gradient test cavity, has been released for fabrication with an expected completion date late in the next quarter. An order for the fabrication of its rf window has been released, and the in-house fabrication of the window frame has begun. The 450-MHz rf test stand required to drive PIGLET was successfully activated during the quarter and is currently running at an output of 1 MW.

The bright-copper-plating development program is proceeding most satisfactorily. After several developmental iteration runs, the plating is now virtually flawless in appearance, and emphasis is currently directed toward the evaluation of the electromagnetic properties of the plating.

Theoretical and experimental studies of different high-energy accelerating structures were continued. A short section of a disk-and-washer structure was built and low-power experimentation begun. The preliminary results are most encouraging.

A preliminary examination of the applicability of the APF concept and the disk-and-washer structure to the problems associated with the development of an electronuclear fuel production accelerator was begun. Some effort was also directed toward surveying the various possibilities of achieving a high-efficiency, high-average-power-output, rf generator essential to the practicability of a fuel accelerator.

Nuclear Chemistry

Additional detector equipment and computer I/O hardware have been added in the counting area laboratories. An exchange of the PDP-11/40 for a PDP-11/34 is being planned to obtain various advantages.

Work has continued on improving the branch of the pneumatic "rabbit" system that runs from the hot cell to the energetic neutron station at the A-6 beam stop. A new "snake" and switch has been designed, fabricated, and installed to overcome the

problems experienced in inserting and retracting the original snake. Despite these problems, numerous irradiations were carried out for Exps. 111 and 161. A new carrier-sensing switch was also installed in the "trombone" of the remote targeting station in proton Line B. This branch of the system is nearly ready for use. The major hardware components for the WNR rabbit system have been fabricated and are being installed.

The major theoretical activities this quarter involved comparisons of experimentally measured pion-absorption phenomena with those calculated with the VEGAS intranuclear cascade code. The total pion-absorption cross sections calculated for ^{12}C appear to be from 10 to 35% too low compared to measurement values. A comparison has also been made of energetic proton production in pion-induced reactions at angles for which the protons are mainly due to pion absorption (Exp. 121). It is concluded that the VEGAS model does not correctly account for pion absorption. Absorption through s-wave channels will be included in an effort to improve this.

Research

Research reported this past quarter features the first extensive angular distributions taken with the HRS. Elastic scattering of 800-MeV protons from D, ^3He , ^3T , and ^4He was measured by Exp. 4. Data were taken over an angular range in the laboratory of 13° to 165.5° , corresponding to momentum transfers ranging from 0.11 to 4.26 GeV/c². Both elastic and inelastic scattering is reported by Exp. 139 on targets of $^{12,13}\text{C}$, $^{58,60,62,64}\text{Ni}$, and ^{208}Pb . Data were taken from 5° to 30° with an energy resolution of 100-200 keV. The ^{12}C data is compared to an optical model analysis, with parameters generated by a KMT prescription using nucleon-nucleon scattering amplitudes and a nuclear-matter density distribution, which shows the importance of spin effects.

Continuing measurements of pion double-charge exchange (DCE) are reported by Exp. 25. They have detected the nonanalog pion DCE reaction $^{10}\text{O}(\pi^+, \pi^-)^{10}\text{Ne}$, which gives the first mass measurement of ^{10}Ne , as well as a cross section that is comparable to the corresponding cross section for the analog transition on ^{18}O .

Five new neutron-rich nuclides, ^{27}Ne , $^{31,32}\text{Mg}$, ^{27}Al , and ^{39}P , have been identified in Exp. 86. Fragments from proton bombardment of a thin uranium target were identified in a silicon ΔE -E detector telescope, with Z and A determined by a combination of $E, \Delta E$ and TOF information. Cross sections for spallation products from 800-MeV proton interactions in copper are reported by Exp. 282.

A number of muonic x-ray transitions in ^{161}Dy were measured in Exp. 166. The data were analyzed with a model which included band-mixing in order to extract nuclear charge-distribution parameters. Quadrupole moments, transition moments, and a (ground state) hexadecapole moment were determined for the ground state and the first- and second-excited states.

Multiple scattering of muons in carbon was measured by Exp. 325. They find excellent agreement with the Molière theory of multiple scattering, as modified to include scattering from atomic electrons and current screening corrections.

Management

A revised production run schedule through August 31 was prepared by the LAMPF Scheduling Committee. The accelerator will be off during September for budgetary reasons. Spokesmen for scheduled experiments have been notified of the revised operating schedule.

The individual and total man-rem exposure levels were maintained at an acceptable level this quarter. Final preparations were made for safe conduct of the tritium-target experiment. No tritium contamination problems were encountered during the run of Exp. 50, and no problems were encountered during removal of the experimental apparatus. A ^{238}U target failed in the TTA on the main beam line when that section of the line was let up to air. The area was decontaminated within hours of the failure, no one received serious contamination, and no activity was ingested.

The LAMPF Users Group, Inc., continues to be an active and guiding force in the operation of LAMPF. This quarter the HRS Working Group held a meeting during the Washington meetings of the American Physical Society. Arrangements have been made to hold an EPICS Working Group meeting at LASL in June.

Arrangements for summer housing for visitors and users have proceeded on schedule, with only a few housing units yet to be found to satisfy the requests received. This is an indication of the enormous amount of work that has been expended in this area by the LAMPF Housing Office, in particular by Billie Miller, in conjunction with the LASL Housing Office personnel. The ability to lease apartments for sublease to visitors has been of utmost importance in filling requests for visitor housing.

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II. ACCELERATOR OPERATIONS

General

The accelerator was in nearly continuous operation throughout the quarter, with 47 days allotted to research and the remaining 42 days used for facility development and routine maintenance. A new 5-week operating cycle has been adopted, as shown in Fig. II-1. Figure II-2 shows the beam current available during the production periods in this quarter. This figure shows weekly dents due to scheduled maintenance and development and the high availability of beam over long periods of operation.

H^+ beam intensity was increased by 50% over the previous quarter, to $150 \mu A$, and the machine ran routinely at that level, with as much as $6 \mu A$ of H^- in simultaneous operation. Machine availability during research shifts averaged 84% for the H^+ beam and 81% for the H^- beam.

Experimental Program

Research-quality proton beams to Area A totalled $142\,000 \mu A\text{-h}$ during the quarter, as measured at the A-1 target station. An additional $1070 \mu A\text{-h}$ of H^- was delivered to Area B. The cumulative total of proton beams delivered for research in this machine

since it first went into operation is $373\,000 \mu A\text{-h}$. The first polarized proton beam was accelerated to 800 MeV and measured in Area B. Thirty-five experiments received beam as shown in Table II-I.

Facility Development

Emphasis was placed, during the machine time allotted for accelerator development, on the improvement of beam-tuning procedures. Work continued on the determination of magnetic and physical misalignments in the beam transport, 201-MHz linac, and the transition region. Positive results were obtained from measurements of the effectiveness of feedback controlled autosteering to reduce horizontal beam oscillations originating in the 201-MHz linac (see Sec. IV). Beam profiles were studied in detail with wire scanners incorporating new 4-decade amplifiers. A $300\text{-}\mu A$ high-intensity test of 2-h duration was completed successfully late in the quarter.

Experimental area development activities included the development of the 28-MeV/c surface μ^+ beam, reduction of the response time of the beam transmission monitor, and measurements of the magnitude of observed horizontal beam oscillations

WEEK	S	M	T	W	Th	F	S
1	P	P	P	P	P	P	P
2	P	P	D	P	P	P	P
3	P	M	T	P	P	P	P
4	P	P	D	P	P	D	D
5	D	D	D	M	M	T	T

Fig. II-1.

Present structure for 5-week operating cycle. P = production, D = development, M = maintenance, T = tuneup.

Fig. II-2.

Beam-current history at first meson production target for Cycles 12 and 13; scheduled beam intensity was $150 \mu A$; 85% availability per day would be $128 \mu A$. Only one day of scheduled beam fell below 50%. Development and maintenance days are marked.

TABLE II-I
QUARTERLY REPORT OF BEAM PROVIDED FOR EXPERIMENTS

<u>Experiment No.</u>	<u>Channel</u>	<u>Shifts (8 h)</u>	<u>μA-h</u>	<u>Experiment No.</u>	<u>Channel</u>	<u>Shifts (8 h)</u>	<u>μA-h</u>
4	HRS	74.0	3	222	P ³	76.0	74 000
15	HRS	74.0	3	236	Biomed	13.0	10 300
27	EPB	18.5	0	239	Biomed	2.0	1 390
29	LEP	31.5	33 200	240	SMC	29.5	28 400
31	Neutrino	65.5	45 200	245	EPICS	35.0	37 900
50	LEP	63.0	69 000	247	P ³	5.0	4 140
54	LEP	31.5	33 200	264	AB-Neutron	49.5	142
67	P ³	8.0	8 250	266	SMC	39.5	39 200
86	TIA	64.0	69 000	267	ISORAD	96.0	66 500
86	AB-Nucchem	1.0	20	270	Biomed	9.0	6 950
93	P ³	42.0	40 600	271	Biomed	32.0	24 600
103	P ³	3.5	3 540	272	Biomed	12.5	10 500
105	AB-Nucchem	0.5	12	273	Biomed	14.5	11 200
106	AB-Nucchem	1.5	23	274	Biomed	20.0	15 900
111	Isorad	4.5	2 760	275	Biomed	32.0	24 000
119	P ³	5.0	4 710	276	SMC	25.5	24 600
130	EPICS	57.0	62 500	288	SMC	10.0	9 800
137	EPB	6.5	0	292	SMC	18.5	17 000
139	HRS	37.5	0	297	SMC	37.5	37 100
140	LEP	16.5	16 800	301	AB-Nucchem	28.5	473
191	LEP	17.0	19 300	323	EPB	53.0	0
206	SMC	4.0	4 150	325	EPICS	9.5	10 400

in Lines X and EFB. Adjustments to beam transport parameters brought observed beam profiles into closer agreement with calculated results. The doubling of the activation-protect system that was started during the last report period was completed and placed into service. Finally, the beam-loss monitor and activation-protection systems were improved significantly by installation of new detectors.

Operating Experience and Downtime

Machine operation continued to be reliable and stable at 150 μ A. Time required for tuning, from startup to production beam, was four to five shifts. Restart operations, following scheduled interruptions for preventive maintenance, continue to take at least 12 h to return to production (see Fig. II-2).

A summary of accelerator downtime during the 140 research shifts is given in Table II-II.

TABLE II-II

QUARTERLY SUMMARY OF MACHINE DOWNTIME

<u>Category</u>	<u>Downtime (h)</u>	<u>Percent of Total</u>
201-MHz amplifiers and transmission lines	33	14
805-MHz amplifier systems	46	20
Vacuum	22	9
Magnets and magnet power supplies	26	12
Interlocks	22	9
Injectors	17	7
Water	3	1
Computer control and data acquisition	18	7
Reference source	5	5
Beam stops, plugs, targets, strippers, scrapers	4	2
Beam diagnostics	9	4
Timing distribution systems	--	--
Miscellaneous (utilities, etc.)	23	10
TOTAL	230	

III. INJECTOR SYSTEMS

H^+ Injector

The H^+ injector was on-line almost all quarter, operating at the 30-mA_p level.

Work has continued on building up the spare parts inventory. Various pc boards for the control systems are being assembled. Two wall-plate amplifier boards, which provide a suitably synthesized drive signal for the fast stabilizer of the C-W, have been calibrated and checked out and are now operational. Additional spare pc cards are also being assembled for other C-W control circuits. Spare units for the H^+ slow stabilizer are now available and have already proven useful.

Studies are continuing on identifying causes of high-voltage faults and on the optimizing performance of the H^+ injector at the present current level before increasing peak current to final design current of 50 mA_p. The fault rate fluctuates for reasons still not fully understood. Cathode deterioration was observed after four months of operation and apparently was one factor in increasing the injector fault rate, since improvement was noted after replacing this cathode. Tests have been carried out to increase the hydrogen pressure in the accelerating tube since there is evidence that as hydrogen pressure increases, the voltage at which breakdown occurs also increases. Pumps were turned off in the dome, thus increasing the hydrogen pressure in the accelerating tube. Some improvement was initially noted, but other operational problems interfered and the results are not conclusive. The x-ray level did increase with increasing hydrogen pressure, but had previously been reduced to rather low levels with the present ion source tuning. These tests will be continued to optimize tune of the injector for minimum fault rate.

H^- Injector

The H^- injector was operational all this quarter and has continued to be operated at the 0.5-mA level, except for a few runs at 0.8 mA with chopped beams.

The spare C-W chassis was tested on the H^- generator and it was found that the gain of the first

amplifier stage was inadequate for H^- operation although it did function properly in the H^+ C-W generator. Modifications in the final output stage were made so this unit is now an operable spare for both injectors.

The modification previously made to the hydrogen pumping elements now definitely show improved lifetime for pumping large amounts of hydrogen. Pump lifetimes in the H^- injector of six months can now be expected.

Polarized Ion Injector

The construction of the polarized ion injector was completed this quarter (see Table III-I) and the first polarized ion beam was accelerated at LAMPF on April 21. Polarization measurements were carried out both in the injector and at 800 MeV to confirm beam polarization. A polarized beam of ~20-pA-average current with 76% polarization was obtained on target.

In this beam test, initial tuning was done with the unpolarized H^- injector. A polarized beam with vertical polarization was then prepared, injected, and accelerated to a polarimeter in the EPB facility in Area B where a proton-proton scattering analyzer was used to measure beam polarization. Due to equipment difficulties, the ion source was operated at very low peak currents during this initial run. When running in the unpolarized beam mode, only 0.6 μ A_p of unpolarized beam was observed from the source where unpolarized beam currents of 50 μ A_p are expected. Polarized beam currents of 0.5 μ A_p will be obtained when the source reaches design performance. In the initial test, the polarization in the source was estimated to be 60% $\pm$ 10%, while the measured polarization at 800 MeV was 76% $\pm$ 8%. The apparent increase in polarization in the linac is not deemed significant at this point. The ion source is expected to produce 90% polarization at design operation.

Several operating problems were found during this first turn-on, but the source did run continuously for many hours after turn-on was finally effected. These problems are now being resolved in preparation for on-line operation of polarized beam during the last half of the next run cycle.

Some problems have been encountered when using an ion pump in a region with cesium vapor. Only

TABLE III-I

STATUS OF POLARIZED ION SOURCE COMPONENTS

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

x = Previously completed.

* = Completed this quarter.

experience will tell whether or not the ion pump will have to be replaced with a different type of pumping unit.

Several equipment changes have been necessary. The R- θ -Z positioning system for the accel-decel electrode has been modified to reduce friction. The X-Y positioning system of the focus lens has had speed reducers added to improve torque to the screw drive. The heaters in the cesium cell have been upgraded to heavier units to eliminate lead burnouts.

The magnetic field in the spin precessor has been mapped to determine its effective length, which was found to be 0.905 m for the two dipole sections

together. The spin precessor is now ready for on-line operation.

Modifications to the NOVA-based control system were made. All other systems seem to be working properly now, so intensity and polarization improvements will occupy most of the off-line time in the future. Work is also beginning on design of the rapid-reversal system.

Extensive work was done on the C-W generator this quarter to bring it to full operational status. Installation of equipment in the dome and of the accelerating column had precluded operation of the dome at high voltage for several months. Upon

resumption of high-voltage tests, several problems were noted. The rectifier stack required a large driving voltage resulting in arcing and corona on the drive lines, corona between the ends of subsequent rectifiers, and corona at the top of the stack. The column conditioned very well to the voltages attainable by the supply, i.e., to about 685 kV. At about 685 kV, corona became quite pronounced and usually resulted in tripping off the high-voltage supply. The corona balls at the end of the rectifiers were replaced by aluminum guards covering the rectifier ends. This modification helped greatly, but did not correct the corona problems on top and bottom of the stack.

Measurements were made to optimize the inductor configuration in the C-W rectifier. With the inductor at the bottom of the rectifier stack removed and the top inductor lowered 3.8 cm to increase clearances, the generator operated up to 803 kV with no difficulty. Some measurements of the voltage distributions up the stack have been made and more tests will be made prior to long-term operation to assure we are exceeding no limits. The power supply has now been run for several shifts at operating voltage for LAMPF and functions normally.

Injector Development

The prototype transistorized arc-pulse modulator has been tested on the ion source test stand and is now ready for initial beam tests on the H^+ injector. Some inductance is still required in the drive line to damp turn-on transients in the arc-current controller, but closed-loop current control is now obtainable over a wide range of arc current. It is anticipated that use of this system will stabilize some of the transients encountered because of the present requirement for turning off the ion source for all fast-protect faults.

The injector beam lines were rematched this quarter when peak current requirements for the H^+ beam were increased from 2.2 mA to 3.1 mA. Since new matching was required in the final doublets, the H^- beam also had to be rematched. Some improvement in emittance damping in both beams was observed upon rematching, but the vertical H^+ output emittance from the 201-MHz linac still remains ab-

normally large, and extensive vertical steering is still required to obtain operational tunes.

Work was started on testing different duoplasmatron geometries in an effort to increase the brightness of the proton beams from the LAMPF ion source. Present operation of the LAMPF duoplasmatron implies an input beam to the linac with a normalized emittance of 0.05π cm-mrad, which results in linac tunes that are marginal. Since emittance damping studies indicate a direct linear relation between input and output emittance, an improvement in the brightness of the input beam will result in a corresponding improvement in the tune of the linac. Modifications to the ion source and extraction geometry are now being tested in an effort to produce smaller, higher density beams prior to acceleration in the accelerating column.

The first attempt to obtain higher density beams involved using much deeper expansion cups, similar to those used at NAL and BNL. Very large arc current, up to 50 A, was required to obtain design beam current and resulted in enlargement of the anode aperture after several hours of operation. Further tests are now in progress using an intermediate cup size. Tests were also conducted using smaller diameter expansion cups and increased extraction gradients. This approach seems to give the most promising results to date.

Work has started this quarter on design of a converging Pierce beam for PIGMI. The formulation of Langmuir and Blodgett¹ has been followed and a solution has been obtained in terms of a truncated series of spherical harmonics. This solution was found for a 50-mA, 8-mm-diam beam which converges to 4 mm at 250 kV. The Pierce anode surface cross section is essentially a wedge having a 25° angle-to-plasma surface and the equipotentials are essentially spherical surfaces with their center at the center of convergence of the beam. This design requires very high exit gradients (in excess of 60 kV/cm) and will require careful engineering of the electrodes.

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IV. ACCELERATOR SYSTEMS DEVELOPMENT

Beam Dynamics

201-MHz Linac Field Distribution

In this quarter, it came to our attention that there is a bead-size effect on field measurements in uncompensated structures which manifests itself as an end-to-end tilt in the field distribution. The error is due to the strong cell-to-cell coupling, which causes the bead perturbation to influence the field of neighboring cells. An end-to-end tilt error in analyzing the beadpull data causes an effect in the amplitude and phase-scan interpretation which is similar to an error in injection energy, an assumption we had used earlier to bring the Tank 1 experimental data into agreement with the PARMILA computer simulation. The implications of this problem on the compromise tune for the 201-MHz linac will be explored in the next quarter.

Studies on the field distribution problem in Tank 1 continued and results were obtained using the new procedures incorporated into the RESFRE code. It now appears that if the gaps are changed according to the algorithm

$$\delta g \text{ g/L} = \Delta (1.0 \ 0.5 \ 0.25 \ 0.125 \\ -0.125 \ -0.25 \ -0.5 \ -1.0) ,$$

then the resulting field distribution is directly proportional to Δ . This appears to be quite promising as a method of smoothing the field distribution by distributing the initial and final gap changes over several cells.

Emphasis on this effort has now shifted to an attempt to verify these results using a modified version of the SUPERFISH code. The procedure involves perturbing several gaps at either end of a 15-cell structure according to the above algorithm and observing the resulting field distribution. Several new codes were developed to evaluate the integrals of the fields in each cell in order to obtain results which could be compared with those of RESFRE. Initial results look promising and work continues on refinement of the integration techniques.

Accelerator Structure Design

Design work for the PIGMI project using the SUPERFISH code continued with emphasis being placed on some of the higher energy portions of the structure. A code was written to optimize drift-tube-face angles based on geometric limitations. These optimization studies continue with the goal of obtaining final design parameters for PIGMI.

Transverse Dynamics

A large number of computer runs were made using the code PARMILA to investigate various aspects of experimental work completed on the transverse trajectories of the H^+ and H^- beams in the 750-keV transport, the 201.25-MHz linac, and the transition region.

Matching parameters at the linac input were recalculated and used to improve the production tune. It was found that further work is needed on the intertank matching. Computer evaluation of the technique of observing the beam width at the end of a tank while uniformly changing the strength of the quadrupole focusing in the tank indicated that a very good measure of the success of matching is possible. Some changes in the experimental technique were indicated; the method is ready for further use next quarter in achieving optimum matching.

Experiments were completed to assess the relative alignment of the 201.25-MHz linac tanks, the transition region quadrupoles and instrumentation, and the 805-MHz quadrupoles, and a beginning was made on the required analysis and computer simulation.

For the 805-MHz linac, the SIMALAC code calculates longitudinal and transverse dynamics through a side-coupled linac for sets of up to 500 individual particles. The code has been extended to allow modeling of certain transverse alignment errors, including tank head displacement and quadrupole doublet displacement and rotation errors. Measured alignment data for the 805-MHz linac, where available, have been incorporated in a file for use with the SIMALAC code. The code was then used to generate trajectories for the various classes of alignment errors acting singly and acting

The wire scanner re-centering experiment conducted by MP-DO and MP-2 was simulated using a modification of the SIMALAC code. In the experiment, the effective center of a wire scanner is determined by turning the previous quadrupole magnet on and off. The beam is steered into the quadrupole such that it drifts to the same point somewhere on the second wire scanner downstream with the quadrupole both on and off. With this steering, the beam is assumed to be centered at the quadrupole and first wire scanner. However, the calculations showed that for any incoming position at the quadrupole (not just the center), there is a corresponding incoming angle such that the beams for the quadrupole on and off will drift to the same point. The calculations were used to estimate the errors from this effect in the experiment of February 9-13, 1977. The estimated errors are larger than one would expect, considering only the longitudinal lever arms involved, but are less than 1 mm. Refinement of the experimental technique as suggested by the simulation would reduce the errors. Also, as better trajectories and matching are achieved, the beam profiles will be smooother, and a more accurate calculation of the centroid will result. Thus the experimental technique can be considered quite accurate in determining the effective magnetic axis of the machine.

A preliminary study indicates that the size of longitudinal beam oscillations in the 805-MHz linac may be roughly estimated from TOF measurements with different rf amplitudes. This is somewhat analogous to the method of measuring transverse oscillation amplitude in the 201-MHz linac by varying quadrupole magnet strengths. The Δt gear will be used to make the 805-MHz linac TOF measurements if further studies indicate that the method appears feasible.

measurements, and additional measurements involving groups of modules, would be used to refine the model.

A possible technique for extending the Δt technique to the 201.25-MHz linac was also conceived. Should this concept prove practical, it would provide a valuable check on the phase-scan procedure.

A 600-V operational amplifier and optional output booster was developed, as shown in Fig. IV-1, for driving the oscillation control electrodes inside TD-QL02. Two development runs were made to test these circuits in controlling H⁺ horizontal oscillations. The first one used the 600-V op-amp directly. The beam position was sensed at two locations using installed fast beam-position monitors (BPM) at the

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downstream ends of Tanks 2 and 3. Positional sensitivity of the beam to voltages applied across both the upstream and downstream control electrode pairs was measured at the two BPMs, yielding four sensitivity partials which were combined in an analog computer to solve deflection equations. The computer output then was used to drive the hv op-amps connected to each electrode pair. A reduction in pulse-to-pulse movement of the beam due to horizontal oscillation was realized, but most pulses produced an error signal from the BPMs which saturated the driver op-amp. The next attempt was made with the booster attached as in Fig. IV-1, but operated open loop. This time, control was exercised on all pulses with $B+ = 1500$ V (voltage swing on electrodes ~ 1000 V). Simultaneous reduction of the oscillation pattern was detected at modules 2, 3, 7, and 9. However, while the oscillation pattern was reduced, a coherent servo oscillation was introduced by the control loop causing excessive beam steering during the pulse. A good deal more work is required to make this an effective control technique, primarily in linearizing the high-voltage driver and compensating the closed-loop electronics.

Space-Charge Effects

The properties of the previously calculated equilibrium phase-space distributions were related to actual machine parameters. To determine this required the development of a computer code for calculating the transverse and longitudinal phase shifts including the effects of space charge. A pocket calculator program was also developed for determining the beam current and emittance given the appropriate accelerator and particle distribution parameters. These space-charge calculations were compared with those using a uniform charge-density envelope model. It is now possible to determine for a given accelerator and beam how near the space-charge limit one is operating and how large is the longitudinal-transverse mismatch.

A study using the PARMILA program was completed to assess the influence of various parameters on emittance growth due to space charge in the low-energy portion of linacs. Parameters investigated included longitudinal and transverse input emittance, the ratio of longitudinal to transverse emittance

(matching), accelerator focusing and synchronous phase laws, accelerating gradient, accelerator rf frequency, and injection energy. The results of this study and the work outlined above using the equilibrium distribution approach agreed generally in all aspects.

The studies in this area to date indicate that a great deal is yet to be learned about space-charge phenomena, and the combination of space charge with other errors, when considering linac applications requiring very high beam quality and/or very low beam loss in the machine. Pertinent directions for further exploration of the parameter space were revealed during the studies this quarter, and the need for continued development of the computer codes became even more clear.

Two code problems are particularly apparent. First, the available space-charge routines have various difficulties with mesh dependencies, calculational speed, and resolution for problems of current interest. Second, an improved technique is needed for fitting a surface to an arbitrary multi-dimensional collection of particles in order to characterize the way the distribution changes as it moves along the accelerator. Of particular interest are the effects of space charge and magnetic-field aberrations.

Mathematical techniques have been developed for fitting a four-dimensional ellipsoid around a set of points in transverse phase space (x, x', y, y'). Specified data are first standardized through a translation of coordinate axes followed by a similarity transformation to remove the cross-product terms.

Depending on the density distribution, different modes of characterization are then appropriate: 1) an actual surface shell distribution is well characterized by a least squares fit to an enclosing shell; 2) a uniform distribution is well characterized by using a second moments approach to define an enclosing hyperellipsoid; and 3) an arbitrary distribution may be handled by a minimization approach, using the hyperellipsoid of minimum size which encloses all the data. (The latter emerges as a linear programming problem.) Numerical investigations are under way.

A version of PARMILA transferred to LTSS in anticipation of code development to increase the efficiency of space-charge calculations.

Permanent-Magnet Modeling

The new magnetostatic computer code PANDIRA was finished during this quarter. A principal use of this code at LASL will be the computer-aided design of the PIGMI permanent-magnet quadrupoles. Preliminary designs for PIGMI have been investigated and prototype magnets will soon be fabricated.

PANDIRA, a computer program for anisotropic magnetostatics solved by a direct method, is a general-purpose code for problems in two dimensions and cylindrical symmetry. Preliminary attempts with this code to solve permanent-magnet problems [B(H) in the second quadrant] were unsuccessful. An extensive literature search revealed that a realistic model of permanent-magnet material must include the very strong anisotropy which such materials exhibit. With the help of K. Halbach, LBL, the finite difference equations for anisotropic materials were developed and incorporated into the code. This development allows not only realistic modeling of permanent-magnet materials, but also the solution of residual field problems in circular accelerator magnets. An example of the flux plot produced for a quadrupole magnet design using permanent-magnet material in conjunction with shaped iron pole pieces is shown in Fig. IV-2.

During this quarter, nine requests were received from other research institutions and universities in the USA, Canada, and Europe for copies of the POISSON GROUP PROGRAMS including SUPERFISH and PANDIRA. Work was begun to prepare suitable documentation so that these programs may be distributed.

Beam Profile Studies and Halo Analysis

The technique for fitting a bivariate Gaussian core to data from one wire scanner was subjected to extensive numerical and graphical experimentation. Test cases studied included those with data generated from sums of two and three Gaussians so that this core/halo fitting procedure could be assessed. Also, a code was developed for determining the number of terms to retain when approximating a measured-beam profile by a sum of Gaussians.

Beam profiles were measured with over 10^4 dynamic range. The data from the first experiment

Fig. IV-2.
Permanent-magnet quadrupole flux plot solution from PANDIRA. The poles consist of a block of permanent-magnet material and a shaped iron pole piece.

were fitted to sums of one, two, and three Gaussians; the three-Gaussian hypothesis is in best agreement with the data. Two of the Gaussians are similar in magnitude; the third is quite small and is required to explain the beam tails. Previous beam-profile studies in the switchyard also indicate that the beam has two major components. The χ^2 of the fits are much larger than expected, possibly indicating underestimated experimental errors and incorrect values of the amplifier gains. Laboratory tests of the amplifiers and preliminary results of our second experiment indicate that these high values of χ^2 could also be the result of our attempt to fit the profiles without including the effects of the beam horizontal oscillations. At a fixed wire-scanner position, the measured beam amplitude may vary from 4 to 25%, depending on where along the profile the measurement is made. Future analysis of the beam profiles will include greatly increased errors to reflect these fluctuations. If the beam still appears to be made up of two approximately equal components, we will follow their behavior in modules 8 through 12. Our initial impression is that the two components behave quite differently as they travel along the linac.

During beam studies the effects of wire bias and scanner-to-scanner interference were observed. A

90-V bias voltage, applied to each scanner wire, adequately prevents the collection of secondary electrons originating from the other wire, at least for the vertical profile measurement. Without this bias voltage, artificial dips appear in the vertical beam profile whenever the scanner wire measuring the horizontal profile intercepts the main portion of the beam. It was also found that beam profiles are significantly altered when upstream scanner wires pass through the beam. Therefore, although we have the capability of simultaneously measuring profiles at three modules, wire scanners must be run individually for detailed profile analysis.

Long-Term Stability Development

The format of the rf-stability plots was updated to match current operating requirements. The phase diode signals were deleted and redundant cavity field signals were added for the 805-MHz linac plots. Also, the rf-stability plot program was modified to permit the accumulation of data from the recording file in one pass rather than two.

Diagnostic Equipment Development

Beam-Position Monitors

The first integrated circuit detector chips for the BPM were received and tested; some modifications were required. The power supplies originally planned for the system have been rejected due to failures caused by overheating. Procurement of all long-lead components for the system is complete with the exception of the power supplies. Final development of the amplifier circuits, range switching, filtering, and component selection is under way.

Beam-Profile Instrumentation

The installation of the multigain wire-scanner amplifiers in the accelerator tunnel eliminated most of the noise, oscillation, and grounding difficulties experienced in the equipment aisle. Other modifica-

tions to the gain-switching latchback circuitry were also successful, and the units now operate with good resolution and reliability. Development of a final packaging configuration and investigation of the required wire-scanner biasing continue.

Tests were completed at 100 MeV on the finger device for directly measuring the x-y density distribution. The device used 20 fingers plated onto a ceramic substrate. Difficulty was experienced from charging of the substrate.

Emittance Gear

Fixed slit EM-3 jaws, 0.3-mm aperture, were installed and have been used by operations.

Δt Hardware

Prototype pc boards for the Δt phase controller and encoder-decoder were procured, stuffed, checked out, and installed.

A new Δt phase controller has been designed and tested for use with the new commercial phase shifters. High-voltage op-amps have been ordered and will be used in the construction of controllers and installation of the new phase shifters. Installation of the new phase-limiting rf amplifiers was completed; all rf amplifiers are now of this type.

Most of the installation for automatic simulation of Δt has been completed. The Δt rf system has been modified to make the simulation and system checkout possible from CCR.

RF Systems Development

Some rf permissive and fast-protect problems which occur at the beginning of the rf gate and end of beam gate were investigated and a potential solution has been proposed. This includes minor modifications to both systems and distribution of proper gates to both systems from the new master timer.

The control system installation for the PIGMI 450-MHz rf test stand was completed, checked out, and is now operational.

Beam Diagnostic Hardware Maintenance

The specifications of a microprocessor-based cart for testing and maintenance of beam diagnostic hardware have been completed and purchase orders for the equipment have been written.

Temporary use was made of the microprocessor-based portable beadpull electronics to run reproducibility tests on a wire-scan actuator on the bench.

New Beadpull Apparatus and Software

The period counter board was modified to include a 10-kHz low-pass filter on its input. The data generated by a signal generator collected by this board have noise only in the least significant 2 of 15 bytes.

Software has been written which tests the graphic capabilities of the new beadpull system by drawing a grid, writing the 128 ASCII characters of the character ROM, and drawing vectors from point to point to form a star pattern. A test routine has been written to run the beadpull motor left or right or stop it, take various actions when a limit is reached, and save, plot, and list data generated by the period counter. These programs are built on the general push-button monitor routine.

Collaborative Programs

Injector Arc Pulse Modulator Controller

The new arc pulse modulator worked well when driven into a resistive load, but was not satisfactory on preliminary tests into the actual ion source load. Development is continuing.

LH₂-Cooled RF Cavity

A test program to determine the benefits to be gained from operating a high-power rf cavity at liquid hydrogen temperatures has been undertaken. It is anticipated that a Q-gain of almost 10 can be realized through the use of this inexpensive coolant and that high accelerating fields may be realized with a proportionately reduced power dissipation in

the cavity walls. The cavity will be operated in a pulsed mode at 450 MHz. At this frequency, the Kilpatrick Criterion indicates the possibility of vacuum sparks at ~ 20 MV/m with clean but not especially prepared metal electrodes, in practical vacuums, and in the absence of external magnetic fields. This implies that potentially very high field intensities lie within the test region. The rf surface resistivity of copper follows classical theory down to about LN₂ temperatures, but deviates considerably due to anomalous skin effect at LH₂ temperatures, where it is reduced to essentially its minimum. Thus, tests will use successively reduced temperatures starting at room temperature and working down through liquid nitrogen, neon, and hydrogen.

A batch immersion dewar has been designed to contain the cavity (see Fig. IV-3). The cavity has been designed with thin walls for good conductivity, and attention has been given to fin-strengthening to prevent excessive deformation under vacuum. The cavity will be demountable for inspection and is equipped with adjustable drive loop and sensor probe, combination vacuum and view port, and

Note: Vent, Fill Lines, and Relief Valves not shown.

Fig. IV-3.

Batch immersion dewar and cooled rf test cavity.

thermocouples for monitoring average operating wall temperatures. All seals are selected for bakeout to 450°C, since without bakeout the cavity will cryopump organics onto the electrode surfaces and reduce sparking thresholds dramatically. The dewar design follows techniques used by CTR-9 and employs a G-10 fiberglass inner shell and a polyester-resin outer shell evacuated in between and enclosing multiple wraps of polymylar radiation film. The cover is insulated from the cold interior by the high resistivity of the G-10, poured foam insulation, multiple radiation baffles, and gas space. The design is complete and detailing is under way.

Biomed Range Shifter

The range shifter continues to operate reliably for patient treatments at Biomed. The only failure logged this far has been a potted power supply in the analog control section of the system. Some improvements to the command section have been made to reduce teletype-MPU interactions with the operator and to hold to a minimum the command functions required for effective treatment control.

The second-generation range-shifter design effort was continued this quarter with major improvements made to the functional package (see Fig. IV-4). The revised design is very efficient, giving an 18-cm stroke in a 30-cm package depth. The cone has been reduced in diameter to a bare minimum, and the unit will be equipped with windows thinned down for a 1.1-cm-minimum thickness. The new range-shifter head will attach to the existing jib boom by means of internal tension studs and side plates. The boom will be trimmed back slightly and the hydraulic hardware inside the boom will be relocated. The cone will have mounting holes to allow the attachment of ancillary hardware (70-kg-max) to the range shifter. The transducer will be immersed in oil within the tank and will use two single-turn potentiometers for redundancy, a tachometer, and a Biomed-standardized absolute shaft encoder for direct digital monitoring of performance.

The software for the crate controlling the voltages output to the range shifter has been updated. The main system program now monitors the control panel, and the teletype monitor program is available, if needed, to load new tapes. Several new treatment table PROMS have been produced.

Fig. IV-4.
Second-generation Biomed range-shifter design.

Biomed Servo Collimator

A servo-controlled collimator is being designed for x-axis control of fan beam width at Biomed (see Fig. IV-5). This is basically a position servo in which each jaw is independently controlled within its own position loop. The drive is all electric and employs a dc torque motor, flexible belt, and sprocket to move the jaws. The unit is designed for a minimum thickness of 3.5 cm, but can operate with thicker jaws up

Fig. IV-5.
Biomed servo-controlled collimator.

to 7 cm for maximum energy beams. The added jaw material does not affect the thickness of the rest of the unit which is based on the 3.5-cm dimension. The collimator is cantilevered off the boom, allowing it to be rotated out of the way during patient-setup without moving the range shifter. The basic design parameters provide a maximum closing rate of 26 cm/s.

EPICS Separator

The oil-filled high-voltage termination of the separator failed during this quarter, presumably from oil contamination resulting from sparks and possibly radiation damage. Disassembly of the rigid hv line showed considerable carbon blackening of the upper insulator and some surface spark tracks on the lower insulator. A light deposit, possibly sulphur, coated the hv conductor in the SF_6 . This line has been operated at 340 kV and has been installed about a year, but quickly deteriorated once failures began and ultimately would spark at 100 kV. Several small changes are being made to the internal parts, especially to the bonding of the ceramics to the stainless steel. No unusual damage was noted in either the series resistor or the voltage divider assembly although some evidence of heating could be seen in the divider resistors. Provision is being made to change the termination oil periodically, and routine maintenance may also dictate changing the SF_6 on some schedule. Additional shielding between target A-1 and the hv line may also be provided.

Delivery of the new 400-kV power supply is expected during the summer.

Hydraulic Servo-Arm Development

The single-degree-of-freedom master-slave operational model was put into operation this quarter following completion of the hydraulic plumbing and the control electronics. First tests showed that the two essential functions are provided by the system: positional tracking and force reflection. However, the quality of these functions was not good because of static friction in the actuator seals.

The mechanical linkage was altered to reduce the manual force gain from 2:1 to 30:1 with pin adjustments, allowing the servo valves to operate at considerably higher pressure without producing excessive force on the control lever. Unfortunately, this fix could not be tried because of persistent leakage at the servo-valve manifolds, which became excessive at elevated pressures. The valves have been returned to the manufacturer for warranty repair, and an analog computer simulation of the control loops was set up to aid in development of the servo system.

Operations-Support Development

Operations/Maintenance Equipment Reporting Data Base

A new, simplified scheme of unit numbers for the operations/maintenance data base was implemented during April. The inventory of unit numbers was reduced from over 800 to ~350. A one-page sequential listing of unit numbers, excluding rf and unit numbers called by device, has been given wide distribution to aid personnel in filling out the operation reports.

The device file (equipment in the SY and beyond) continues to expand and now contains some 350 device types. Experimental Area A and its secondary beam lines will be added during the next quarter.

The daily report program required extensive modification to accept the smaller inventory; the new version is now being used.

General Support

Implementation of the AREA A JOBS data base proceeded smoothly, concentrating on training of personnel to operate the system. Systemic analysis consulting was provided to MP-1 in designing a new data base for computer maintenance activities. Improvements were incorporated in all data bases; maintenance and operational assistance were provided when needed.

Bibliographic Data Base

Programs were written to conveniently add microfilm reel and frame numbers to the data base

as documents are filmed. A second set of documents totalling about 3200 pages was filmed. Work continued on the compilation and editing of material.

V. ACCELERATOR SUPPORT

201-MHz RF Systems

An average of 1960 h was accumulated on each of the 201-MHz rf modules. This is 96% of the total time available during the quarter.

Four 4616 driver tubes failed during the quarter. Three failed with control grid shorts and one with a vac-ion pump failure. One tube is being returned to the manufacturer under warranty for repair and evaluation.

The prototype oil-immersed screen supply transformer was completed and installed in an IPA modulator for evaluation at the test stand. Two more of the epoxy screen supply transformers failed during the quarter.

Design was completed and p.c. cards fabricated for the 4616 plate voltage controller. Implementation awaits delivery of an operational amplifier for the card.

The plate voltage detector for module 1 was completed and installed.

Brakes were installed on the tuning mechanisms for the 7835 final amplifier cavities in modules 3 and 4 and at the test stand. A new spare 201-MHz tuning slug was fabricated and assembled.

The spare lower-half 7835 amplifier cavity was disassembled and 6-mil fingerstock installed to replace the 4 mil stock supplied with the cavity. The cavity will be installed at the test stand, to insure that it mates properly with the original hardware, and checked at high power.

Modifications to the test stand for 4664 operation were completed and three 4664s were processed for Tank 1 final amplifier spares. In addition, testing and processing were completed on four small modulator tubes and three 4616s.

The 7835 that was removed from service during the previous quarter was gas-checked satisfactorily, and the current being run for the gas-check cleared the low resistance between control grid and cathode. A final high-power test of the tube will be run early in the next quarter.

805-MHz RF Systems

Final modifications to the 805-MHz resonance controllers have begun. The present power supplies

are being replaced with precision power supplies that will improve interchangeability and stability. The resistors in the temperature-sensing circuit are being replaced with resistors that have a temperature coefficient of ± 1 ppm per Celsius degree. An out-of-tolerance temperature alarm circuit is being added to alert operations when a water valve needs to be replaced. When the water temperature error exceeds one-tenth of a Celsius degree, warning lights on the front panel will come on and a normally closed pair of relay contacts will open to alert the computer.

The temperature of the cooling water supplied to the mixing tanks in Sector D is being monitored to determine what temperature results in the best resonance control.

Drawings for the MI and MII tank resonance controllers have been updated and new instructions have been written for calibration of the p.c. cards.

A controller and thermistor assembly that covers the range of 18 to 24°C were prepared for use in the Bucket Rotator.

A quad magnet power supply system was designed and constructed for MP-8. It will be used in the testing of quad magnets at EIL.

Since one of the main weaknesses of the quad magnet power supplies is the Variac drive motor, two lower gear, higher torque motors are being evaluated. The first motor has cycled the Variac the equivalent of once a day for 10 years with no problems. It will now be put into service and the second motor will be given a similar test. Because a few quad magnet power supplies are difficult to reset after tripping at a high setpoint, an automatic setpoint run-down circuit has been incorporated in one of the supplies. It is installed in module 21 for evaluation.

Several changes were made in the Δt system. The original tube-type amplifiers have been replaced with solid-state amplifiers. Printed circuit cards are being constructed for the decoder-encoder system. One set of these cards was completed and tested. The Δt simulation system is being converted from a manual to an automatic system. This will eliminate delays in use that often result in inaccuracies.

The capacitor room fan test stand has been completed and the first set of eight fans has been run in for 143 hours. The test stand should improve reliability by revealing those fans that will fail during their early life.

A system to monitor and digitally display forward power, reflected power, and cavity field has been designed, constructed, and installed in module 21 for evaluation.

The first set of data from the current RG-218 insulation growth test indicates that the insulation expansion is a function of both being immersed in oil and of temperature rise. Previous studies indicate that the rate of growth will decrease with time and may even stop completely.

Other activities included the following:

1. Six new ion pump power supplies for WNR were modified to remove flammable materials.
2. The maintenance responsibility for the standard ACI, ACII, BCI, BCII, MOE, IND, Relay, and Meter NIM modules was taken over during the quarter.
3. The Belden 8871 hv cable under test at ETL has 12 285 hvh and 10 894 h drawing current.
4. The rerouting of the tank power signal to CCR was completed.

Low-Level RF Systems

Upgrading of systems in the 201-MHz and 805-MHz source has been an ongoing project for some time. Based on the results of last quarter's study of phase and amplitude stability, several changes have been made in the control loops, and a solid-state 201-MHz buffer amplifier has been installed to replace the tube-type amplifier which was shown to be contributing to phase instability.

RF power meters have been purchased for the source and are being installed between stages and on the output of both amplifier chains. These meters will replace the present units which are no longer considered accurate enough for amplifier tuneup.

The 201-MHz solid-state IFA drawings have been released for construction of 14 units.

The prototype 805-MHz solid-state IFA has been extensively tested and has either equalled or outperformed the tube-type IFA in all respects. Feedthrough power between pulses and phase shift with changes in output power is much lower. A comparison of reliability, the big problem with the tube-

type units, will be made by constructing five more solid-state IFAs and retrofitting one sector with these units. Only operating time will answer the reliability question for sure, but every indication is that these units will be far more reliable than the tube version.

The 12-MHz timing signal from the H⁻ beam chopper has been provided to several new experimental locations. The experimenters find this signal useful in maintaining proper phasing in TOF-to-rf measurements with chopped beam. Experimenters also use the 201-MHz signal derived from the 805-MHz drive line; the question has been raised as to the phase stability of the latter signal relative to the 201-MHz signal from the source. To make this comparison, the signal from the source was brought down to the end of Sector H on the high-quality coax line recently installed in the beam channel to provide a temperature-controlled environment. A 3-day comparison of the two 201-MHz signals showed a 0.2° oscillation with 1-h period, a 0.3° shift over 12-15 h, a step change of 0.6°, and one 4-5-h period with a 1° shift. The maximum deviation noted during the 3-day period was less than 2° (~30 ps).

Phase and Amplitude Control Systems

The repair, refurbishment, and modification of phase subsystems are complete through module 24. The redundant phase-monitor system has been completed, and data obtained during the last two months of operation indicates that all units are functioning as expected.

Resonance problems in the 201-MHz tanks have prompted the development of a tuning slug resonance-control system. A prototype system has been built to help obtain temperature response information on the 201-MHz tanks. This information will be used in the design of the final system. Preliminary data obtained on Tanks 2 and 3 indicate that this approach is sound.

Since higher beam currents are being used in the accelerator, more feedforward adjustments are now required. To increase the ease of these adjustments, the pots have been mounted externally to the phase and amplitude control chassis. Installation of the modified units is complete through Sector F.

Beam Diagnostics

A new method for storage and organization of spare parts was devised which appears to be quite helpful. A review of all beam diagnostics systems drawings and the writing of maintenance manuals and procedures for beam diagnostics systems continued. Operational testing on the beam diagnostics systems linear actuators using the central control computer continues to demonstrate the importance of this method in the early detection of equipment problems.

A modification was designed to facilitate the adjustment of the oscillator on stepping motor driver cards and the adjustment of the position pot signal amplifier zero offset. All Type II and standard linear actuator drive modules in use in the accelerator control system (approximately 150) were modified, tested, and reinstalled.

Mechanical assembly was completed for the 12.5-cm stroke linear actuator to be used to insert a harp at the end of the drift-tube linac.

Emitance jaws with manually adjustable slits were designed, fabricated, assembled on linear actuators, and installed at station EM-3. Testing of the jaws was initiated.

Design was initiated for the installation of a wire scanner, with its associated control and data system, between Tanks 3 and 4 of the drift-tube linac. The wire-scanner actuator and wire-scanner device have been assembled.

Power Supplies

All dual-Acme power supplies have been rebuilt and converted to use the LAMPF standard regulator and standard control and metering chassis.

The installation work on Line 1L of the WNR facility is complete. Six power supply systems and four bypass shunt systems were installed and checkout is under way.

The three Lin_g power supplies for the quads in EPICS have had transducers installed, and modifications to these supplies are complete.

The rebuilding program continues on the 2000-A reversing switches.

A new control system for the Lines A and X bending magnet power supplies has been completed and installed on the Line A (LAMP05) power supply.

The new system features memory on all interlocks, proper reversing-switch control, LAMPF standard on/off control, and ground current monitoring.

A new control system for the HRS spectrometer magnet power supplies has been designed and built. It will be installed in the supplies late this summer.

The new shunt amplifier card, using a special isolation amplifier, has been on test in Line D for two months. It appears to have adequate stability and a common-mode rejection ratio of 160 dB. Ten more amplifiers have been assembled and are ready for installation.

Vacuum Systems

Vacuum support of the accelerator included diagnostic device and actuator maintenance and the replacement of an rf window, an ion pump, and four ceramic ports for sampling loops. Additional fabrication and installation of Line C equipment was the major effort in the experimental areas. Assembly of beam line components in Lines B and EP required moderate support. Fixtures for test and evaluation of beam diagnostic hardware are being designed to help insure adequate reliability of the devices.

Installation of cooling-water and air systems on the EPICS spectrometer was completed.

Reliability

Operations and maintenance reports are studied regularly in an attempt to pinpoint those units with high failure rates. Table V-I tabulates those units with the most failures during the second quarter of FY-77. All other MP-11 units had seven or fewer faults during the quarter.

The total number of klystron crowbars for the first quarter of FY-77 was 170 or an average of 2.64 per day, a slight increase from the previous quarter. Of the 170 crowbars, 88 were on the 6 Litton tubes and 82 were on the 38 Varian tubes.

A comparison between the reports for the first quarter of FY-77 and the second quarter of FY-77 reveals a slight improvement in all categories except "Equipment Downtime." The mean time between failures decreased slightly from 5.6 h to 5.48 h.

When all aspects of the above are considered, MP-11 equipment reliability was about the same as the previous quarter.

More detailed reliability reports are available from the MP-11 Group Office.

TABLE V-I
MOST FREQUENT FAILURES OF RF UNITS

<u>Unit No.</u>	<u>Name</u>	<u>Section</u>	<u>No. of Failures</u>
1147	Modulator switch tube	805	38
2001	Quad magnet power supply	805	18
2034	Wire-scanner amplifier	Beam Diagnostics	11
1111	IFA	Low Level	9
1142	Klystron	805	8
2011	Steering magnet power supply	805	8
103	G-2 modulator	201	8

VI. ENGINEERING SUPPORT

LAMPF Accelerator

Support

In support of the program to reduce the beam oscillations in the accelerator, a pulse transformer system was designed for the proton beam deflector plate. The transformers are now being fabricated and tested.

A water-cooled collimator to be installed in front of the quadrupole doublet magnets in the early section of the 805-MHz portion of the linac is in the design stage. A prototype model is being fabricated to study the ability of the aluminum vacuum seals to survive thermal shocks.

The aperture card reader/printer installation is complete. An aperture card record can be viewed on the screen, printed as a 460-mm by 610-mm drawing, or half of the aperture card printed as a 330-mm by 460-mm drawing. The computer drawing file program prints a cross-referenced index by drawing number, by name of the originator, and by key word.

805-MHz RF System

The VA-862A klystrons have accumulated 1.17 million fh with 15 failures, two of which were repeat failures of earlier repairs. There are now twenty-four VA-862A klystrons with more than 20 000 filament hours. The oldest unit, operating in Sector B, has accumulated 33 000 fh. Two of the LAMPF rebuilt klystrons have logged over 14 000 fh. Eight of the ten VA-862A klystrons ordered have been received, tested, and accepted.

The L-5120 klystrons have accumulated 180 000 fh with 19 failures. Three were repeat failures of earlier repairs. One original L-5120 has 20 000 fh, and one LAMPF rebuild has 15 000 fh.

The LPT-44 modulator triodes have logged over 1 181 000 fh. Thirty-three of these have been scrapped. The tubes can be reprocessed; however, it is not economically feasible to repair them. There are twelve LPT-44 triodes with more than 20 000 fh, and two of these have accumulated 26 000 fh.

Klystron Repair Facility

During this quarter, 28 klystrons were installed at ETL for checkout, processing, repair, or clean up, with a maximum of 5 klystrons serviced in one week. Two VA-862A klystrons and one L-5120 klystron were repaired during the quarter. Five units now in the repair cycle require extensive machining and brazing to rectify vacuum leaks and damaged nose cones. Six klystrons were removed from the accelerator for processing. Five were successfully processed, and one exhibited vacuum problems and may have to be rebuilt.

Fifty-five LPT-44 triodes have been processed this quarter; four were sent to salvage, and seven may be scrapped if recovery proves unsuccessful.

805-MHz Modulator

A solid-state modulator for the 805-MHz klystrons is being designed, and a prototype is under construction. The unit will have 40 parallel output transistors driving two transformers in series, with an overall voltage step-up ratio of 1600:1 to 80 kV. The first transformer will be in the equipment rack, and the final transformer will be in the modulator oil tank to pulse the modulating anode.

Injector Area

Most of the components of the polarized ion line were processed through the tooling dock prior to installation. Following installation, alignment of all of the major beam-line devices including quadrupole magnets, beam boxes, and spin magnets, was completed.

Experimental Lines

Weapons Neutron Research Facility — Line D

Mechanical design of the WNR fast-kicker magnet is complete, including the vacuum chamber, support structure, electrical feedthroughs, electrical connections, and load resistor. Detail drawings are presently in preparation.

The order has been placed with a vendor for fabrication of the m.i. coils for the radiation-hard version of LD-BM-00. The detail drawings of the core are nearing completion and can be finished when the final field clamp configuration and pole profile have been established through the use of analytical field study programs.

Engineering input has been provided for the storage ring vacuum-system design.

Beam boxes and diagnostic devices were aligned in the beam dump area, and follow-up alignment surveys were performed on the flight tube.

Energetic Pion Channel and Spectrometers

The two large spectrometer magnets, EA-PM-05 and -06, were aligned. After installation, the three quadrupole magnets EA-QM-01, -02, and -03 were aligned in the spectrometer frame. To provide an accurate rotation-reference system for the spectrometer system, optical-alignment monuments were fabricated, positioned, and installed.

The fabricated parts for the spectrometer detector frame have been completed and delivered to the ETL building for staging. Precision assembly and doweling of the frame will be performed at the tooling dock prior to installation on the spectrometer in the experimental area.

Experiment Support

Twenty-one experiments received significant support this reporting period. Many devices fabricated for prior experiments are being adapted for use in subsequent experiments, and an increasing stockpile of versatile equipment is being accumulated. Some innovations were the successful forming of large prototype mirror blanks and the second successful application of a permanent-magnet in the experimental area. Ten of the new water-cooled coil sections for the Ames C magnet have been received. The magnet is being reworked on a time-available basis.

Significant support was provided on the following experiments:

Experiment 4 (HRS). An extension structure was provided to increase the height of the platform at the HRS scattering chamber.

Experiment 25 (LEP). Engineering consultation was furnished concerning the design of a target chamber and attachment of a 0.25-mm Mylar window for a water target.

Experiment 27II (EPB). The design, fabrication, and installation of the polarimeter target chamber was completed (see Fig. VI-1). Fabrication and installation of the chamber stand in EPB, along with the phototube support brackets, were carried out during the mounting period prior to Cycle 13. The EPB beam line vacuum pipes were designed, fabricated, and installed in the experimental portion of the line. The system was isolated upstream and downstream from the rest of the EPB beam pipe. Chambers, stands, targets, and beam pipe were aligned during the set-up period. Planning has commenced on the Cycle 15 phase of this experiment which will use a polarized target magnet. An engineering analysis was completed on a scattering chamber under construction at Case Western Reserve University. The new chamber will replace the one presently in use. An LH_2 target-support apparatus was constructed that allows 100 mm of motion to elevate the target above the beam. This apparatus attaches to the support structure now installed at the target position.

Experiment 29/54 (LEP). A platform was built and attached to the Bicentennial magnet and stand. This platform allows the experimenter to have access to the detector chambers mounted above the

Fig. VI-1.

Complete polarimeter as installed in Line EPB.

magnet (~4 m above the floor). Existing bolt holes in the magnet core were used for mounting this structure, and the platform can remain in place on the magnet during subsequent moves.

Experiment 50 (LEP). Field assistance was furnished for the demounting of this experiment. The tritium cart track system, reported last quarter, was placed in storage. The twin "C" magnet was transported on the pad system from the LEP cave to temporary storage on the air-pad platform along the south wall of Area A. The air-pad transport system, when used over a sheet metal interface on the floor, has proven to be an effective means of transport.

Experiment 65/66 (B). Fabrication drawings of a magnet stand have been completed for the polarized beam target magnet. This stand can be attached to the spectrometer presently in Area B. A detector cart design is presently 50% complete.

Experiment 93 (P³-East). Support continued during the remainder of the run including alignment assistance and minor modifications to portions of the structures. The main activity was removal of this setup in preparation for Exp. 201. This required the complete removal of the Kon-Tiki spectrometer stand, floor tracks, 30D40 magnet, and the Ames C magnet and structural components.

Experiment 96 (LEP). Design continued on the detector holders and mount for the target-scattering chamber.

Experiment 130 (EPICS). Two mirror blanks were formed using the ETL brazing furnace as a forming oven. These blanks were sagged successfully into a graphite mold having a spherical cavity which allows a 25-mm sag on a 1-m² plate glass blank (~13-mm thick). One plate thickness formed in this mold was 6-mm thick, the other 12-mm thick. These blanks were given to the user for further processing. A total of four blanks will be required for the Cerenkov chamber planned for this experiment.

Experiment 137 (EPB). The design and drafting of an optical bench were completed. In preparation for some beam measurements, the Model L side-coupled cavity was moved to EPB along with its modified support structure. (This 5-cell prototype linac was used to obtain a current signal by extracting rf power from the EP beam.)

Experiment 179 (B). The existing setup was modified by designing, fabricating, and installing a special long-stroke target actuator in the main scat-

tering chamber. The actuator has been used and operates satisfactorily. A target ladder was also fabricated for the actuator. The ladder is an aluminum frame holding an aluminized Kapton foil.

Experiment 181 (LEP). Major design, drafting, and fabrication effort continued on the π^0 spectrometer stand. Portions of the stand are being assembled in ETL, and the remaining components requiring redesign are being detailed. Drafting continued on the crate rotator, outboard cable support, detector crate, and front support frame. Two detector crates and two frames are presently being fabricated; standard hardware items for these units have been ordered. The multiwire chambers were designed and drawn, material was sized for these chambers, and the printed circuit artwork is in progress. One complete prototype chamber was fabricated, wirewound, and assembled. This chamber is presently under test by the user. The fabrication of 30 mounting tubes for the 130-mm phototube assemblies is complete.

The columns, reported on previously, are being modified to allow for higher cantilever loads on the mounting carriages in order to reduce structural deflection of the detector crates during operation. Design changes are being made to the support carts to provide maximum position flexibility for the detector crates. Several items of hardware including lasers, casters, and screwjacks, for use with the columns and carts, are on order.

The one-eighth scale model of the π^0 spectrometer system has been modified to reflect the design changes made this period.

Experiment 201 (P³-East). This experiment was set up in the P³ cave. Floor track plates for two sets of tracks supporting three instrument arms were fabricated and installed. Modifications were made to strengthen the 5.5-m and 3.5-m arms furnished by the University of Virginia. The experimenter's pivot pedestal was also modified to incorporate an adjustable alignment mechanism for supporting the scattering chamber. Alignment assistance was furnished during the experiment setup.

Experiment 222 (P³-West). Support to this experiment was in the form of alignment assistance of a continuing experiment. Five large solenoid coils were fabricated for use on this experiment.

Experiment 276 (SMC-West). A 4-kG permanent "C" magnet, obtained and tested for use in this experiment, performed satisfactorily. (This is the second time a permanent-magnet was incorporated in an experimental setup at LAMPF.) Built-up permanent-magnet assemblies are being investigated for possible use by the engineering staff.

Experiment 286 (P³-West). A redesign was completed for the rotation and linear motion actuator previously reported. A job order and purchase request were prepared covering the items needed to assemble this mechanism. The servo indexing motors for the mechanism were furnished by the user.

Experiment 323 (EPB). The major effort was assistance in removing the setup to make way for Exp. 27II, which was mounted prior to Cycle 13.

Experiment 328 (SMC-West). Because of the compressed time scale for this experiment, it is receiving intense engineering support. A series of magnetic shielding tests were run using the Ames C magnet. These tests provide confidence that a magnetic field of ~ 1 G can be obtained at the target using passive magnetic shielding. Design and drafting have been completed on a crate frame for the 45 NaI crystals weighing 1500 kg. This design was approved by the user, and fabrication has started. A stand to support the NaI detector and associated shielding is being designed. Also, a carbon-steel beam pipe and target shield are being designed to shield the SMC beam from the experimental magnets.

Experiment 329 (SMC-South). An engineering planning review revealed that no unusual requirements were apparent for the low-field portion of the experiment, and the mounting of the experiment can be handled in a conventional manner.

Metrology Lab

A series of measurements was taken on the accelerator beam boxes and actuators to determine the accuracy of the components, accuracy of the assembly, and repeatability of positioning.

Two WNR beam boxes and actuators were processed through the tooling dock.

In preparation for installation in the polarized ion line, two quadrupole magnets and a spin precessor magnet were fixtured in the tooling dock.

Assembly, functional tests, and deflection measurements were performed on the two columns constructed for Exp. 181. Minor corrective rework was performed to minimize the deflection under load.

Fabrication

The fabrication effort this reporting period was as follows:

Experiment Support	50%
Accelerator Support	29%
Klystron/Ion Pump Rebuild	17%
Other (PIGMI, WNR, EPICS)	4%

A total of twenty-nine H₂ furnace heats were completed for various brazing and bakeout purposes. One new application was the formation of large spherical mirror blanks for use in Exp. 130.

Three 2400 l/s and six 500 l/s ion pumps were rebuilt and tested during this reporting period.

Outgas rate measurements and ion pumping speed measurements were conducted on all drift-tube linac tanks this quarter.

Light Pipe Shop

Thirty-nine light pipes were completed, and twenty-six units were repaired. In addition to fabricating 37 scintillators, 9 circular rods were constructed for light pipes.

Wire-Winding Shop

The following is a review of the services provided during the quarter:

Requester	Service
Biomed	Constructed gelatin slicer
EPICS	8 Helix chambers
CalTech	2 Signal frames
MP-11	10 Harp frames
Exp. 32	2 Signal frames; 8 high-voltage frames
Exp. 96	7 Signal frames
Exp. 137	2 Screens; 2 gratings
Exp. 180	1 Signal frame; 6 helix frames
Exp. 221	2 Signal frames

VII. 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

The LAMPF accelerator and the primary beam lines in the experimental area are operated through a central control computer interfaced to 2 operator consoles, 68 data-acquisition and control terminals (RICE), and a network of 4 satellite computers which perform certain dedicated tasks.

Control Computer

The old disk system on the control computer is being replaced by a new system to increase the data-storage capacity from 3- to 40-million, 24-bit words. The remaining two disk drives arrived to complete the new system configuration of one controller and three drives. The disk system is being interfaced to the control computer through a PDP-11/34 which will act as an input/output processor to relieve the control computer of the work of handling disk transfers. The checkout of the interface between the SEL-840 and the PDP-11/34 was completed and the chassis was installed. The file-handling software of DEC's RSX-11M is being used to reduce the programming for the conversion.

Control Consoles

A third operator's console is being developed for CCR. Digital communications between the control computer and various devices on the console will be carried over a standard data bus, the IEEE 488 General Purpose Instrumentation Bus (GPIB). The bus controller and the first device, a function button panel, were installed this quarter. The bus con-

troller is a microprocessor-based design packaged in a CAMAC module. The bus approach minimizes cabling requirements and provides flexibility in evaluating new console devices. The logic for the function button panel is also designed around a microprocessor which performs tasks formerly requiring the attention of the control computer.

A new hardcopy model, a Tektronix 4631, has replaced the model 4610 on console No. 1 to provide improved reliability. The hardcopiers see continuous use during operations to provide black on white permanent copies from the storage scopes; availability and maintenance were problems with the earlier model. Work on a duplicate hardcopy system for console No. 2 is nearing completion. The hardcopy unit and three storage scopes were modified and are ready for installation at the next break in operations.

Microprocessor Developments

A new interrupt structure board was designed as a companion board to the family of CAMAC-size microprocessor boards described in previous reports. This board utilizes a new Intel LSI integrated circuit that provides eight priority-encoded, individually masked interrupts that are programmable to provide a high degree of flexibility.

Master Timer

The new microprocessor-based master timer was completed and checked out. The controller, power supply, distribution chassis, and 23 timing modules are ready for installation in the CCR. This new master timer is being developed to meet the operational requirements for a facility with three ion sources and to satisfy the expanding need for timing signals in the experimental areas. The design review committee responsible for overseeing the development witnessed a demonstration of the capabilities of the new unit and approved it for gradual integration into the facility. The plan is to have the accelerator rf systems on the old master timer while switching the injectors and experimental area to the new unit to gain operating experience.

Accelerator Interface System

Four satellite computers are connected to the control computer by CAMAC-based data links. To reduce the load on the control computer from these data links, the controller was redesigned around a microprocessor with buffer memory. Initially, six microcontrolled-data-link (MCDL) modules will be produced, four to replace the older modules now in operation, one for a spare, and one for further testing and future expansion.

The successful operation of the polarized ion source required the troubleshooting of several problems associated with the Injector C data-acquisition and control terminal. To suppress electrical noise from ground loops, grounding straps were added to the RICE and the junction box from which the data and control wiring fans out to the equipment. Repairs were made to the ADS channel selector, the ADS power supply, and one amplifier.

Computer System Software

Several programs which exercise the central processing unit of the control computer were rewritten to run under the operating system so that hardware faults can be diagnosed even though the accelerator is in operation. One of these programs was used to diagnose a failure mode in the extended arithmetic unit that was sensitive to certain bit configurations. The system software for the function button panels was modified so that the execution of a program (e.g., a drop sequence) can be initiated whenever a button card is extracted from the panel. A general-purpose button card simulator was written for the character scopes to provide a backup in case the function button panel is inoperative.

Accelerator Application Programs

When a new procedure is being developed for the accelerator, the computer program which automates the procedure is designed with a multitude of options to provide the degree of flexibility needed in a development code. As the procedure becomes more reliable, the computer program matures to the level of a production code. At this point, it is desirable to mask all of the development options with a new

operator interface that simplifies the use of the program. New operator interfaces with preselected options were written for the Harp and SY wire-scanner control programs.

A program was put into use to display the data from any selected six Line X and Line B current monitors. A Line B current reading was also added to the accelerator status display. These programs were patterned after the Line A system and include a similar calibrate and background measurement to give readings in microamperes. The hardware is also similar and features voltage-to-frequency converters to permit accumulation of integral beam current in CAMAC scalers read through the SY and Line B satellite computers.

The Area A Transmission Monitor System was modified to permit entry of the monitor time interval (between 1/60 s and 2 s) from the operator's console. Also, the operator message program in the SEL-840 was modified to show which current monitor pair caused a transmission trip.

The success of one of the emittance-matching programs warranted an extension of its capabilities. This program calculates the changes in magnet currents needed to produce a specified change in beam position and angle at a given emittance station. In its expanded form the program will execute the setting procedure at emittance stations 2, 3, 5, and 11. Moreover, it can now read a disk file associated with the emittance programs to retrieve the desired position and angle rather than relying on the operator for this input.

To simplify the operation of Injector C, the polarized ion injector, a program was written to assign its controls to push buttons on the function button panel. The corresponding program for Injector B was revised to be compatible with the Injector C version.

A display program was written to plot the calibration data for any analog channel in the channel table. The graphical display makes it easier to detect suspicious data points.

A new motor test program was written and tested. This version is able to detect much smaller deviations of the motor travel from the expected travel than earlier versions.

The diagnostic software for the emittance gear, linac harps, linac wire scanners, absorber collectors, beam scrapers, and viewing screen hardware was put into full operational use.

One of the most useful programs is the pulse-plotting program which allows the computer to behave as a sampled-data oscilloscope attached to any signal available to the RICE terminals. Because it is often used by more than one person at a time, this program was revised so it could run concurrently on any number of consoles. The technique used is to plot a few points on one console and then cycle to the next console in turn. Options were added to synchronize the data acquisition with the H^+ and/or H^- beam gate and either of the 60-Hz axis crossings.

The scheduler program which manages all of the periodic data-scanning programs on the control computer has been losing programs from its list because of occasional drum malfunctions. This program was rewritten to protect against such failures. Its data base is now checksummed so that a drum write failure or any other destructive action can be detected and the backup files used.

Experimental Area Controls and Instrumentation

Area A

As part of the program to upgrade the beam current monitor (BCM) system, two different prototype amplifier-processor circuits were built and bench-tested. One model has been packaged for field evaluation. Both circuits employ a "negative resistance" input characteristic so that the input loop circuit resistance is effectively zero, thereby making the I/R pulse droop time constant very long.

Sixteen new thermocouple signals were connected to the data system. All of the collimator thermocouples in Area A were tested, repaired as necessary, and calibrated. Records of the calibrations were sent to the appropriate system engineers.

The control trailer for the tritium experiment was moved near to the LEP channel. The control and monitoring circuits were revalidated to support Exp. 50. At the completion of the experiment, the cables were removed and the alarm panel was stored for future use.

The portable water system, commonly called ROVER, was moved from the SMC area to the old mass spectrometer stub-out area.

The Alcatel vacuum system was put into operation at the A2 target. This required the fabrication of a control rack with special internal wiring, the installation of shielding and interconnecting wiring, the interfacing of new readout devices, and the checkout of the Alcatel converter.

EPICS

A major effort was mounted to complete the controls for the EPICS spectrometer.

The thermal switches for the spectrometer magnets were wired and their interlocking function verified. The magnet safety lights were installed and wired.

The electrical wireways for the scattering chamber and associated target mechanism were installed. The mechanism for target insertion was made operational after several false starts in selecting a drive motor. A single air solenoid was plumbed to drive the guide jaws.

A coaxial patch panel was mounted on the frame. A smaller patch system was installed between the EPICS counting house and the P^3 shield wall.

SMC, LEP, P^3 , PIP, and Test Channel

A 70-cable coaxial patch system was fabricated and installed between the Yale trailer and Cave B of the SMC. A package of timing signals was connected to the trailer.

The magnet control software for the SMC was converted from DOS to RSX-11D and tested successfully. The associated documentation was updated to reflect the new operations.

A chassis of controls for the Proton Irradiation Port (PIP) experiment was designed, fabricated, installed, and checked out.

Beam Stop Area

In the process of calibrating the thermocouples at A6, it was discovered that a large percentage of the T/C amplifiers and trip circuits did not work. An investigation showed that the amplifiers, trip circuits, and trip relays were damaged because of a power-supply failure. Since these devices are part of the

Run Permit system, they must have a high reliability. Therefore, a search was initiated for replacement power supplies with good reliability. If no such unit is located, a detector circuit will be installed to alarm whenever the power supplies fail or oscillate. Both approaches are under investigation.

A new thermostwitch for the A6 window was wired to the Run Permit system in a way that provides a two-out-of-three interlock with the shield cooling.

Lines B and EPB

Production beams were run in Area B/C during most of the quarter. This fact, plus the shortage of electrical craftsmen, hampered new installations. The following work was completed and documented.

The target controls for Exp. 179 were converted to use an ac motor. A bin of control equipment was fabricated and installed in the Line B Counting House (BCH) to operate the motor.

The ion pump start supplies for Line B were installed in a rack in Equipment Room B in order to reduce the clutter in this area.

The method of selecting the EP mode for the Run Permit system was made automatic by wiring the out limit switches of the beam plugs into the circuit.

The target controls for Exp. 27/II were remoted to the Case-Western trailer.

The controls for operating a pickup coil for a laser power meter were installed in the University of New Mexico trailer.

Line C and HRS

The controls for the two new Line C beam plugs were installed in Equipment Room B. A scheme for by-passing LCSV06 and LCQM13 in the Run Permit system was implemented in the same area.

Magnet warning lights for LCQM12 and LCQM13 were put into operation.

A chassis of latching relays was fabricated for the HRS controls in an attempt to keep the rod transfer mechanism from being reversed until it is in the proper state to be reversed.

Communications

The importance of the communications system was proved once again when a failure in one of the circuits caused a serious deterioration in system performance so that it was virtually impossible to carry out the schedule of accelerator development operations. After the fault was corrected, the documentation developed in the course of isolating the problem was submitted to drafting.

As a follow-up to this system failure, every channel on every station was tested. All of the problems discovered were of a minor nature and were repaired. Numerous other repairs were made during the quarter in response to problems reported in the daily failure report.

The following installations were completed. Two universal stations were installed, one in the AMO and one in the Health Physics office. Regular paging speakers were connected to these stations along with monitoring speakers for the HP line and CCR line. These stations created an AMO line, and all face plates had to be changed from LOB to AMO by means of stick-on labels. A new station was installed in the rack in Area A that houses the vacuum pump power supplies. An expanded communication system to support the spectrometer in EPICS was designed and submitted to the electricians. A new speaker with the cutout option was installed in the SY. A special intercom unit for the Biomedical Facility was received and installed.

Because the staff available to support the communications staff is not adequate to maintain and document the existing system as well as to expand and modify it, a moratorium was placed on additions to the system until the documentation can be brought up-to-date.

Cable Shop

A facility called the Cable Shop was set up over two years ago within MP Division to provide a quick response to orders for the fabrication of special-purpose cables. This facility continually proves its value by meeting deadlines for experimenters and the accelerator staff.

During the past quarter, the Cable Shop produced 507 cables and repaired 38 others. Of the new cables, 428 were coaxial and 79 were multi-conductor cables. The material costs of \$3800 were recharged to the requesters. At the end of the quarter, there was a backlog of 3 orders totalling 479 cables. Approximately 55 manhours per week are expended in the Cable Shop operation.

As an adjunct to this operation, an inventory of cables and connectors commonly used at LAMPF is kept on hand. A computer data base is used to keep track of this inventory. Approximately \$10 800 of this material was issued last quarter from this stock.

Experimental Data-Acquisition System

The LAMPF experimental data-acquisition system includes computers, software, CAMAC interfaces, and electronic modules from an equipment pool, all for the purpose of acquiring and analyzing data from experiments.

Experimental Area Computers

Approval was received and an order placed for a PDP-11/70 to be used to analyze data. This purchase was in response to a recommendation in the summer study report, LA-6543-MS. Quick action got the order placed before a 5% price increase by DEC took effect. Delivery is scheduled for December 1977.

The first group of new 9-track magnetic tape drives was received. These, too, were ordered at the recommendation of the summer study group. Kennedy drives with Datum controllers were selected on the basis of price and performance. These drives can operate at 800 and 1600 bpi, giving a significantly higher packing density for data and thus reducing the number of tapes required for an experiment. The drives will be installed during the next down period.

Data-Acquisition Software

Development work continued on the general data-acquisition package Q which runs on the PDP-11s under the RSX-11D operating system. The MBD code supporting Q was extensively reworked to add

event rejection operations and a limited DO-loop capability. Additional changes improved the maintainability of the code. The run-time MBD loader, its supporting System Global Area, and the associated system start-up code were all extended to support the new DO-loop and event rejection operations. This new code has not been checked out yet.

The QAL (Q-Analyzer) compiler which supports the Q data-acquisition language was extended to support the new MBD operations. A new keyword was added to support the "increment" test operation for scalars. A number of new CAMAC modules were added to the inventory of modules recognized by QAL: the LAMPF PACE 8 interface, Nuclear Enterprises 9060 ADCs, the new LeCroy Research 2700 PCOS system, and the EG&G Model 811 TDC. Finally, the first section of a commissioning test for Q was written and is being used to validate the functions of the QAL compiler in a systematic and reproducible manner. When completed, this test program will be used to validate any new version of QAL before it is released to the users.

The dot-plotting task and associated user subroutines for the Q system were rewritten to conform to the new histogram system data base. The task is now overlaid, thereby reducing its core requirement. The routines involved were made to be compatible with the RSX-11M system. Modifications were also made to the histogram system common. These changes necessitated some minor changes in the histogram display system routines.

The subroutines which allow a user to write a Q-structured magnetic tape were extended to allow a user to write a series of five file marks on the tape and then to reposition the tape such that the file marks would be written over if further tapewriting was performed. The start-run subroutine call was extended to include an optional run number so that a user could write more than one distinct run on a tape. Some other bugs which were discovered were corrected.

Work was completed on a proposal for handling magnetic tape operations during the data-acquisition phase of an experiment. Design work was done on a scheme for the translation of tapes by the Q-replay handler so that a user will be able to replay his tape at the Terminal computer without first translating the tape, if it was written on a KS-90 or LBL controller. Programs to implement these

improvements will be incorporated into the Q system next quarter.

Three new manuals were distributed. They describe the Control Command handler, the histogramming system, and the module repertoire of the QAL compiler. These manuals are part of an ambitious plan to upgrade the documentation on all of the PDP-11 software, particularly Q. A manual entitled "QAL and the Analyzer Task" was distributed in rough-draft form to the users for their comments.

Supporting the operation of the Terminal computer and consulting continued to be major efforts. The day-to-day operation of the Terminal computer has taken on the character of a true computing center. This computer is being operated in a multiuser mode for software development, data analysis, general computing, word processing, and some limited data-base applications. The machine is reserved from 11 a.m. to 2 p.m. daily for systems software developments. Part of this period is scheduled for media translation, code distribution, disk and tape formatting, and hardware checkout. These services are provided to users on request to save them time and effort.

A new version of RSX-11D was released. The first steps were taken toward converting from Version 6A to Version 6.2. The latter provides a greatly improved terminal interface, time-slicing and swapping of active tasks, and a more flexible command file capability. The new version should be installed next quarter.

The design of the CAMAC Test Language, CTL, was completed. The software will run interactively under RSX-11D. A grammar and manual were drafted for review before programming begins next quarter.

Computer Maintenance

The number of service calls for the quarter topped 400 for the first time. A full schedule of experiments for two cycles and a growing inventory of equipment were the reasons.

The maintenance costs on the Tektronix 4010 terminals were raised 50% to \$75/mo because the CRT only lasts about nine months in the mode used by experimenters. Users were alerted, through the

Data-Acquisition Newsletter, to a technique for preventing excessive wear. Not unexpectedly, the experimenters have too many other things on their minds to remember to turn off the graphic mode. Consequently, a pc card with an electronic time-out circuit was developed and installed on two of the display units on a trial basis. It automatically resets the mode of the terminal if no graphs are drawn within a five-minute interval. If this scheme is successful, the maintenance cost may be reduced.

Three new KS-90 magnetic-tape-drive controllers arrived in March. They allow IBM-729 tape drives, which may be obtained free from excess lists, to be used on the PDP-11 computers. These units each replace an LBL synchronizer which performed the same electronic function but which proved to be unmaintainable. This purchase responds positively to one of the recommendations of the summer study group.

Fifteen additional IBM-725 magnetic tape drives were ordered to expand certain systems with spare drives and to provide spare parts for existing drives.

The problem of user-initiated maintenance was attacked this quarter through a series of meetings. A set of guidelines was published, with the approval of the maintenance teams, which, if followed, will avoid these problems in the future.

A small trailer was installed near the computer maintenance trailer. The new area will provide storage space for spare computer peripherals and more room for repair facilities.

A schedule of training schools for the maintenance technicians was prepared. These schools are offered by manufacturers of computer equipment used at LAMPF. The value of the schools was emphasized when the time-to-repair for MBDS went down drastically after two technicians attended a factory course.

LAMPF Electronics Equipment Pool (LEEP)

The initiative to establish a disk renovation service through LEEP came to fruition this quarter when the first 20 cartridges were reconditioned, all successfully. The front-loading disks can be renovated for \$35; the top-loading disks cost \$40. This is half the cost of a new disk.

A Randomex disk-pack cleaner was delivered. This cleaner will accommodate the disk packs used on the new CalComp disk drives supplied by Diva. Since the disk packs cost \$400 each, it is worthwhile protecting this investment. The cleaner is ready for use as the new disk drives are installed.

An order for 20 pulse-delay boxes was placed with Panel Components Corporation, a subsidiary of Lemo, USA. These boxes will have standard rack mounts, 3½-in. high. They will have 18 delay lines, ten 64-ns, four 32-ns, and four 16-ns. At the quantities ordered, they cost \$217 each. Shipment is scheduled for May 11.

The question of NIM prescalers was reviewed by the LEEP committee. A group at Northwestern University is developing a 12-channel prescaler with a 200-MHz counting rate. It is expected to cost about \$500. Each channel would have a fixed prescale factor of 10 or 100. The channels could be cascaded to obtain a wide variety of scaling factors. A second unit is available from a commercial vendor. It is a dual-channel model costing \$850. Each channel has seven synchronous outputs with prescale factors of 10^0 to 10^{-6} . A final decision was postponed until a unit has been delivered and evaluated.

Experiment Debriefing

A policy of debriefing experimenters after they finish an experiment was established to evaluate the support received for their data-acquisition system and to identify improvements that would make the experimental time more productive. During the quarter, personnel from Exps. 266, 86, and 200/323 were debriefed. The pertinent points from these sessions were:

- LEEP support is generally excellent. The pool is somewhat weak in slow electronics and needs high-speed scalers or ADCs.
- Computer maintenance is generally satisfactory. The worst problem for these particular experiments was the IBM-729 tape drives.
- Program Q worked well in its present form but needed enhancements. Histogramming facilities were inadequate. The magnetic tape software only supported the event-by-event mode. Users would like to write out

histograms built up by the histogramming package but cannot under Q.

- There is a class of experiments which can use a small computer system, i.e., a data logger. In such systems, the experimenter does all his own programming and support.

As personnel from more experiments are debriefed, a composite picture of the needs for computer support should become clear and help set priorities for future developments.

Cryogenic Pressure Servo

The Cryogenic Pressure Servo was given its first field test under the supervision of a cryogenics engineer. After two trouble calls, the test was pronounced a qualified success. While several problems were identified, the unit performed all functions more or less as designed. The system was reassembled at Q Division for further operational checks. A wiring error was corrected and a lack of uniformity among transducers was identified as a problem in this test. Several design modifications were suggested for future models of the unit. Another field test will soon be performed in Area A.

Liquid Hydrogen Refrigeration Controller

In order to reduce the number of manhours required to perform a system cool-down on LAMPF targets, an automated microprocessor-based system is being designed. The system is to oversee the cool-down procedure and continue monitoring once cool down is completed. Various alarms will be provided in the event of an equipment failure.

Portal Monitor

A radiation detector was developed to monitor the exit gate at LAMPF for any radioactive materials leaving the site in vehicles. The portal monitor was installed, tested, and put into operation in February. The system now operates 24 h/day. Visual and audio alarms are mounted at the exit gate. Alarms and resets are located in CCR and at the Health Physics office.

Experimental Area Evacuation Alarm

The Evacuation Alarm system reported on last quarter was installed and operated successfully during the second tritium experiment.

Electronics Perspectives Seminars

The effort to keep the technical staff abreast of the latest in technology continued through two Electronics Perspectives Seminars. The first, "An M6800 Technical Update," dealt with recent advances in microprocessor chips. The second covered basic principles of "Voltage-to-Frequency and Frequency-to-Voltage Converters."

VIII. BEAM LINE DEVELOPMENT

H⁺ Beams

Tuneup and Operations

Assistance with tuning the SY and Line A was regularly provided at the beginning of each cycle and after development and maintenance days. Operation of MAGSET has been improved and resetting the transport magnets is fairly routine. A small amount of steering is normally required in the SY to compensate for changes in the position or angle of the beam leaving the linac.

Halo Studies

Halo measurements were made near the beginning and end of Cycle 12. Two new Loss Monitor (LM) units were placed adjacent to the halo plate locations and calibrated from 300 V to 1000 V (5×10^3 gain range) to provide convenient and permanent halo readout. One halo plate (LA-HL-01) is located in the upstream SY; the other (LA-HL-05) is located downstream of the Line A bending magnets to determine if momentum selection reduces the halo. The results do not show any substantial difference:

	%Halo	
	X	Y
LA-HL-01	34	27
LA-HL-05	47	46

where the halo is defined as the excess beam size at the 0.05% level relative to the Gaussian continuation of the beam size at the 16-84% level.

300- μ A Heat Run

Three-hundred microamperes of proton current were transported from the linac to A6 for ~ 2 h at the end of Cycle 13. Spills were maintained within acceptable limits although the low-momentum spill in the SY approached 100 nA. All standard production targets were in the beam until 2A-TW-01 ceased to rotate. It was then removed from the beam and the

run continued with increased beam current incident on 5A-TW-01. All beam line diagnostics continued to operate adequately. An interesting effect was noted when the guard ring signals from 5A-GR-03 (just downstream of 5A-TW-01) decreased slightly with increasing dose but recovered when the beam was turned off for a short period.

Switchyard Contamination

On April 11, a 3.5-mg/cm² uranium target which had been irradiated for more than $10^6 \mu\text{A}\cdot\text{h}$ was accidentally disintegrated by a sudden blast of air when a vacuum valve was opened too quickly. Subsequent entry into the vacuum system resulted in distribution of α -active dust over a portion of the SY area. The bulk of the loose active material was cleaned up within 24 h.

An evaluation of the level and extent of the remaining contamination was made during the week of April 25, in conjunction with the normal maintenance scheduled for that period. The floor was extensively cleaned by Health Physics, and a few remaining hot spots were covered with tape. Booties worn by all personnel working in the SY were checked and no activity was detected during a 4-day period. Checks for α activity in sections of the vacuum system which were not directly affected by the accident were negative, indicating that the activity is not spreading in the vacuum pipe.

H⁻ Beams

Tuneup and Operations

Assistance in beam setup and tune maintenance was provided on the H⁻ beam lines. A closer approach to a standard Line X stripper configuration to prepare an emittance-limited beam for Line C has been achieved. Usually less than half the beam is lost by stripping and no problem arises with unchopped beams. But, when the rf chopper is used, the requirement of the Line B user for at least $0.5 \mu\text{A}$ of beam current demands frequent attention to optimizing transmission through the strippers. The Line X-Line B quadrupole setpoints established during Cycle 12 have been suitable for Cycles 13 and 14.

H⁻ Polarized Beam

The first polarized beam was transported to EP during the last shift of Cycle 13 (April 21, 1977). The normal H⁻ production beam was used to set up the Lines X, B, and EP magnets. Unpolarized beam was then delivered from the polarized source and was detected on an ion chamber in EP. After tuning the H⁻ transport to maximize the intensity arriving at the ion chamber, the beam was polarized. A 10- to 20-pA beam (intensity too low to be seen on most Lines X and B diagnostics) was detected in EP and the left-right asymmetry was measured to be 0.38 ± 0.01 , corresponding to a polarization of 0.76 ± 0.08 .

The low-intensity thresholds for the present H⁻ beam diagnostics have been measured. A beam of <0.1 nA is visible on the LX-TV-2 phosphor, and ~5 nA is needed to be visible on the LB-TV-1 phosphor. The Line X wire scanners have detectable profiles at ~10 nA, the Line A wire scanners need ~20 nA, and the Line B wire scanners need >20 nA of proton beam current. Use of a modified wire-scanner amplifier which integrates for ~50 ms (i.e., ~6 beam pulses) improves the sensitivity by a factor of ~5. One concludes that proton currents ≤ 1 nA will be difficult to tune with present instrumentation.

Transverse Oscillations

The transverse oscillation of the H⁻ beam was studied by the transmission method, i.e., by using a

stripper edge at beam center to convert the position variation to an intensity variation which is then monitored downstream. Beam center was determined by finding the 50% transmission point. The beam intensity was recorded on a strip chart from the output of a scintillation counter in the Line B TOF apparatus.

One section of a strip chart is reproduced in Fig. VIII-1. The waveform evidently has dominant components around 10 Hz with some multiple frequency structure giving an envelope.

The amount of motion relative to one beam rms width (assuming a Gaussian shape on the peak of the profile) is $\Delta X_{p-p}/\sigma = 25\%$. This is a dimensionless measure of motion which would tend to be independent of beam focus. The motion in real units is $\Delta X_{p-p} = 0.4$ mm at this location.

It is noteworthy that less oscillation is observed at LX-ST-4X, which is the point of highest momentum resolution. This is consistent with the assumption that the oscillation of beam energy is small with respect to its intrinsic energy spread.

H⁻ Beam Diagnostics

A program to improve and to add to the H⁻ beam diagnostics has begun. Several 2-jaw strippers are being designed and will be installed in place of the present series of fixed-size strippers. The new flexibility will allow a stripper opening of arbitrary size to be centered on the beam trajectory and to be varied in size with very fine resolution. A counter

Fig. VIII-1.

Strip chart showing the intensity variation of the H⁻ beam in Line B due to transverse motion of the beam across the edge of LA-HL-1X.

telescope and electronics for tuning the beam chopper have been added to Line B. Several secondary emission current monitors will be built and installed in Lines A, B, and C, and at the two beam stops 1XBS and 2XBS. They will be used to complement and/or replace some existing toroids. Four or five harp-like profile monitors (integrating MWPCs) will be constructed and installed in EP. These devices must work in the 1-pA to 1-nA beam-current range and several must be remotely insertable. Standard harp multiplexers will be used for readout. One fixed MWPC has been constructed and used in EPB.

A fixed ion chamber to be located in front of the Faraday cup has been designed and will be used primarily for low currents. In addition, the EP-IR-01 ion chamber has been completely rebuilt and now has a lower limit of sensitivity of 0.1-0.01 pA as determined from noise tests.

A polarimeter designed and built by an experimental group and MP-8 has been installed and tested in EP. A method of making the beam polarization value available to CCR, ICR, and the experimenters is under study.

H⁻ Current Monitors

The H⁻ beam current monitor system with integrated current readout through the SY and Line B CAMAC systems became operational. The system, as has been available for Line A for some time, gives a real-time display of Line X-Line B average current in CCR and on the Status Display available to experimenters. The current display is very useful for tuneup purposes, e.g., in tuneup of Injector C (the polarized beam source) or in determining the amount of H⁻ beam being stripped. The calibrate-background procedure makes it possible to obtain better estimates of the relatively small H⁻ currents, down to ~10 nA, than is feasible with the conventional beam current monitor waveform displays. The accuracy and data-accumulation capability are particularly useful for Line B Nuclear Chemistry runs.

Beam Line Protection

Transmission Monitor

The Transmission Monitor period in the Area A PDP-11 was shortened to 0.25 s near the end of Cycle 13. This appears to be approaching the maximum usable rate in the present noise environment. An apparent spark discharge was finally identified as a long-standing source of spurious trips on transmission at 1A-CM-02; grounding of the toroid core is being tried as a fix. Another cause of spurious trips was traced to arcing at the CCR key-release buttons. These noise-chasing efforts involved much patient observation by MP-1, -2, and -13 personnel.

Beam-Spill Detector Improvements

The AP spill-detection modules in the SY have been modified to operate at higher signal currents (~1 μ A), to provide an analog output signal proportional to the spill, and to be more uniform in unit-to-unit properties so replacement of a unit does not necessitate recalibration with the proton beam. These new units have been calibrated and are performing well.

Additional lead shielding has been added to stop the low-momentum particles which leave the transport system just after LA-BM-02. The uniformity of response of LA-AP-04 to these spills has been improved markedly. A new detector, LA-AP-05, has been added to provide sensitivity to low-momentum beam which passes through the Line D beam pipe hole in the lead shielding.

MP-2 installed two spill monitor pairs in the CNC-11 cave at the request of MP-13. The detectors are placed to the left and right of LB-CM-03, one of the last restrictive 200-mm apertures past LB-TW-01 (the neutron line target), and are intended to protect the CNC-11 cave against excessive spill especially when thick metallic targets are in use upstream.

Guard Ring System Development

In collaboration with E-3, a system has been specified and designed which will terminate a beam

pulse within 100 μ s after the proton beam striking a guard ring has exceeded 1.7-mA instantaneous current. The purpose of the guard rings is to provide fast protection to beam line components from errant beams. A prototype dual-threshold detection module has been constructed and is in the testing stage. A test pulse, which checks the operation and continuity of the threshold circuit, the cabling, the collection voltage, and the amplifier circuit, is generated following each beam pulse. Improper response to this test pulse results in inhibition of the proton beam.

A 50-mm inner-diam secondary emission guard ring has been installed in Line A-Direct just downstream of LA-WS-09 and LA-TV-02 to provide protection to the water-cooled window and vacuum flange during tuning exercises when the switchyard APs are disabled. This device is capable of detecting beam spills on the order of 0.01% of the beam in the presence of the background produced by the stopping of the entire proton beam in a beam stop only ~ 1 m downstream.

The only difficulty with implementing this protection scheme at the present is the use of the LA-TV-02 phosphor in the beam when tuning. The phosphor scatters enough beam into the guard ring to raise its signal about two orders of magnitude above the previously quoted number and thus limits the usable level of protection.

Vacuum System Protection

The fast-closing valve (LA-FV-02), which was installed last quarter to protect the Line A harps from vacuum accidents, suffered a failure after exposure to five weeks of spill from a 150- μ A production beam incident on the 3.5-mg/cm² uranium target at LA-TW-01, 9 m upstream.

The Delrin plastic gear-reducer used to open the valve failed during a routine test of valve operation. Inspection revealed that: 1) two gears had broken teeth, 2) all gears were very brittle, and 3) the color changed from white to brown. Hardness and dimension comparisons showed little change; however, impact tests indicated that the strength of the material was reduced by an order of magnitude.

The beam spill has been reduced in the area of the valve, and alternatives to the plastic gears are being

investigated. The drive train was replaced by a spare assembly and the valve continues to operate to specifications (closing in 23.5 ms).

An assembly for manually opening LA-FV-02 has been constructed so total loss of the gear train, motor, or power source will not prevent use of the valve. A 2-min switchyard entry would allow the valve to be reopened whenever necessary.

Design and drafting of a 250-mm fast valve for use near the 4A doublet is $\sim 90\%$ complete.

Instrumentation

Switchyard Wire Scanners

A second wire scanner in the downstream section of Line A failed due to a weakening of the signal wires by the higher intensity beam being transported through the SY to Area A. The original ribbons (0.8 μ m by 2 mm) of Stablohm 650 ribbons (similar to Nichrome) have been replaced with 0.1-mm-diam silicon-carbide wires. A short section at each end of the SiC signal wire is electroplated with copper to allow attachment by soldering to small nickel tabs. The assembly is then mounted on the wire-scanner frame in the usual manner, using two 1.5-mm-diam coil springs to provide ~ 0.4 -0.5 N of tension.

The first SiC signal wires tested on a SY wire scanner were installed on LA-WS-05 in October 1976 and are still in operation. Similar wires used for a high-voltage collection field, which were not spring mounted, have broken at the attachment points, apparently due to vibration induced by the stepping motor used to drive the wire scanner.

Two additional wire scanners, LA-WS-01 and LA-WS-07, have been converted to SiC signal wires to reduce the beam spills which occurred when the original 0.1-mm-diam tungsten wires passed through a 150- μ A proton beam.

At 300- μ A proton currents, the 0.1-mm tungsten wires were raised to a sufficiently high temperature at production beam spot sizes that thermionic emission contributed significantly to the current in the wire. (At 150 μ A these effects were absent.) The new SiC wires should show no effects of thermionic emission even at 1 mA of beam current.

Chopped Beam Diagnostic Instrumentation

A TOF telescope for chopped beam monitoring has been completed. The system consists of four 25- by 25- by 1.6-mm scintillators and two 25- by 25- by 12.7-mm Lucite Cerenkov counters. The six-element telescope was intended to insure directionality from the LB-ST-01 stripper foil and to allow for sufficient flexibility in the initial test runs. Shielding provides additional directionality. It was found that both of the Cerenkov counters were necessary. Without the Cerenkov counters there was a 1-5% main peak contamination in the side lobes. This lobe contamination was found to depend very critically on the positions of the various stripper foils in Lines A and X. In addition, the early and late side lobes differed by a factor of 2 for the different phases of 60-Hz line signal. An additional 12.5-MHz structure in the 40-ns chopped beam was observed due to the alternating directions of motion of the deflected beam past the chopper aperture.

Live-time display of the chopped beam time structure in CCR and ICR is expected to improve tuning and operation. Electronics for a permanent TOF installation, including equipment in the Line B racks and CCR, are in procurement.

Sieve Stripper

A sieve stripper for EPB has been constructed and installed as LB-ST-00. The sieve is a 25- μ m aluminum foil with 112- μ m-diam holes spaced 1 mm apart on a rectangular grid to yield a transmission of 1%. The purpose of this device is to reduce the H^- beam intensity without changing the macro-properties of the beam phase space. Subsequently, the LB-ST-01 stripper jaws can be used to reduce the intensity further with a resolution 100 times finer than would be possible without the sieve.

Dual Actuators

Design and drafting have been completed for a dual actuator unit to be used in the LAMPF SY and Line B for foil-type strippers and halo scrapers. Two independent linear actuators, each with a 76-mm stroke, provide an opening between foils which may be adjusted from 0 to 76 mm, with the centroid adjustable over ± 19 mm from beam centerline. Max-

imum opening with both jaws retracted is 114 mm in the present configuration, but may be increased by reducing the amount of foil overlap. The minimum step size of each foil position is 0.01 mm. Resolution of the present three-turn potentiometer and the ADS limit the position readout to ~ 0.03 mm.

Ten units will be built to provide two 4-jaw stripper units and three 2-jaw units plus spares for Line X.

Switchyard Beam Box

A new SY beam box (for the 150-mm-diam vacuum line) has been designed for use with devices or diagnostics requiring four openings into the beam line at one location. Two boxes have been fabricated for use with the new 4-jaw strippers to be installed in Line X. All mounting, installation, and alignment dimensions remain identical to the original SY beam boxes, which have two openings at 180° .

Harps

An investigation into anomalous harp profiles was conducted. The problem was caused by timing problems in the harp CAMAC crate. The reset module occasionally issues a reset in the middle of the readout cycle and destroys the profile.

The 0.33-m harps with silicon carbide wires are ready for mounting on lids when the lids become available, and three profile monitor harps were constructed.

Current Monitors

A number of Mu-metal core, radiation-hardened toroids have been manufactured for the Line A profile monitor insertions.

Secondary Beams

Secondary Beam Development

Low-intensity (50-500 nA), 40-ns chopped beam was supplied to Area A at the end of Cycles 12 and 13 for development studies on the secondary beam lines. The normal H^- beam was stripped to H^+ at

LA-ST-01 and transported through Line A-South and Area A. A four-foil secondary emission monitor was used to measure the average beam current.

Chopper efficiency for removal of the two pulses adjacent to the allowed pulse was about 99%, although frequent adjustment of the chopper phase was required to maintain this low level of contamination.

P³ Development

Ten shifts of development beam time were devoted to the study of the P³-East channel. Characteristics studied were: 1) rates and contamination at full phase space, 2) TOF measurement of the central momentum, and 3) steering algorithm vs maximum rate. Rate measurements at full phase space were of interest because previously published information was extrapolated from small solid-angle measurements.

Fig. VIII-2.

P³-East π^- rates vs channel momentum at full phase space.

Through particle identification by TOF from rf over the channel length, rates and contamination were studied simultaneously. The proton beam incident on the A2 production target (6-cm graphite) was a low-intensity ($\leq 0.5\text{-}\mu A$ chopped beam with 40 ns between micropulses). The rate normalization measurement was made on the proton beam with a secondary emission monitor located in the SY. Figure VIII-2 shows the π^- rates as a function of channel momentum for a total momentum bite of 1.7% (MS03A = 25.4 nm) and full solid angle (MS01 and MS02 full open). This data agrees reasonably well with the previously published extrapolated curve.¹ Figure VIII-3 shows the rate variation with momentum-slit (MS03A) setting at a central momentum of 600 MeV/c. The linearity indicates that the momentum distribution at the MS03 location is comfortably uniform from 0 to ~3%. Table VIII-1 lists beam composition as a function of momentum and momentum bite at full phase space as determined by TOF particle identification.

Fig. VIII-3.

P³-East π^- rate vs momentum bite at 600 MeV/c.

TABLE VIII-I
P³-EAST BEAM COMPOSITION

P_π	MS03A (cm)	Composition	
700 MeV/c π ⁻	7.62	π ⁻ + μ ⁻ = 100%	side lobe = 0.4%
700 MeV/c π ⁻	2.54	π ⁻ + μ ⁻ = 100%	
600 MeV/c π ⁻	7.62	π ⁻ + μ ⁻ = 100%	side lobe = 0.6%
600 MeV/c π ⁻	1.27	π ⁻ + μ ⁻ = 100%	
500 MeV/c π ⁻	1.27	π ⁻ + μ ⁻ = 98%	e ⁻ = 2%
500 MeV/c π ⁻	5.08	π ⁻ + μ ⁻ = 97%	e ⁻ = 3%
450 MeV/c π ⁻	1.27	π ⁻ + μ ⁻ = 96%	e ⁻ = 4%
450 MeV/c π ⁻	2.54	π ⁻ + μ ⁻ = 96%	e ⁻ = 4%
400 MeV/c π ⁻	1.27	π ⁻ + μ ⁻ = 93%	e ⁻ = 7%
400 MeV/c π ⁻	0.635	π ⁻ + μ ⁻ = 93%	e ⁻ = 7%
350 MeV/c π ⁻	1.27	π ⁻ + μ ⁻ = 89%	e ⁻ + lobe = 11%
300 MeV/c π ⁻	2.54	π ⁻ = 76%	μ ⁻ = 3%, e ⁻ = 21%
300 MeV/c π ⁻	5.08	π ⁻ = 76%	μ ⁻ = 4%, e ⁻ = 20%
250 MeV/c π ⁻	2.54	π ⁻ = 60%,	μ ⁻ + lobe = 6%, e ⁻ = 34%
200 MeV/c π ⁻	5.08	π ⁻ = 40%,	μ ⁻ = 4%, e ⁻ = 56%
200 MeV/c π ⁻	2.54	π ⁻ = 39%,	μ ⁻ = 4%, e ⁻ = 57%
150 MeV/c π ⁻	2.54	π ⁻ = 16%,	μ ⁻ = 4%, e ⁻ = 80%

Because the timing resolution (FWHM) was no better than ~1 ns, all particle species could not be resolved at every momentum.

There have been several independent indications that the central momentum of the P³ channel is different from that predicted from calibration data on the magnets, as interpolated by the P³ program, SHUNT, and most suggest the momentum is low. Using the TOF telescope, the time separation of π⁺ - p, π⁺ - d, and π⁺ - ³He were measured at a nominal momentum of 450 MeV/c. Corrections were made for the momentum loss of each different species in the Havar windows and for air at the MS03A location. These data suggest the central momentum was between 0.4% and 1.1% low. There were, however, systematic uncertainties which make these measurements somewhat unreliable. Efforts continue to exploit this method to accurately measure the channel momentum.

P³ Tune for Exp. 286

A special tune of P³-West was developed to meet the needs of Exp. 286 for a ~200-MeV proton beam with a horizontal spot size of 1-mm FWHM, divergence <15 mr, ΔP/P ≤ 0.2%, and a central momentum stable to better than 5 × 10⁻⁵. Proton rates were not a problem; hence solid angle could be traded for higher resolution. Multiple scattering in the Havar windows and the air near the momentum slit (MS03) was an important effect to accommodate. To achieve a divergence <17-mr (FWHM) requires additional slits in the output leg. The central momentum stability requirement implies regulation of the first P³ bending magnet to better than 5 × 10⁻⁵. A Monte Carlo ray-tracing code, TURTLE, which includes the effects of slits and multiple scattering, gave a final and positive check on the tune achieved using the TRANSPORT code and first-order transport matrix constraints.

Stopped Muon Channel

A new mode of channel operation has been investigated and appears to be very useful. In this mode, the entire channel is tuned to accept μ^+ originating from π^+ decays in the target. The π^+ yielding these muons will be nearly at rest, so the μ^+ will occur in a narrow spectrum around 29 MeV/c. This energy is sufficiently low that only those muons originating in a thin surface layer on the target will escape; hence, this mode is referred to as "surface" muon production. The μ^- surface beam is suppressed by π^- capture.

The μ^+ surface muon beam was developed to the point of obtaining encouraging fluxes at 28 MeV/c. At one set of parameters, a rate of 23 000 $\mu^+/\mu\text{A}$ was observed with a μ^+/e^+ ratio of ~ 6 at the muon peak when a degrader was used to separate the muons and electrons. Without the degrader, the muon flux was ~ 3 times higher but the μ^+/e^+ ratio was 0.02. This beam will be used in an experiment to search for the decay $\mu \rightarrow e\gamma$.

Measurements of the stopping π^- flux were made at SMC-East with 2M-BM-03 removed. The observed stopping rate was $9 \times 10^9 \pi^-/\text{s/g/cm}^2$ of target in an area 0.15 m by 0.15 m when normalized to 100 μA of proton beam current. This result leads one to be optimistic about the possibility of running the bent-crystal spectrometer experiments at the SMC.

Magnet Systems

Magnet Assembly

Assembly is proceeding on the first spare target cell triplet to be fitted with improved coils. The

square 13.46-mm m.i. cable that is used has been considerably improved by the manufacturer to handle 1000 A (see Table VIII-II). Note that current ratings are very dependent on the cooling supplied to the cable. The ratings given apply to LAMPF conditions, i.e., 2.1-MPa nominal inlet pressure, 0.28-MPa approximate back-pressure, and an elevation of 2.1 km above sea level. Under these conditions, 1000 A could run in 55 m of cable without the exit water reaching boiling temperatures.

Improved terminations have been provided for the up-rated triplets (see Fig. VIII-4). The changes in these parts were discussed in LA-6819-PR.

An extra steering magnet of 8-kG $\cdot$ cm capability has been wound.

Magnet Repair

A leaky ceramic-to-metal seal was replaced on the target cell triplet upstream of the 2A target. This cracked seal is believed to have been present since the magnet's installation in 1973; it has taken since then for enough moisture to leak into the MgO insulation to give a ground-fault indication.

Magnet Measurement and Analysis

The major measurement made in this period was of the high-field C-magnet owned by P-DOR. Two radial directions were mapped and the data processed to determine uniformity of field vs radius.

Some effort was spent on determining the coil requirements for measuring PIGMI permanent magnet quadrupoles, which have a very small bore

TABLE VIII-II

CHARACTERISTICS OF HIGH-CURRENT MINERAL-INSULATED CABLE

	Original Specification	Revised Specification	Test Results
Conductor size	9.1 mm by 9.1 mm	10 mm by 10 mm	
Conductor resistance/km	0.30 Ω	0.25 Ω	0.24 Ω
Insulation thickness	1.4 mm	1 mm	
Water pressure test	2.1 MPa	3.1 MPa	
Water flow at 23 kPa/m	0.03 l/s	0.04 l/s	0.053 l/s
Current rating (nominal)	750 A	1000 A

Fig. VIII-4.
New and old m.i. cable terminations.

(~10 mm). Standard integrators were modified to give a gain of 10 000, and appear to be adequately stable.

Superconducting Solenoid

Preliminary conceptual design of a superconducting solenoid for spin precession of the polarized beam has been completed. This will be a ~35-kG·m solenoid with a 0.10-m warm bore and will be capable of rotating the spin vector of an 800-MeV proton through $\pm 90^\circ$ about the axis of the solenoid.

Software Support

Computer Programs

Two computer programs were adapted to run from a keyboard terminal on the CDC 6600. One

program calculates the field components due to combinations of solenoids. The other program traces a charged particle trajectory through a cylindrically symmetric field. This latter program has been extended to trace the spin direction of a particle through the magnetic field along with the particle.

A program was developed to convert a LASL-formatted TRANSPORT deck to the format needed to run the SLAC version of TRANSPORT.

REFERENCE

1. R. D. Werbeck and R. J. Macek, "Performance of the High-Energy Pion Beam at LAMPF," IEEE Trans. Nucl. Sci. NS-22, 1598-1600 (1975).

IX. EXPERIMENTAL AREAS

Proton Irradiation Port

A new facility for high-current proton radiation-damage studies has been implemented. The Proton Irradiation Port (PIP) allows irradiation of thin samples (0.25-mm aluminum equivalent) in the full LAMPF 800-MeV proton beam. With a 3- by 1-mm spot size and 150- μ A beam current, the level of exposure to radiation damage is 1 dpa (displacement per atom) per 7.5 h.

The PIP facility consists of a 25- by 75-mm cooled sample holder (Fig. IX-1), a 60-mm-diam by 6-m-long shield bar containing instrumentation and cooling tubes, and an evacuated can for target changes. Target changes can be made without affecting the main beam line vacuum, but retracting the shield bar must be done with beam off. The PIP penetration is 50 cm upstream of the A-1 target. The sample is pushed horizontally through the beam and can be stopped anywhere along the 75-mm length of the holder, permitting several targets to be used or several areas to be exposed. The vertical beam position is fixed at about the sample midline.

Three irradiations have been carried out with two aluminum samples mounted on the first sample

Fig. IX-1.

PIP target holder, 25- by 75-mm usable area holding several targets. Cooling tubes can be seen at top and bottom of samples.

holder. One sample received $\sim 350 \mu\text{A}\cdot\text{h}$, while the other received two irradiated spots of $\sim 1000 \mu\text{A}\cdot\text{h}$. Thermocouples attached to the sample supports indicate that beam position can be detected within 1 mm, certainly with an accuracy that is comparable to the normal horizontal beam position variation. Controlled sample cooling was accomplished by using flowing nitrogen gas.

The gamma flux leaking through the shielding that was noted during these irradiations was indiscernible from the background of $\sim 0.5 \text{ mrem/h}$. No activity was detected in the vented gas coolant.

Experimental Area Plant and Facilities

Plant

Planning and criteria preparations have been completed, and a consulting structural engineering firm has been selected to carry out design and construction supervision for the Area A-East service structure (Fig. IX-2). Title I design will start early in May 1977.

Fig. IX-2.

Proposed Area A-East service structure. A roof will be added from A-4 to A-6 covering a 30-ton crane which will extend past the beam stop shielding to permit truck loading.

A conceptual study of a facility for a proposed electronuclear fuel production experiment using the high-intensity LAMPF proton beam has been made. This facility could be built beyond the present main beam stop.

Final design has been completed and construction bids will be solicited for a new craft building to be located away from the experimental areas. This building will house the shops and stores supporting the electricians, pipe fitters, and other crafts in their work at LAMPF. The present craft building (just south of Area A) will be converted to a cryogenic laboratory and a nonradioactive assembly area. Design for this conversion is complete and cost estimates are being prepared.

A movable guardrail system has been obtained to enhance safety around openings in the massive shielding along Line A. In the past, when large shield doors have been opened for repair or for maintenance at the target stations, rope barriers have secured the openings. Safety procedures for the operation of high-pressure hydraulic systems in the experimental areas have been implemented.

Shielding

Additional shielding was installed at the top level of the Biomed beam line at Target Station A-5. This reduced the measured radiation levels in the adjacent equipment room.

Installation of a new shield plug between the shield doors above the A-5 target station was completed early in this quarter. Radiation surveys indicated streaming through joints in this plug. Additional concrete (0.5 m) has been placed over these joints to stop the streaming.

Extensive radiation surveys were carried out during the 300- μ A run on April 28, 1977. Good results were obtained in the general evaluation of the experimental area shielding. All open sections of the Area A floor were <1.0 mrem/h neutrons and 0.5 mrem/h gammas, while normally occupied areas (counting houses) were less than half these dose rates. At the top of the shield in exclusion areas, dose rates in general were from 4 to 10 mrem/h, with readings in selected cracks somewhat higher. The crack streaming has been successfully reduced using filters of hydrogenous material. Surveys around Area A-East gave similar results with high readings

above the A-5 target. The previously discussed shielding addition was made subsequent to the surveys and has reduced readings to acceptable levels. Additional shielding around the Biomed beam line is planned later this summer.

A thick concrete shield was installed near the top of the HRS spectrometer frame to shield the detector arrays from the beam line sources on the floor. A 0.6-m slab was poured between the top structural members of the frame, and a like thickness of concrete blocks was stacked in the areas at service and cable penetrations.

Shielding material acquired during this quarter included ~25 metric tons of excess lead ballast (from the U.S. Navy). This lead was shipped to a commercial lead company to fabricate standard lead bricks. We have also obtained 3000 interlocking 90- by 90- by 180-mm concrete blocks for hand-stacked shielding, to be used mostly in the experimental caves.

Experimental Area Cooling-Water Systems

Design and installation have begun on a system to interlock the experimental area magnet power supplies with the X02-08 cooling-water pumpmotors. The power supplies will shut down to protect the magnets if the pumpmotors stop. These interlocks will replace the existing flow switches in an effort to improve reliability.

The assembly of the spare pump/heat-exchanger package was started at the TA-3 Zia pipe fabrication shop.

Procurement for the major components of the tritiated water disposal system was initiated.

The EPICS spectrometer magnet-cooling system is completed and is operational.

Radioactive Air Exhaust System

An additional air-sampling manifold was installed at A-4.

Two foam-application firms were invited to demonstrate their sealant foams on permanent shielding in Area A. The purpose is to seal the shielding in order to contain radioactive gases that are generated in the target cells. The demonstrations were encouraging and the matter is still under study.

Experimental Area Beam Lines

Main Beam Line

The A-2 vacuum pumping station has been moved from floor level to the top of the shielding. This modification improved the vacuum at Targets A-1 and A-2; a similar modification will be implemented at Pumping Station A-3.

Secondary Beam Lines

A vacuum system for SMC-West has been designed and built; new vacuum valves have been ordered for the exits of SMC-South and SMC-West.

A new target box built by CNC-11 was installed in the cave at the end of Line B for nuclear chemistry irradiations.

During the time that usable beam was targeted in Area A, secondary beam-line components caused channel downtimes of $<0.5\%$ in P^a and $<1\%$ each in LEP and SMC.

Primary Targets

Target Systems

Significant progress has been made toward upgrading the present target systems this quarter:

•**A-2 Target Wheel.** The new solid-disk graphite wheel (designed and manufactured last quarter) has been operated successfully at $150\ \mu\text{A}$ for 1160 h. Approximately 150 h of the total running time was with the wheel stationary. This same wheel was operated in a stationary mode for a few minutes during the $300\text{-}\mu\text{A}$ development run on April 22, 1977. Inspection of the wheel revealed some minor cracks. The cracks, however, could have been caused by thermal shock rather than temperature or stress. Analysis indicated that this wheel can operate satisfactorily at $300\ \mu\text{A}$ in the spinning mode.

•**A-1 Target Wheel.** Analytical calculations on a new solid-disk wheel that is similar to the new A-2 wheel have been completed.

•**A-2 Spin-Drive Mechanism.** This new mechanism was designed last quarter and is nearing

completion. Installation is planned for the end of Cycle 15.

•**A-5 Target.** The A-5 target that was fractured during the $300\text{-}\mu\text{A}$ development run is shown in Fig. IX-3. A replacement was installed having an extra 20 mm of material on the bottom. Calculations indicate that the additional radiating area will lower the maximum operating temperature by $\sim 100^\circ\text{C}$.

Target Development

Computations using the heat-transfer code TRUMP have been made to determine temperature distributions of an I-beam-shaped pyrolytic target, heated in the web of the I by the proton beam and

Fig. IX-3.

The A-5 pion production target after the $300\text{-}\mu\text{A}$ beam test. Beam enters at upper left and exits to the right. Part of the missing pyrolytic graphite was broken off during post-run handling. The actual beam interaction area remained intact without significant loss of pion production; the fracture occurred just outside the beam locus.

cooled at both ends of the web 3 cm away from the proton beam. At 1-mA proton current, the hottest temperature calculated was 1900°C at the center of the target; the heat sink was maintained at 200°C in these calculations. A lower heat-sink temperature ($\leq 100^\circ\text{C}$ for water cooling) would further reduce the hot-spot temperature. On the basis of these and other computations, an effort was made to bond pyrolytic graphite to a material that could contain a coolant and remain vacuum tight, and have good mechanical strength and good thermal properties. These criteria were met with varying degrees of success for pyrolytic graphite bonded to copper. After the bonds were accomplished, heat-transfer tests were made on the bonds. The tests were made by inductively heating the graphite and extracting the heat by pumping water through the copper tube (Fig. IX-4). Our most successful bond extracted 625 W/cm² heat flux through the bond. No deterioration was seen in over 15 h of cyclic heating tests. A full-size cooled target has been assembled using the most successful bond. An inductive heating assembly is being constructed to provide test heats at 40 kW or more.

Remote Handling

Hot Cells

A summary of improvements made to the hot cells during this quarter is as follows:

- A Kollmorgan periscope was installed in order to provide distortion-free viewing and photography.
- Special shield blocks were designed and installed to separate the radiochemistry cells from the service cell.
- Special lights were installed to improve lighting at service cell windows.

Experiment Support

Cryogenics

A complete hydrogen/tritium target system containing 80 000 Ci of tritium was assembled and run for Exp. 50. New target flasks and vacuum chambers were built and installed in gas-control ap-

paratus previously used on Exp. 50. The apparatus was refurbished, and additional safety equipment and monitoring instrumentation were added. The system was installed in the experiment cave,

Fig. IX-4.
Test geometry for development of graphite-to-copper bonding techniques in an induction heating assembly.

operated and monitored continuously throughout the run cycle, and dismantled without incident. In addition, two other targets, a refrigerated target containing ~1 l of liquid neon and a reservoir target containing ~8 l of liquid hydrogen, were built and operated for Exp. 50.

The hydrogen target for Exp. 222 was redesigned and rebuilt. At the end of Cycle 13, the target was destroyed by overpressure. A new target system employing additional safety devices was built and made operational for Cycle 14.

A refrigerated deuterium target system was built, test run, and installed for Exp. 201.

A refrigerated hydrogen target system has been assembled for Exp. 27II/194 and is ready for test runs.

Drafting is nearly complete for the hydrogen targets for Exps. 144 and 196.

A refrigerator system for Exp. 137 has been ordered.

Two surplus LN_2 dewars of 2.0- and 0.6-m³ capacity have been obtained, refurbished, and put into service.

Modifications to improve reliability and to reduce installation effort have been completed on one

refrigerator system pump cart. Flex hoses to connect the refrigerator systems have been purchased to further reduce installation effort.

Plans for the new cryogenics laboratory are nearly complete. A hydrogen-detection system and high-volume exhaust fan have been purchased; an acid sink and a welding bench have been obtained from surplus.

Polarized Proton Target Development

A nuclear magnetic resonance (NMR) detection system has been fabricated. The system is capable of detecting a room-temperature water NMR signal. Using a small water sample for a probe, the system was used to perform magnetic-field measurements on a 55-cm C magnet. It was possible to detect field variations of <0.2 G in 25 kG.

The ^3He gas-handling system, ^3He pumping system, and microwave system have been designed and fabrication has been started. Designs for systems to measure ^3He pressure, ^3He and ^4He flow rates, and various vacuum pressures are in progress.

X. LARGE-SPECTROMETER SYSTEMS

Energetic Pion Channel and Spectrometers

The channel was operated successfully for the completion of Exp. 245. However, at the end of this experiment, the high-voltage termination located at the separator vacuum box failed. Analysis of the components indicated that redesign of the termination is required to allow larger spacing of components. The necessary modifications have been completed and assembly is under way, with installation expected in July 1977.

Approximately one running cycle was devoted to beam studies, with the objective of obtaining a more reliable beam-intensity calibration. This work included a normalization done by pion-proton elastic scattering in a coincidence setup. Although the equipment functioned well for π^- , the large proton flux in the π^+ compromised these results. This calibration may be repeated when the separator is repaired.

The installation of the spectrometer is proceeding smoothly, with completion estimated in mid-May. Two difficulties which will compromise early performance have been discovered. First, the scattering chamber cannot operate properly in vacuum without overly thick windows. This problem will be solved temporarily by using a helium gas-filled scattering chamber. Second, the target-changing mechanism cannot be operated unless the scattering chamber is at atmospheric pressure. A redesign of the motor-drive mechanism is required.

High-Resolution Proton Spectrometers

The delay-line chambers for determining trajectory position and angle at the focal plane have performed adequately, although the optimal situation and configuration have yet to be realized. Problems with the periodic breaking of anode wires and large chamber currents appear to have been solved. These problems were traced to 1) the anode ground wires being too close to the side of the chamber aperture and 2) bowing of the chamber frames when clamped in place. A new chamber frame has been designed and constructed which allows for much easier servicing of the delay lines. One such chamber has

been constructed and tested. The existing chambers will be replaced with this newer version at the next opportunity.

Two drift chambers which will serve initially as calibration chambers have also been constructed and will soon be installed. The drift chambers have an inherent spatial resolution of about 0.1 mm and could also be used as the focal plane detectors if chamber resolution better than 1-2 mm is required.

Another scintillator was added to the event trigger system. Its position is 0.5 m downstream of the first scintillator. The present trigger system of four scintillators spanning a 2-m flight path has performed quite well.

It has been demonstrated that the particle identification dot plot (pulse-height vs time-of-flight) remains clean, with ~ 1 -MHz instantaneous singles rates in all the trigger counters. It has also been shown that the delay-line chambers perform well for instantaneous rates up to about 0.5 MHz. At higher rates the apparent chamber efficiency drops significantly below 95%.

Line C. To eliminate the need to use the 4-jaw collimator LGCL03 and turn off LCBM04 and -05 in order to make entries into HRS when the accelerator is operating, two beam plugs have been designed and constructed for installation at the front of Line C. Installation will occur between Cycles 14 and 15.

A polarimeter consisting of two 2-arm scintillator telescopes to monitor transverse beam polarization by (p,p) scattering has been designed, constructed, and installed ~ 1 m downstream of the Line C twist-er. The polyethylene targets of various thicknesses are inserted into the beam by a standard beam-scanner driver. Also mounted on the target ladder is a phosphor which can be viewed by a camera. This brings the total number of TV phosphors located along Line C to 10. Testing of the polarimeter vs target thickness vs beam current began before the end of the cycle. Preliminary results indicated that about 10% of the singles events in the counters are (p,p) coincidences at beam levels < 1 nA.

An insertable-strip ion chamber has been installed between LCBM04 and -05 giving a total of four ISICs for tuning subnanoamp beams. The multiplexer readout controls have been remoted to CCH. It is planned to rely heavily on the ISICs for tuning low-intensity beams (such as the polarized

beam), and after the limitations of the existing ISIC systems are fully understood, the system will be improved and expanded.

The ion pump, cryopump, turbomolecular pump, and blower pump system, which bridges the region 10^{-9} torr to 10^{-4} torr between the end of Line X and the HRS scattering chamber, has worked well to date.

A 300-mm-diam, 6-collector ion chamber has been installed at a location immediately before LC-QM13 to serve as an additional beam-current monitor.

Scattering Chamber. The only substantial problems that remain with the HRS system are those with the rod transfer mechanism and vacuum leaks associated with the sliding seal. Towards the end of the quarter, the mechanical plungers were replaced with air-actuated plungers, and the problem of transferring rods seems to have been solved. However, achieving a vacuum seal with the sliding

curtain has been entirely unpredictable. This seal is critically dependent upon the proper alignment of the transfer mechanism itself, as well as proper physical adjustment of the rollers and adjustment of the air and friction clutches. Furthermore, we have found that each particular curtain has its own characteristics such that complete readjustment of the transfer mechanism, rollers, clutches, etc., is necessary every time the curtain is changed. We found that the air clutches significantly changed their characteristics between Cycles 12-14 with the result that 1) the stainless steel curtains have been permanently deformed under too much pull, and 2) the window frames attaching the curtain to the transfer mechanism have been permanently distorted. There remain a few possible solutions to these vacuum problems and these will be explored during the downtime between Cycles 14-15.

A new target wheel has been installed inside the scattering chamber, allowing up to 36 targets to be inside the scattering chamber simultaneously.

XI. PRACTICAL APPLICATIONS OF LAMPF

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

Pion Biomedical Program

•Therapy Beam Development -- Dosimetry (Exp. 271) (Univ. of New Mexico, LASL)

New tunes and new range-shifter functions have been developed to accommodate the needs of the clinical and radiobiological programs. A catalog of beams with different dimensions, dose rates, and depth-dose distributions is now available on the Biomedical channel.

Dosimetry measurements were made on the "fan-tune" during the last quarter. This beam was designed to be narrow in both the z (i.e., depth) and y dimensions, but broad in x . Through a combination of scanning the treatment couch in y , collimating the beam in x with a variable collimator, and scanning the beam in z with the dynamic range shifter, it will be possible to treat tumors of arbitrary size and

shape. Initial measurements on this tune have been most encouraging, and results are shown in Figs. XI-1-5.

Figure XI-1 shows the dose as a function of depth for this beam, with and without the range shifter. Without the range shifter, the beam is quite narrow in z , as evidenced by the steeply rising plateau and high peak-to-entrance ratio (5.5:1). The dose rate is ≈ 44 rad/min/110 μ A proton current. An 8-cm range-shifted beam has a peak-to-entrance ratio of 2:1 and a dose rate of ≈ 20 rad/min/110 μ A.

Use of the fan tune requires synchronizing the motions of the range shifter and the treatment couch. The necessary rapid range-shifter cycling time has been achieved by using smoother range-shifter functions which are less taxing on the hydraulic power supply. Figure XI-2 shows the range-shifter function used for this purpose. The left panel shows the command and response signals utilizing a 10-s period, and the right panel shows the signals for a 4-s period. Very little tracking error is introduced even at a 4-s period.

Figures XI-3-5 show x - z , y - z , and x - y profiles for the range-shifted fan tune. As can be seen, the beam is broad and uniform in x and z , and extremely sharp in y .

Fig. XI-1.

Biomedical pion beam dose as a function of depth with and without range shifter.

Fig. XI-2.

Range-shifter function for fan tune, showing command (top) and response (bottom) for 10-s (left) and 4-s (right) cycles.

Figs. XI-3-5.

The x-z, y-z, and x-y measured isodose contours for range-shifted fan tune. Note uniform broad peak in x and z, and sharp peak in y.

Inhomogeneities can alter pion dose distributions in two ways. First, they can produce displacements in the position and shape of the pion stopping distributions as a result of differences in density, stopping power, and scattering properties. Second, they can produce local (≤ 1 -mm scale) "hot" and "cold" spots in the dose distributions as a result of their different densities (which results in a loss of charged particle equilibrium near the interface) and atomic composition (which results in different star products).

We have made a preliminary study of the "local" dose perturbations near an interface using an extrapolation chamber. Dose measurements were made by placing the chamber inside a polyethylene phantom which was homogeneous except for a single slab of inhomogeneity located near the chamber. Slabs of lucite, teflon, and styrofoam of several thicknesses were used. The thin window of the chamber allowed absorbed dose to be measured as near as $6 \mu\text{g}/\text{cm}^2$ from the inhomogeneity boundary. This insured that changes in the heavy charged particle component of the dose resulting from pion stars produced in the homogeneity could be detected (a thin-wall chamber is necessary since these particles have very short ranges). Measurements were made for the inhomogeneity slab oriented both parallel and perpendicular to the beam direction.

Inhomogeneities oriented parallel to the beam were found to produce large changes in the dose dis-

tribution due to changes in pion range. For a narrow depth-dose curve ($\text{FWHM} \approx 4$ cm), a 1-cm-thick inhomogeneity altered the dose by up to 20%, and for a range-shifted beam (8-cm flat dose) altered the dose by 2-4%. In addition, dose buildup from the sides of the phantom (due to multiple coulomb scattering) was found to be on the order of 10-30%, depending on field size.

For inhomogeneities placed perpendicular to the beam direction, the major effect seems to be a displacement of the peak position due to changes in range. Solid inhomogeneities of between 0- and 2-cm thickness produced no measurable change in the dose rate, however. Air (or styrofoam) inhomogeneities, on the other hand, lowered the dose rate both in the peak and in the plateau by up to 7%. It is interesting to note that while solid inhomogeneities do not seem to alter the dose rate, the peak dose rate is different in solid phantoms of different materials. In particular, the dose in a solid lucite phantom was found to be 2% lower than in a solid polyethylene phantom.

•Therapy Beam Development — Microdosimetry (Exp. 272) (LASL)

Microdosimetric spectra have been obtained for a broad beam (8-cm deep) at depths of 7, 12, 15, and

16 cm for π^- and at depths of 7, 15, and 16 cm for π^+ . The measurements used the system described in previous progress reports and included rejection of piled-up pulses and a measurement of dead time. The present system is capable of accumulating data at a faster rate (for the same quality) than any system available commercially.

We are also performing experiments to determine the displacement factor for this detector and for ion chambers used in dosimetry. Preliminary measurements indicate that the effective center of the chamber is ~ 0.7 cm upstream from the geometrical center.

●Activation Technique for Measuring Pion Dose (Exp. 272) (LASL)

A series of experiments was initiated to check the possibility of using the long-lived residual activation induced by negative pions in various targets to monitor the dose. The main reason for those experiments is to establish the feasibility of an *in vivo* dosimetry system to be used with the present radiotherapy and radiobiology studies.

The first experiment used principally aluminum targets. The dominant β^+ residual activities one would expect from aluminum are ^{11}C ($T_{1/2} = 20$ min), ^{13}N ($T_{1/2} = 10$ min), and ^{18}F ($T_{1/2} = 109$ min). Four aluminum targets were placed in the plateau, peak, and downstream sections according to previously measured depth-dose curves for a narrow beam. After being irradiated for about 1 h, targets were brought to an off-line measurement system and placed between two NaI(Tl) crystals. Single and coincidence rates of the annihilation 0.5-MeV γ rays were recorded as a function of time. This data, together with the beam variations in time (during exposure) were recorded on line on the Biomed PDP-11/45 computer.

Decay spectra were subsequently analyzed using an unfolding program (CLSP). The activation count rates at the end of bombardment were evaluated by folding in the experimental efficiencies of the coincidence unit.

The predominant residual radioactive nucleus was found to be ^{18}F , useful because the half-life of ^{18}F (108 min) is longer than typical irradiation times in patient treatments or biology experiments.

The analysis of these data is in progress. We also plan to build a low-background system using a Ge(Li) detector in order to repeat these measurements for γ -ray residual activity.

●Pion W-Values (Exp. 272) (LASL)

The effects of δ rays on the measurements of W-values for pions (described in the last report) have been investigated experimentally and theoretically. The W-values for air, argon, nitrogen, tissue-equivalent (TE) methane, and TE propane were determined by using an ionization chamber and determining pion fluence with an activation technique. The effects of δ rays were determined using an extrapolation chamber and, independently, an analytical treatment code. By measuring energy deposited in the chamber as a function of chamber wall thickness, the δ -ray contribution to the energy loss can be determined. The results for air are shown in Fig. XI-6. The δ rays appear to contribute 5-10% of the dose from negative pions.

Treatment Planning

Primary emphasis this quarter was on upgrading the clinical capabilities of PIPLAN. The bolus

Fig. XI-6.

Dose deposited in air past foil barrier, to measure δ -ray contribution to pion energy loss.

model was expanded to provide flat-top and flat-bottom shapes, in addition to the existing surface-conforming shape, as required by some treatment setups. Bolus output was modified to produce full-scale templates for easier fabrication. Output options were expanded and simplified for both intermediate calculations and final dose maps. The ray-tracing dose calculation was increased in efficiency by a factor of about 1.75. A requirement for using predefined collimators for overlapping fields was identified and a solution developed.

The data link from the LAMPF Biomed facility to the LASL Central Computing Facility was established and code conversion from batch to interactive mode initiated. The 20-in. printer-plotter was installed for full-scale output and the sonic digitizing system was received. Magnetic tapes from CAT scans of pion patients were received and decoding and interfacing of this data with PIPLAN started.

Several errors in the dose calculation were identified and new range-energy and multiple-scattering models are being developed. New calculations to be done by the Monte Carlo program PION1 at ORNL were defined and initiated. These include fluence and dose distributions at bone-tissue interfaces, average path lengths of star products in small silicon detectors, and fluences in ion chambers with varying wall thicknesses.

Practical Applications Experiments

●Muon Spin Rotation Studies (Exps. 266-297) (LASL, Univ. of Wyoming, Sandia Labs.)

During the past quarter the feasibility of doing μ^+ SR experiments at the Stopped Muon Channel at LAMPF was demonstrated conclusively. It was possible to resolve depolarization rates as low as 1% per μ s, which is as good as any results reported in the literature. Counting times required are of the order of 1 h per data point, which is altogether acceptable for mapping out μ^+ behavior as a function of sample temperature.

Specific results obtained include the following:

1. In polycrystalline copper a μ^+ depolarization is observed between 19 K and 100 K, consistent with the view that the muon is localized at a unique interstitial site in that temperature

range. This, and the onset of motional narrowing at higher temperatures, agrees with results for similar experiments with low values of applied external field done in Dubna and at SREL, and is in striking contrast to recent unpublished results obtained at SIN for higher applied fields. No published data exist for copper at high temperatures. Our measurements at sample temperatures up to 970°C showed no evidence of trapping of muons at vacancies in thermal equilibrium. This observation contradicts recent published theoretical speculations.

2. In polycrystalline aluminum the depolarization expected for muon localization at unique interstitial sites was not observed down to 19 K. However, a slight rise in depolarization was seen at low temperatures, which could be explained, for example, by tunneling of muons among several interstitial sites. Again, our measurements at high temperatures are the first for aluminum. Just as for copper, no evidence of trapping at vacancies was observed. The difference in behavior at low sample temperatures of muons in copper vs aluminum is not explained theoretically at this point and should stimulate work in the area.
3. Our measurements on the BCC metals vanadium and tantalum showed analogous differences in μ^+ behavior. The trend to μ^+ localization in vanadium at low temperatures is qualitatively similar to the behavior in copper, while in tantalum the muon is either not localized at a unique site or undergoes localization at temperatures lower than 19 K.

The copper and aluminum results are shown in Fig. XI-7.

●Proton Axial Tomography (Exp. 286) (LASL)

The major components of the proton axial tomography experiment have been designed and are presently on order or under construction. These include a hyperpure germanium detector capable of stopping up to 70-MeV protons, a variety of scintillation counters, and a computer-controlled scanning mechanism. Final preparations are under way for the experiment which will start in Cycle 15.

Fig. XI-7.

Temperature dependence of μ^+ precession-damping rate Δ in polycrystalline copper and aluminum. T_M is the melting point.

●Mesic Chemistry (Exp. 288)
(LASL, Princeton Univ.)

This experiment continues studies dealing with chemical and structural effects in the capture of negative muons in matter. The objectives are to investigate the composition dependence of the muon-capture ratio and the individual elemental x-ray spectra. Targets irradiated in the first run include two series of solid binary metal solutions, copper-aluminum and silver-zinc (five samples each, two pure and three solutions). Such systems provide the most basic test for theoretical models which are not yet adequate for dealing with the more complex molecular systems. Targets to be irradiated in later runs include solid-state solutions of NaBr, KBr, NaI, KI.

A program is now being prepared to test the two principal theoretical models (developed at Los

Alamos and Cal Tech, respectively) against experimental data on muon-capture ratios in simple systems, particularly solid metal solutions. Both models involve lengthy Monte Carlo codes which must be drastically simplified to make numerous comparisons. An analytic approximation of the strictly classical model (Cal Tech) has been made and results are in fair agreement with the data. Coding simplifications for the Fuzzy Fermi-Teller model are essentially complete and comparisons with the data will follow.

Technology Transfer

The local-current-field (LCF) temperature controller mentioned in the last Progress Report was recently demonstrated to a representative of Univ. of New Mexico Cancer Research and Treatment Center (CRTC) and has now been loaned to that institution. This controller is capable of interrupting the rf power source in cases of unusual temperature rate effects. Such effects are often seen when the control thermistor is unintentionally moved during treatment. Another LCF unit has been loaned to the CRTC for evaluation; this portable unit was used previously to treat "cancer-eye" in cattle and may be modified for use by the CRTC if their evaluation indicates clinical applicability. The LCF temperature-control unit mentioned in the last Progress Report has now been loaned to Tufts Univ. Medical School; preliminary evaluation of localized current fields is now under way at that institution. A future three-way collaboration in the application of localized hyperthermia involving Tufts Medical School, CRTC, and LASL seems very probable.

Some of the equipment for the bioelectric-potential/breast-carcinoma investigation has been transferred from LASL to CRTC. This experiment will be delayed due to heavy commitments to other work by individuals at both locations.

Five portable LCF units for "cancer-eye" treatment in cattle are 75% complete. These units will be loaned to various individuals for further evaluation. LASL's evaluation of the technique and equipment is essentially complete.¹

An effort has begun to develop an LCF technique for the generation of heat (60-80°C) at depth in the cornea. It would be necessary to spare the superficial layer of the cornea, to preserve a 12- μ structure called Bowman's membrane. This technique might

prove useful in shrinking collagen (at 0.02 to 0.07 cm to alter the shape of the cornea and correct refractive errors of the eye. Prior work² has usually involved the application of a heated metal probe to the surface of the cornea, destroying Bowman's membrane (0.005 to 0.01 cm under the surface). Initial computations and experiments with phantom material indicate that it should be possible to preferentially heat the deeper portions of the structure with rf current, while holding the superficial layers below destructive temperature levels with the rf electrode clamped at 5-15°C. If the technique and equipment can be developed to a promising level, animal tissue evaluation would be made in

collaboration with McGee Eye Institute in Oklahoma City.

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XII. LINAC TECHNOLOGY

(Summarizes work being performed under the auspices of the National Cancer Institute, Division of Research Resources and Centers, of the Department of Health, Education, and Welfare.)

The Geometry of Alternating-Phase-Focusing

The alternating-phase-focused (APF) linac structure being developed under PIGMI is a drift-tube-loaded structure, in which the drift-tube and gap geometries are modulated in a periodic way about the smoothly varying geometries common to the conventional quadrupole-focused drift-tube linac structure. The geometries and locations of the drift tubes are required to satisfy a number of constraints related to the dynamics of the particle beams which are to be accelerated, the resonant frequencies of the unit cells that they compose, and some convenient symmetries. An algorithm for determining all of the geometrical properties of the APF linac structure has been developed.

Each drift tube is symmetrical about its midplane and is supported by one or more stems in this plane of symmetry. The portion of the structure between the midplanes of adjacent drift tubes is referred to as a "unit cell." Each unit cell (of length L) has a gap region (G) consisting of the space between the drift-tube faces. Each gap region is required to be approximately symmetrical about the center of the minimum gap. It is assumed that the rf fields are symmetrical about this same center, and that the peak voltage on the gap is equal to the product of the average axial electric field times the cell length.

A family of geometries has been defined for the cells of the PIGMI prototype. The longer drift tubes of this family have cross sections that are essentially trapezoidal with rounded corners. The drift-tube faces are offset from the plane normal to the axis by a face angle FA . The conical face is blended to a cylindrical midsection of radius RD by an outer corner of radius RO . The drift tube is penetrated by a bore hole of radius RH , which is blended to the drift-tube face with a hole corner (or nose) radius RN . The nominal values of these five quantities for the PIGMI prototype are $FA = 10^\circ$, $RD = 4.0$ cm, $RO = 1.0$, $RN = 0.25$, and $RH = 0.5$. These quan-

ties describe a standard "face contour" which can be used for the longer drift tubes of the prototype.

For the shorter cells, however, there are two conditions under which the face geometries must differ from this standard — one based on gap geometry, and the other based on drift-tube geometry.

The introduction of a face angle must be accompanied by a reduction in the gap length in order to maintain a fixed frequency. As the gap length of a given cell is reduced, the voltage gradient on the drift-tube surface is increased. For the longer cells, a 10° face angle has a small fractional effect on the gap length and surface fields and is thus considered acceptable. For the shortest cells, the fractional effect of a 10° face angle on the surface fields in the gap is unacceptably large. Therefore, the tangent of the face angle is reduced in proportion to the gap length below some critical gap length.

Because of the exact symmetry required on the drift tubes and the approximate symmetry required on the gaps, the face contours must be similar throughout the APF period, and can, at most, undergo a slow monotonic evolution towards the standard face contour as the particle velocity increases. Consequently, the face-angle constraint must be satisfied for the shortest gap in the immediate APF period.

The outer corner of radius must be made smaller than the nominal value of RO for drift tubes shorter than $\sim 2 RO$. The effect on resonant frequency is weak. Corner radius symmetry is not maintained across these gaps but is nevertheless strictly maintained on the drift-tube body.

Hence, for the shorter cells in the APF structure, there is a two-dimensional array of possible geometries, namely, a range of cell lengths, and for each cell length, a limited range of face angles. For the longer cells in the APF, the array of possible geometries reduces to one dimension as the range of face angles converges on the standard face angle of 10° . However, even in the latter case, there is a two-dimensional array of transit time factors (T) involved, since for every geometry there is a range of possible velocities for the synchronous particle depending on the position of the cell within the APF period.

Two-dimensional arrays of G/L and T can be collected from SUPERFISH output over the array of geometries of interest, and organized for use by

PARMILA in the generation of the geometrical and dynamical properties of the structure.

The locations of the gap centers are chosen to satisfy the requirements of the particle dynamics, and the gap geometries are chosen so that each unit cell will resonate at the desired frequency. The drift-tube lengths and locations are then chosen to satisfy these constraints on the gap lengths and locations.

In practice, this is an iterative procedure because the gap locations depend on the particle velocity, which depends on the gap voltages, which depend on the cell lengths, which depend on the locations of the drift-tube midplanes, which, in turn, depend on the gap lengths and locations. The linac generation and beam dynamics code, PARMILA, executes this iterative procedure based on its own knowledge of the particle dynamics and the two-dimensional tables of G/L and T abstracted from SUPERFISH, the code for cavity field distributions.

The 450-MHz Test Stand

The MP-8, MP-9, and MP-14 personnel successfully activated the 450-MHz PIGMI klystron test stand during this quarter. Some preliminary measurements are shown here.

Frequency	450 MHz
Power Output RF	1.035 MW
Power Input DC	2.550 MW
Klystron Beam Voltage	85.0 kV
Klystron Beam Current	30.0 A
Modulating Anode Voltage	55.0 kV
Efficiency	40.6%
Gun Perveance	2.33×10^{-6}
Tube Perveance	1.21×10^{-6}

Current effort is being directed toward a more thorough calibration of the output directional coupler, reduction of the harmonic content of the driver signal, and experimentation with raising the tube perveance to a value more equal to the gun perveance. The latter is being pursued in order to attain a higher power output which would more comfortably satisfy the 9-MeV PIGMI prototype accelerator requirement. Preliminary estimates of the power required for this device are of the order of 0.9 MW, i.e., marginally within the current output level. The 1 MW achieved, however, is more than

adequate to satisfy the experimental requirements for the next year. PIGLET, a six-cell test cavity, will require 0.514 MW to reach an average axial field of 6.0 MV/m. At 1 MW, the drift-tube geometry is such that a maximum boundary gradient in excess of 40 MV/m is expected. This exceeds the Kilpatrick limitation by over a factor of 2.

The concept of using a single cavity to bunch a klystron beam at two frequencies was evaluated. This concept would be most practical in low-frequency klystrons. A design for a dual-mode cavity, resonant at two harmonically related frequencies, was accomplished with the aid of SUPERFISH.

Field Gradient Studies

PIGLET, the six-cell, 45-MeV drift-tube geometry, field gradient test cavity designed by MP-8 and MP-14 personnel, has been released for fabrication with an expected completion date during July 1977. MP-8 is currently evaluating available commercial bright-copper-plating facilities to perform the required plating following fabrication.

Initial design and layout of a rf/vacuum window for PIGLET have been initiated by MP-8 and MP-14 personnel. Both in-house and vendor fabrication are being pursued in an attempt to optimize cost and delivery. Ceramic blanks with metalized edges are on hand for the development. The dominant problems would seem to be associated with fabricating the Kovar seating ring and effecting a vacuum-tight ceramic-to-Kovar brazing.

Bright-Copper-Plating Development

The joint CMB-6, MP-8, and MP-14 bright-copper-plating development is proceeding most satisfactorily. After several runs, the plating is now virtually flawless in appearance. Emphasis is now on the completion of a single-cell test cavity for evaluating the electromagnetic properties of the plating. A 15.24-cm-long, 39.37-cm-diam test cavity was fabricated, and an oxygen-free high-conductivity copper (OFHC) drift tube identical in geometry to those being plated is nearing completion. It is proposed that the cavity Q loaded with the

plated drift tube be compared with that obtained with the OFHC replica. Initial measurements of the cavity in a pillbox mode yielded a Q 92% of theoretical with excellent repeatability indicating that the easy-disconnect end plates are acceptable.

The drift tubes being plated are fabricated from mild steel. The PVC plastic plating fixtures, shown in Fig. XII-1, were designed to provide a strong and uniform air agitation over the plating surfaces. A recently plated drift tube is shown in Fig. XII-2. It is virtually flawless, and measurements of its electromagnetic properties are eagerly awaited.

High-Energy Accelerating Structures

Theoretical and experimental studies of different accelerating structures were continued. Figure XII-3 gives the results of extensive calculations made with the SUPERFISH program code. The LASL-optimized cavity showed the highest shunt impedance. However, the disk-and-washer (DAW1) structure, and its improved version (DAW2), which uses shaped washers, have compatible shunt impedance and also a higher coupling coefficient (~50%), which makes them less sensitive to the manufacturing tolerances and beam loading. Besides the simplification of the tuning procedures, the DAW2 cavity has a smaller outer radius and, therefore, less overall weight. It is, therefore, more economical than DAW1. Figure XII-4 shows

the outer radii of all three considered accelerating structures vs synchronous velocity.

A short section of DAW2 was built, and low-power experiments were started. Preliminary results show good agreement between calculated and measured properties.

Electronuclear Fuel Production Accelerator — Low Energy

Transporting the high-intensity proton beam to the accelerator without degrading beam emittance is essential to proper accelerator performance. This transport is complicated by beam neutralization phenomena. Beam bunching, chopping, or other preparation may be quite complex for the fuel production requirements. Beam loss over the entire accelerator length is determined primarily by the quality of the beam injected into the accelerator. Recent theoretical and experimental studies indicate beam "halo" leading to subsequent beam loss

Fig. XII-1.
Drift-tube plating fixture (exploded assembly).

Fig. XII-2.
Bright-copper-plated steel drift tube.

Fig. XII-3.

Calculated shunt impedance vs synchronous velocity (ZT^2 vs $\beta = v/c$) for three cavity geometries — disk-and-washer (DAW1), optimized disk-and-washer (DAW2), and side-coupled cavity (LASC).

in the high-energy portions of the linac may be produced in the relaxation of nonequilibrium beam distributions into equilibrium configurations. Low beam loss would then require precise beam-bunch tailoring at injection — perhaps tailoring by means of an "accelerator-buncher" with very low injection energy. The application of the APF system being developed under PIGMI could provide this function with high efficiency. An initial modified PARMILA APF run was most encouraging, but further study is required.

Electronuclear Fuel Production Accelerator — High Energy

The development of the side-coupled cavity resonant accelerator structure has made possible the

Fig. XII-4.

Outer radius vs synchronous velocity for three cavity geometries.

efficient acceleration of high-current proton beams with adequate feedback control for low beam-loss conditions. A requirement for the fuel production application, more important than high shunt impedance, is high group velocity or rf energy transfer characteristics which allow single point feedback control of accelerator cavities under severe beam loading. Operation in the $\pi/2$ mode has as a characteristic the "self-locking" of phase and amplitude of the accelerating cavities, with beam loading effects appearing only in field changes in the energy transfer cavities. Recently, several new cavity geometries have been proposed which operate in the $\pi/2$ mode and which exhibit a substantial increase in the cell-to-cell coupling available for energy transfer. The most interesting of these, the disk-and-washer structure, is discussed in more detail elsewhere in this report. Since this structure together with its housing and powering represents the dominant cost in a fuel production accelerator, a heavy premium is placed on its optimization.

XIII. NUCLEAR CHEMISTRY

Nuclear Chemistry Laboratory

Counting Room Equipment

A steel-lined lead shield and a standard plastic shelf system have been fabricated and installed for use with our third high-efficiency Ge(Li) γ -ray detector.

Specifications have been prepared and bids requested for additional CAMAC scalers required to take the outputs from our standard alpha- and beta-proportional counters for transmission to the data-acquisition computer.

Data-Acquisition System

The emphasis again this quarter has been on hardware. We have received a Kinetic Systems Model 90 IBM 729 to UNIBUS magnetic tape controller. It uses a Digital Equipment Corp. (DEC) TM-11 controller as a front end and is therefore compatible with DEC operating system magnetic tape software. As a result, we are no longer dependent on special modifications to Program Q code as well as a special handler to use our IBM 729 tape drives.

We have also received a Versatec D1200A Printer/Plotter and have obtained plotting software for it. Program output is now printed at 500 lines per minute vs 30 characters per second on the DECwriter. The Versatec is also used for direct output of graphs, for example, the spectrum obtained from a multichannel analyzer.

Considerable thought has gone into the proposed exchange of our PDP-11/40 for a PDP-11/34 now on hand in Group C-9. This switch would give us several important advantages. It would decrease our UNIBUS load by at least four loads, and at the same time provide improved bus drivers. The DAS would then go from a heavily overloaded bus to a somewhat below-capacity bus. We would also then be able to obtain a hardware floating-point processor which we cannot get on the PDP-11/40, allowing use of DEC FORTRAN F4P which would increase execution speed of programs by factors of

from 2 to 10. This trade should be accomplished by the end of May.

Considerable effort was spent getting the plotting software operating, with difficulties partly due to the lack of adequate documentation and partly due to the lack of a large disk system. The problem with disk space is that the plot working file for a 4096 channel spectrum can be more than 1-million-words long. Work has also been done on the program to handle communications between the PDP-11/03 in the dual-parameter system and the PDP-11/40. The current version of Program Q has been installed and is running. Several problems were encountered due to the DAS not being able to use FORTRAN F4P which Program Q is based on, but these have been solved.

Pneumatic "Rabbit" System

Work has continued on improving the reliability of the branch of this system that runs from the hot cell to the energetic neutron station at the A-6 beam stop. Because of increasing difficulty in inserting and retracting the "snake," which determines the stopping location of the target carrier, and also because of shorting out of the carrier-sensing switch on the end of the snake, a redesigned snake has been fabricated. All metal parts of the end switch have been gold plated to resist corrosion in the high-radiation environment (the ozone concentration is suspected of being high). Also, the switch circuit now uses a mineral-insulated wire passing through the hollow tubing and joints of the snake in order to protect it from abrasion. This arrangement appears to be working well. Even with the older version of the snake, several dozen short irradiations were successfully carried out for Exp. 111, and a 6-h irradiation was carried out for Exp. 161. A fast, semiautomatic transfer from the beam stop through the hot cell to the adjacent chemistry hood was also executed.

A new switch was designed, fabricated, and installed in the "trombone" of the remote targeting station in Line B. The switch works well and we are now able to transfer targets mounted in a special swivel carrier to the proton station and back to the hot cell. Control of positioning the trombone in and

out of the proton beam resides with the CCR. Completion of these controls will make this branch of the rabbit system ready for experiments.

The system is still plagued by occasional faulty relays, failing air valves, and receiving terminals. These are gradually being replaced by more reliable components. Design of heavy-duty terminals will be completed soon and a bid package for their fabrication will be prepared.

Work has progressed on the development of the WNR rabbit system. A radiation-hardened switch has been fabricated and assembled. This unit will be assembled inside the remote rabbit head mechanism. "Canning" of these assemblies will make this unit a throw-away item. A cam follower and guide system has been designed for the J-tube drive assembly for up/down and swinging motions. Adapters for mounting the bottom bearing of the J-tube assembly inside the crypt have been designed.

Theoretical Support

The VEGAS Intranuclear Cascade Program

Pion absorption in the VEGAS intranuclear cascade model takes place through the intermediate state of the p-wave (3,3) resonance and assumes the pion-nucleus interaction to be completely incoherent. We have investigated how well this model reproduces the total pion-absorption cross section. Unfortunately, very few direct data are available for pion absorption. All of the experiments are done with bubble chambers, cloud chambers, or nuclear emulsions, and ^{12}C is the most common target. Figure XIII-1 shows a collection of these pion-absorption data¹ for ^{12}C and a comparison with pion absorption computed with the VEGAS model. We see that the calculated values are about 35% lower than the measured values. The data are ambiguous at 50 MeV, so it is difficult to say anything about the trend with energy. In the experiments, a reaction event with a π^0 emitted may be counted as an absorption event. Hence, we have also plotted the total absorption plus π^0 production cross section, and even with this we find the cross section about 10% too low. Thus the absorption is calculated to be from 35% to 10% too low.

Fig. XIII-1.

Lower graph: Measured pion absorption¹ (σ_A) in ^{12}C (black circles), the VEGAS values (open circles), and the VEGAS absorption plus π^0 cross section (open triangles) vs incident π^+ energy.

Upper graph: Percentage of absorption to total reaction cross section vs incident π^+ energy.

Carbon may be an inadequate nucleus to test the model since it is small and has a nonuniform density. In the absence of direct pion-absorption data on heavier nuclei, we have compared energetic proton production in pion-induced reactions at angles for which the protons are mainly due to pion absorption. In Fig. XIII-2 we compare the measured proton cross section² for all protons with energy greater than 60 MeV at two angles, $\theta = 45^\circ$ and 94° , with the calculated values as a function of the atomic mass. For 220-MeV pions we see that the agreement for low-mass targets is good but that for

Fig. XIII-2.

Cross section for protons emitted with energy greater than 60 MeV for π^+ (measured,² black circles; calculated, open circles) and π^- (measured,² black squares; calculated, open squares) vs atomic mass A of the target for 100- and 220-MeV incident pions and protons emitted at two angles, $\theta = 45^\circ$ and 94° .

both π^+ and both angles the agreement deteriorates as the target mass increases. For 100-MeV pions this is true at 94° as well. For 100-MeV π^+ at 45° there is a large discrepancy at all masses.

The conclusion is that the VEGAS model does not account correctly for pion absorption. We will include absorption through the s-wave channels to see how much this will increase the absorption. However, it may be that the ultimate understanding of pion absorption will need to include coherent nuclear processes.

In a recent paper by Gadioli *et al.*,³ it is claimed that in order to improve the agreement of intranuclear cascade calculations with proton spectra measured in proton collisions with nuclei, the mean free path (mfp) should be increased by a factor of 4. We did this in the VEGAS program and showed that, in fact, the proton spectrum disagrees more with the measured spectrum than when the normal mfp is used.⁴ Furthermore, the total reaction cross section calculated will decrease by a factor of 2, in serious disagreement with measured reaction cross sections. In Table XIII-I we compare the measured reaction cross section for 62-MeV protons on ^{54}Fe and ^{90}Y compared to that calculated with a normal mfp and that calculated with four times normal mfp. We see that the normal calculation agrees to within 10% of the measured values whereas the four-times-normal calculation is about 60% smaller than the measured values. This leads us to conclude that the discrepancies between measured proton spectra and intranuclear proton spectra are due to other physical effects rather than an underestimation of mean free paths.

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TABLE XIII-I

EXPERIMENTAL AND CALCULATED TOTAL REACTION CROSS SECTIONS

Target	Exp. (mb) ^a	Normal mfp	4 × Normal mfp
^{90}Y	1059 ± 26 (^{90}Zr)	928 ± 16	467 ± 12 mb
^{54}Fe	733	678 ± 13	302 ± 9 mb

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XIV. RESEARCH

Results of Experiments

Elastic Scattering of 800-MeV Protons from Deuterium, Helium-3, Hydrogen-3, and Helium-4 (Exp. 4)

(UCLA, LASL, Univ. of Texas, BNL, Univ. of Minnesota)

During Cycle 12, data were taken on p-⁴He elastic scattering at 800 MeV using the HRS facility. The target was liquid helium contained in a 2-cm-diam cylindrical flask. The beam target interactions were monitored by two 4-scintillator telescopes placed at angles of 45° and 115°. The focal plane detectors of the spectrometer were three delay-line chambers designed and built at LASL. The event trigger was generated by the coincidence between four scintillators, S2, S6, S3, and S4, behind the focal plane position-sensitive detectors and on the line of particle trajectories through the spectrometer. The first scintillator, S2 (76 by 8.9 by 0.6 cm), was placed just behind the last delay-line chamber, while the last scintillator, S4 (107 by 14 by 1 cm), was 2.06 m behind S2. In addition to the event trigger, the signals from both ends of these four scintillators were used to generate TOF and energy loss (dE/dx)

Fig. XIV-1.

Particle-identification spectra obtained from the scintillation counters behind the focal plane.

values for each event. Figure XIV-1 shows a typical dE/dx vs TOF spectrum for particles through the spectrometer, demonstrating good proton, deuteron, and triton separation. Figure XIV-2 presents typical missing-mass spectra for protons through the spectrometer. A well-defined peak due to p-⁴He elastic scattering is seen in all cases. At back angles (spectrometer angle $>90^\circ$), there is a fairly large continuous proton background from interactions in the target cell walls, which was studied in target empty runs. We were able to run with 800-MeV proton beams of up to 40 nA. Data were obtained in the angular range from 13° to 165.5° in the laboratory, corresponding to an angular range in the c.m. system of 18.3° to 170.5°, and a range in four-momentum transfer, $-t$, from 0.11 to 4.26 GeV²/c².

Fig. XIV-2.

Missing-mass spectra for the protons. The peak is from proton elastic scattering on ⁴He.

Final analysis of the data tapes obtained during this run is in progress.

Observation of Pion Double-Charge-Exchange Reaction (Exp. 25) (LASL, Univ. of South Carolina, ANL)

While it has long been recognized that pion double-charge-exchange (DCE) to a two-body final state could be a useful tool in nuclear research, this reaction has only recently been definitively observed during the course of this experiment.¹ Moreover, it has usually been assumed that DCE reactions would proceed preferentially to final states with the same configuration as the target, i.e., $\Delta T = 0$, $\Delta T_z = 2$ analog transitions. This is based on the plausible surmise that reactions involving orbital rearrangement should be substantially weaker than elastic charge-exchange scattering. Here we describe a measurement of the $\Delta T = 2$ nonanalog pion double-charge-exchange reaction $^{16}\text{O}(\pi^+, \pi^-)^{16}\text{Ne}$ leading to the ground state of ^{16}Ne . The result indicates that there appears to be no strong preference for analog transitions in pion DCE. Thus, mass determinations of proton-rich nuclides with these reactions are clearly feasible. We report here the first measurement of the mass of ^{16}Ne .

The differential cross section $d\sigma/d\Omega$ (0°) was measured at a mean pion energy of 145 MeV, using the LEP beam line as both a pion channel and fixed zero-degree spectrometer, by placing an ^{16}O target at the midpoint of the channel directly behind the momentum-selecting collimators. In this configuration, the initial half of the channel was tuned for π^+ with a point focus at the target. The second half of the channel, tuned for π^- , functioned approximately as an energy-loss spectrometer. The detection system, located near the focal plane of the spectrometer, served to identify the emerging pions and to locate their position on the focal plane. Helical wire chambers defined particle trajectories while an array of plastic scintillator and Cerenkov counters were used to discriminate between pions and electrons on the basis of velocity and rate of energy loss. Time-of-flight, measured relative to the 201-MHz accelerator rf, provided another means of particle separation.

The spectrum obtained at 0° for the $^{16}\text{O}(\pi^+, \pi^-)^{16}\text{Ne}$ reaction with incident pions of 145-

MeV mean kinetic energy is shown in Fig. XIV-3. A distinct peak is observed near the energy predicted on the basis of mass systematics. This peak is superimposed upon a low, presumably constant, background and another energy-dependent background that is assumed to come from breakup reactions yielding multiparticle final states. These are expected inasmuch as ^{16}Ne is ~ 2 MeV unbound with respect to two-proton decay to ^{16}O . After subtraction of background as shown, the centroid of the observed peak yields a mass excess for ^{16}Ne of 24.4 ± 0.5 MeV.

Were there an appreciable excitation of the first excited state of ^{16}Ne [$E(2^+) \approx 1.8$ MeV],² the centroid would have shifted and given a larger value for the mass excess. Under the present kinematic conditions, however, one would not expect significant excitation of a 2^+ state at zero degrees; the linear momentum transfer $\vec{K}_{in} - \vec{K}_{final} = 0.2 \text{ f}^{-1}$ allows

Fig. XIV-3.
Spectrum of $\pi^+(^{16}\text{O}, ^{16}\text{Ne})\pi^-$ reaction at 0° for a mean energy of 145 MeV. The arrow at the peak indicates the centroid after background subtraction. The arrows on the abscissa are theoretical predictions.

angular momentum transfer $\ell = |\vec{K}_i - \vec{K}_f| X \vec{r} < 1$ for a ^{10}O radius of 3 F.

The area under the peak in Fig. XIV-3 corresponds to 134 ± 26 events. Folding in the measured efficiency of 43%, we obtain a zero-degree differential cross section for the DCE reaction $^{10}\text{O}(\pi^+, \pi^-)^{10}\text{Ne}$:

$$(d\sigma/d\Omega) (0^\circ) = 0.87 \pm 0.21 \mu\text{b/sr}.$$

The error results primarily from uncertainties in background subtraction as well as systematic errors in knowledge of the pion flux and detector efficiency.

The present result for a $\Delta T = 2$, $\Delta T_z = 2$ pion DCE reaction is comparable to the corresponding cross section¹ for the $\Delta T = 0$, $\Delta T_z = 2$ analog transition $^{10}\text{O}(\pi^+, \pi^-)^{10}\text{Ne}$, where

$$(d\sigma/d\Omega) (0^\circ) = 2.00 \pm 0.34 \mu\text{b/sr}.$$

In the simplest shell-model description of the nuclei, ^{10}O and ^{10}Ne may be viewed as a totally closed 1p shell and a closed shell plus two neutrons in the 1d_{2s} shell, respectively. The DCE reaction then yields final configurations for the nuclei ^{10}Ne and ^{10}Ne or $\pi(s, d)^2 \nu(p^{-1})^2$ and $\pi(s, d)^2$, respectively. Therefore, this model requires that the cross-shell transition be comparable to the in-shell transition in order to achieve near equality in the two reactions.

More realistic wave functions would include particle-hole configurations in both ^{10}O (^{10}Ne) and ^{10}O (^{10}Ne), thereby allowing additional reaction routes. Even so, one probably still needs cross-shell transitions between, for example, the ^{10}O closed-shell core and the ^{10}Ne 2p-2h components.

Counter Experiments in the Thin Target Area (Exp. 86)

(LASL, BNL, LBL, Texas A&M Univ., ORNL)

Five new neutron-rich nuclides, ^{27}Ne , ^{31}Mg , ^{32}Mg , ^{34}Al , and ^{30}P , have been produced by the interactions of 800-MeV protons with a 3.5-mg/cm² uranium target. The fragment Z was identified with a silicon ΔE -E detector telescope, and the mass number was determined by a TOF method which utilizes the rf microstructure (~ 0.5 -ns-wide pulses at a frequency of 201.25 MHz) of the primary proton

beam at LAMPF to provide one of the two timing signals. The high beam current (35 μA at the time of this experiment) made it practical to use a very long flight path (4.3 m) to achieve excellent fragment-mass resolution. Because the fragment flight times are much longer than the rf period, they are uncertain by an unknown multiple of this period. Thus, an essential component of this method is the simultaneous TOF measurement over a short flight path between the ΔE and E detectors to obtain the fragment velocity with sufficient accuracy to determine the number of rf periods in the flight time over the long flight path.

The experiment was carried out in the Thin Target Area at LAMPF. The long flight path from the target to the ΔE detector was 433 cm, and the short flight path between the ΔE and E detectors was 39 cm. The short flight path distance was chosen to ensure a total lack of ambiguity in the calculation of the long flight path flight time while minimizing the loss of events due to multiple Coulomb scattering in the ΔE detector. The aluminum target ladder, which was insulated from the scattering chamber, was used as a beam-timing pickoff. The zero-crossing point of the output of a fast bipolar amplifier, which was dc coupled to the ladder, was used to derive the beam-pickoff signal. The time measured was the interval between the ΔE fast-timing signal and the next following beam-pickoff signal. A time resolution of 150 ps (FWHM) was achieved for the short flight path, and the time resolution for the long path was 0.5 ns. The fragment Z was determined by means of a table-lookup method of particle identification with a correction which used the short flight path mass measurement to eliminate the mass dependence.

The final fragment mass is calculated from the total long flight path flight time and the total kinetic energy:

$$A = 2(E + \Delta E) t^2/d_l^2,$$

where d_l is the long flight path distance. The background due to random coincidences and other spurious effects was reduced from 0.5 to 0.2 events per nuclide by requiring that the final flight time differ from the estimated flight time by < 1.5 ns, and that the final mass differ from the short flight path mass by < 0.4 amu. Only 5% of all of the events were rejected by these requirements.

The results are shown in the form of a scatter plot in Z and A in Fig. XIV-4. The good resolution in both parameters is clear, and, more importantly, it can be seen that there is no tailing, in any direction, from an abundant peak into the region of a lightly populated one. All of the stable and known neutron-rich nuclides (except for ^{24}O and the more neutron-rich sodium isotopes) are seen. The five previously unobserved neutron-rich nuclides, ^{27}Ne , ^{31}Mg , ^{32}Mg , ^{34}Al , and ^{30}P , are clearly evident; each of these peaks contains 10 or more events. There are five additional nuclides whose existence is suggested by from three to six events each, but we do not consider this evidence to be conclusive. Elemental mass spectra (cuts through Fig. XIV-4 with windows on the Z peaks) are shown in Fig. XIV-5 for the elements neon, magnesium, aluminum, and phosphorus. The five new nuclides appear as peaks, and it can be seen that the yields of these nuclides follow systematic trends from the yields of the known nuclides. The energy spectra of these nuclides were found to be consistent with those of the adjacent known nuclides.

All of these new nuclides have been predicted to be particle stable. Because of the pairing-energy effect, the particle stability of ^{27}Ne and ^{34}Al strongly implies that ^{28}Ne and ^{36}Al should also be particle stable. The nuclide ^{33}Mg is predicted to be bound by only 0.48 MeV, a value which is close to the expect-

ed uncertainty of the predictions, and it would thus be of interest, with an order of magnitude more data, to see if it can be observed.

Preliminary Proton-Scattering Survey with HRS (Exp. 139)

(LASL, Univ. of Minnesota, Univ. of Texas, UCLA, BNL, Northwestern Univ., Univ. of Oregon)

The elastic and inelastic scattering of 800-MeV protons from $^{12,13}\text{C}$, $^{58,60,62,64}\text{Ni}$, and ^{208}Pb has been studied using the HRS over the laboratory angular range 5° to 30° . The spectrometer was moved in angle increments of 1.5° to 2° ; since the acceptance angle of the HRS in the scattering plane is 3° , good angular overlap between angle settings was achieved. It was possible to sort the data into 0.1° to 0.2° angular bins with good statistics. Energy resolution was typically between 100 to 200 keV depending upon target and scattering angle. No major attempts were made to improve the resolution to <100 keV during this run since most of the states of interest were easily resolved.

Figure XIV-6 presents a typical energy spectrum for $p + ^{12}\text{C}$ at 12° laboratory scattering angle. Figure XIV-7 presents the elastic-scattering angular distribution for $p + ^{12}\text{C}$ over the c.m. angular range 5°

Fig. XIV-4.

Distribution in Z and A of fragments detected. Each dot represents one event. The boxes outline the regions of the nuclides ^{27}Ne , ^{31}Mg , ^{32}Mg , ^{34}Al , and ^{30}P . The solid lines enclose the region of previously known nuclei [see J. Cerny, "Studies of Exotic Light Nuclei, CERN Report 76-13, p. 225 (1976)].

Fig. XIV-5.

Mass spectra for the elements neon, magnesium, aluminum, and phosphorus.

Fig. XIV-6.
Typical energy spectrum for $p + {}^{12}\text{C}$ at 12° laboratory scattering angle.

to 25° . The solid curves are optical-model calculations based on the Kerman-McManus-Thaler prescription for generating the medium-energy optical-model potential from the nucleon-nucleon scattering amplitudes and the nuclear-matter density distributions. The two calculations include a "weak" and a "strong" spin-orbit potential and demonstrate the key importance of possible spin effects in elastic scattering at medium energies. The inelastic angular distributions are nicely fit using standard Distorted Wave Born Approximation codes with relativistic kinematics. The data are in the final stages of reduction, and tabulations should be available soon.

Muonic X Rays and Nuclear Charge Distributions (Exp. 166) (Cal Tech, Univ. of Wyoming, Coll. of William & Mary)

As part of our studies of the radial and angular charge densities of nuclei in the highly deformed region of the periodic table, we report the measurement of the energies of the $4f \rightarrow 3d(M)$, $3d \rightarrow 2p(L)$, and $2p \rightarrow 1s(K)$ muonic atomic transitions in ${}^{101}\text{Dy}$. In contrast to our earlier analyses^{3,4} of ${}^{100}\text{Ho}$ and ${}^{181}\text{Ta}$, where a simple application of the strong

Fig. XIV-7.
Elastic scattering angular distribution for $p + {}^{12}\text{C}$ over the c.m. angular range of 5° to 25° .

coupling (assuming that K is a good quantum number) collective model⁶ was sufficient to explain the hfs of the muonic $2p$ levels, it is essential to include band-mixing effects in the interpretation of muonic data from ${}^{101}\text{Dy}$ in terms of nuclear charge distribution parameters.

Figure XIV-8 shows our fitted $2p \rightarrow 1s$ spectrum taken at LAMPF with a $50\text{-}\mu\text{A}$ proton beam *without* use of a beam telescope. These data were used for the analysis of the $2p$ hfs. However, the majority of the data used in this analysis was taken with a beam telescope at proton currents of 10 to $30\text{ }\mu\text{A}$.

Fig. XIV-8.

Muonic $2p \rightarrow 1s$ transitions in ^{161}Dy . The solid curves indicate the least squares fits of the full energy peaks and the assumed quadratic background. The line spectrum below indicates the positions and relative strengths of the individual transitions. Vertical bars topped by n horizontal bars indicate that the nucleus remains in the n^{th} excited level of the ground state band when the muon reaches the $1s$ level. Vertical bars topped by a circle indicate the positions of the ^{162}Dy contamination K lines.

Using the muonic $3d$ hfs from the M transitions, we determined the ground-state spectroscopic quadrupole moment Q_0 to be 2.468 ± 0.028 eb. The ground-state intrinsic hexadecapole moment II_0 was found to be 1.2 ± 0.5 eb². Because of the small penetration of the nucleus by the muon, these values are essentially independent of the assumed form for the nuclear charge distribution.

Because the first two excited nuclear levels of the ground-state rotational band have energies comparable to the atomic fine structure and hyperfine structure of the muonic $2p$ level, considerable excitation of the nucleus by the muon occurs. The first (second) excited level of the ground-state rotational band is excited 20% (5%) of the time when the muon is in the $2p$ level. This allowed us to determine the quadrupole moments of these states as well as the transition moments connecting these states to the ground state. In Table XIV-I we list the observed values of these $E2$ moments as well as those obtained by correcting for band-mixing effects. We also include, for comparison, values obtained by

other methods. In general, there is excellent agreement between our work and that by other methods.

A more thorough discussion of the analysis as well as the nuclear charge parameters assuming a generalized Fermi distribution can be found in an article that has been submitted to Nuclear Physics.

Precision Measurement of the Decay Rate for the Dalitz Decay Mode of the π^0 Meson (Exp. 221) (LASL, Arizona State Univ.)

Analysis of the data is proceeding. Preliminary results, presented at the Washington meetings of the American Physical Society by M. Schardt, indicate a Dalitz-decay branching ratio of $(1.2 \pm 0.1) \times 10^{-2}$, in agreement with existing results. This result is based on only a few percent of our data, and the error is dominated by statistical uncertainties. We accumulated enough events to reduce the statistical error below the 1% level. The important

TABLE XIV-J
E2 CHARGE MOMENTS OF ^{161}Dy

	Intrinsic Moments^a This Experiment (eb)	Observed Moments^b This Experiment (eb)	Observed Moments Other Determinations (eb)
$Q_0(5/2)$	7.10 ± 0.08	6.91 ± 0.08	6.61 ± 1.12^h
$Z_0(7/2)$	6.32 ± 0.43	6.64 ± 0.43	$(1.12 \pm 0.27) Q_0(5/2)^c$
$Q_0(9/2)$	8.1 ± 2.2	7.93 ± 2.2	
$Q_0(5/2 \rightarrow 7/2)$	7.13 ± 0.08	6.93 ± 0.08	7.38 ± 0.22^d 7.06 ± 0.88^e 7.61 ± 0.66^f 8.0 ± 2.0^g
$Q_0(5/2 \rightarrow 9/2)$	6.89 ± 0.16	6.70 ± 0.16	8.50 ± 0.46^d 5.97 ± 0.72^e 4.9 ± 1.3^g

^aIntrinsic moments with band mixing corrections removed.

^bObserved moments in the body centered coordinate system not corrected for band-mixing.

^cMössbauer effect (Ref. 6).

^dCoulomb excitation inelastic scattering (Ref. 7).

^eCoulomb excitation internal conversion yield (Ref. 8).

^fPartial E2 half-life (Ref. 9).

^gCoulomb excitation γ -yield (Ref. 10).

^hAtomic beam magnetic resonance experiment (Ref. 11). No Sternheimer correction.

outstanding question is whether the systematic uncertainties can be kept below this level.

**Measurement of the Decay Rate for $\pi^0 \rightarrow e^+ e^-$
(Exp. 222)
(LASL, Arizona State Univ.)**

Data are being taken, with the experiment scheduled to end in May. At that time, the magnet, chambers, and electronics will be moved to the SMC to become part of Exp. 328 ($\mu^+ \rightarrow e^+ \gamma$).

In order to lower the trigger rate, several trigger requirements were added; these include requiring a pulse from the threshold gas Cerenkov counter on both sides of the spectrometer and reducing the number of hodoscope counters. These changes reduced the trigger rate by a factor of ~ 100 while reducing the acceptance for good events by 30%. At the end of Cycle 13, while the liquid hydrogen target

was being emptied, there was an explosion and short-lived hydrogen fire. This made it necessary for us to rebuild five MWPCs in the span of ten days. We were able to rebuild the chambers on time, and we started taking data again at the start of Cycle 14, as scheduled.

**Measurement of Cross Sections for Proton-Induced Formation of Spallation Products in Copper by Activation Analysis (Exp. 282)
(Kansas State Univ., LASL)**

Recent radiation-damage calculations by Coulter *et al.*¹² entail the use of spallation cross sections calculated by the Nucleon-Meson Transport Code¹³ (NMT) on the basis of an intranuclear-cascade subroutine following the model of Bertini *et al.*¹⁴ There is a serious question as to the validity of cross sections thus obtained,¹⁴ as well as for cross sections

calculated by a different and more sophisticated intranuclear-cascade model by Harp,¹⁵ for which some experimental comparisons of spallation cross sections are available.^{10,17} The need for an experimental check and possible verification of calculated spallation cross sections appears to be in order.

Results of the project will provide experimental values for the spallation cross section of several species produced in a copper target bombarded with protons of 800-MeV energy by use of activation-analysis techniques. These will be compared against cross sections derived on the basis of theoretical models.

Outline of Experiment. This experiment is, in many respects, similar to previous work performed by B. J. Dropesky *et al.*,¹⁰ for relatively long-lived ($t_{1/2} > 3$ h) radioactive spallation products produced by protons of 590-MeV energy in a variety of target materials. The proposed experiment differs by its emphasis on shorter lived species ($t_{1/2} > 10$ min) and, of course, spallation induced by 800-MeV protons to match the projectile energy employed in calculations by Coulter *et al.*,¹² and also of calculations performed by Ginocchio¹⁸ using the VEGAS intranuclear-cascade code (based on the more sophisticated model of Harp¹⁵).

Foils of copper and aluminum are exposed to a beam of 800-MeV protons on LAMPF Beam Line B. Gamma-radiation spectra of the irradiated copper samples are then observed using a Ge(Li) spectrometer system. The ²⁴Na activity in aluminum samples irradiated simultaneously is used to monitor the proton beam current. Spallation cross sections are then obtained from the observed spectral data.

Parameters of Bombardments Performed:

Run #1: June 21, 1975

Proton beam: E = 800 MeV,
I = 108 nA

Copper foil: d = 246 μ m

Aluminum foil: d = 26 μ m

Run #2: July 11, 1976

Proton beam: E = 800 MeV,
I = 98 nA

Copper foil: d = 34 μ m

Aluminum foil: d = 26 μ m

Preliminary Results:

a. Cu(p,spall)⁴⁸Cr

$\sigma = (3.5 \pm 0.3)$ mb Experiment
(5.7 $\pm$ 1.3) mb VEGAS
(7.3 $\pm$?) mb NMT

b. Cu(p,spall)⁶³Cu

$\sigma = (15.9 \pm 1.4)$ mb Experiment
(14.6 $\pm$ 2.0) mb VEGAS
(34.0 $\pm$?) mb NMT

c. Cu(p,spall)⁴⁷Sc

$\sigma = (2.7 \pm 0.2)$ mb Experiment
(3.9 $\pm$ 1.1) mb VEGAS
(1.8 $\pm$?) mb NMT

The experimental data tend to disagree significantly with the theoretical calculations by Coulter *et al.*,¹² which are founded on the NMT model of Bertini *et al.*,¹⁹ but experimental data are in fair to good agreement with Ginocchio's calculated values¹⁸ obtained using the VEGAS code, which is based on a theoretical model by Harp.¹⁵

Pion and Muon Multiple Coulomb-Scattering Experiment on the EPICS Beam Line (Exp. 325)

(LASL, Univ. of Texas, Northwestern Univ., New Mexico State Univ., Univ. of Colorado)

This experiment was performed on the EPICS channel to investigate the details of multiple Coulomb scattering. Data were taken with incident pions, muons, and electrons at a single beam momentum of 151 MeV/c. The targets used included lithium, beryllium, carbon, aluminum, copper, and lead. The target was placed in the beam vacuum chamber which provided about 0.8-m drift space to the first delay-line proportional chamber. This chamber measured the scattering angle of each event. A second chamber, run in the drift mode, allowed an accurate calibration of the first. A series of scintillation counters was used to provide an event trigger as well as to identify the particle type.

Figure XIV-9 shows preliminary results obtained for μ^+ multiple-scattering in carbon. It is seen that there is excellent agreement with the prediction of the Molière theory as modified by Kenneth Hanson

Fig. XIV-9.

Preliminary data for μ^+ multiple-Coulomb scattering in carbon.

(MP-3) to include scattering from the atomic electrons (the Fano correction) as well as to incorporate modern atomic form factor information in the screening parameters. The data clearly show the departure from a simple Gaussian distribution for scattering angles >50 mrad. Over 50 000 events were accumulated for each particle-target combination. It is expected that the analysis of these data will result in measurements of the width of the multiple-scattering distributions which are accurate to $\sim 1\%$.

Programming for Experiments

The off-line analysis program for Exp. 222, "Measurement of the Decay Rate for $\pi^0 \rightarrow e^+e^-$," was split into three passes. The first pass reads raw data tapes and produces an edited file of all events which pass broad cuts on the number of hits in the wire

chambers and Cerenkov counters. The second pass processes this edited file and finds a best (χ^2) fit to the chamber hits on both sides. Data from the mapping of the magnet are used in this tracing procedure. For events with low χ^2 , the intersection of the two best tracks is found and effective mass is computed. In the third pass, histograms and 2-dimensional plots are produced from a file of successful events written during the second pass.

A new PDP-11/45 was installed and is being used to test PCOS modules and to process Exp. 222 data. In the future, this computer will be used primarily to test data-acquisition hardware and software before running experiments.

A 6600-7600 subroutine was written to decode tapes written on the PDP11/45 with the KS90 controller, in which all data are treated as single-word integers.

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XV. MANAGEMENT

Budget and Personnel Levels

Operating costs through April 1977 exceeded the forecast by about 1%. The overrun is attributable to increased power costs and the cost for new accelerator spare units such as klystrons and 7835 tubes. About 76% of capital equipment funds are obligated or committed.

The average number of full time-equivalent employees chargeable to the medium-energy physics program is 329, slightly less than forecast.

LAMPF Scheduling

The LAMPF Scheduling Committee has completed a revised production run schedule through Cycle 17, and a memo was sent to all spokesmen for experiments scheduled during Cycles 14-17.

Safety

Radiological Safety

The LAMPF Health & Safety Office (HSO) continued to focus attention on the control of personnel exposures to maintain them as low as is reasonably achievable, and individual and total man-rem exposures were held to acceptable levels this quarter. The H-1/LAMPF Health Physics Section is a major element in this part of the program.

Considerable effort was expended in final preparations for the Exp. 50 tritium-target experiment on the LEP channel, which required 85 000 Ci of tritium gas, and for the 24-h surveillance required when tritium was in the target flask. No T_2 releases occurred and no tritium contamination problems were encountered during the three weeks the gas was on site and during the subsequent removal of the experimental apparatus.

The LAMPF accelerator and experimental buildings and surrounding areas are classed "Restricted Area." Permanent signs have been erected defining the perimeter of these areas and designating that only authorized personnel and visitors are permitted access. The general policy adopted for access to restricted areas is the following:

1. Film badges are required for all people who work in restricted areas.
2. All visitors must be escorted by an authorized person wearing a film badge. Visitors on tour will not be issued film badges.
3. Any LASL or ERDA employee or guest scientist wearing a film badge is considered knowledgeable of radiation in general and is authorized access to all LAMPF experimental areas.
4. Zia and other maintenance personnel will be instructed by H-1/LAMPF about safety hazards, particularly in areas where they have to work.
5. Contractor service, maintenance, and construction personnel who have to work within a restricted area must be issued film badges and indoctrinated in radiation safety by H-1/LAMPF.
6. Persons not employed by LASL/LAMPF will be permitted to drive into the experimental area parking lots to pick up members of their families or friends. They must remain in their vehicles; they are not permitted inside any building in the experimental areas.

The control of radioactive materials continued to receive considerable attention. A sensitive crystal detector system was installed as a gateway monitor to detect radioactive material inadvertently being carried off the site in a vehicle. This system will alarm when a source passes over it at 16 km/h and is of such a strength as to raise the level to twice background. The alarm is remoted to the CCR.

The LAMPF Radiological Safety Procedures were updated this quarter. Several sections were revised to reflect current practice developed from operational experience. Major revisions were made to the sections on Radiation Dosimetry, Fixed Radiation Monitoring Instrumentation, and Radioactive Waste Management; a new section was written on Labeling and Storage of Radioactive Materials.

The Experimental Areas Operations Group (MP-7) successfully conducted tests on the use of polyurethane foam to seal the cracks between the blocks in semipermanent shielding to aid in the control of radioactive gas created by the scattered beam in the target cells and along the main beam line.

The failure of a ^{238}U target in the TTA on the beam line resulted when that section of the beam line was let up to air. Mixed radioactive contamination, resulting from spallation products, was released when the target chamber was opened. The floor area in the beam switchyard was contaminated with alpha activity. Through the intense efforts of H-1/LAMPF, experimental-area/operations personnel, and a crew from the H-1 decontamination section, the area was cleaned up in a few hours, no one received serious contamination, and no activity was ingested. The inside of the main beam pipe remains contaminated and requires special additional precautions whenever it must be opened for maintenance purposes.

Safety Review of Experiments

Each experiment that comes up for an engineering review in preparation for installation also receives a careful safety review. Special problem areas such as LH_2 targets or high-pressure systems are referred to the appropriate safety committee for further review. This program continued throughout the quarter.

Safety Interaction with Staff and Users

A common concern of all safety specialists is their interaction with the personnel they are trying to protect from injury. The LAMPF HSO have embarked on a program to shift their primary role from that of enforcing numerous rules to one of providing advice and assistance in the safety area within the guidelines and standards which govern the work. The assumption here is that, through better understanding of the reasons and logic behind the safety rules and procedures, all personnel — staff and users alike — will be willing to follow the safer path, and the overall safety program will be more effective.

Safety Inspections

The formal safety inspection program continued, and 14 regular and 3 special inspections were conducted this quarter. With the shift in approach to safety as discussed above, greater assistance was provided by the HSO to the responsible groups to aid them in correcting safety deficiencies.

Housekeeping continues to be a major problem from both fire-protection and industrial safety standpoints. Through the acquisition of small van-type trailers from surplus and assistance in equipping all storage trailers with shelving, better storage space has been provided. A noticeable improvement in the clutter and housekeeping has been achieved, but further effort is required.

Safety Meetings

Meetings were held by the LAMPF Safety Committee, the Group Safety Officers, Experimental Areas Safety Representatives, and the Hydrogen and Cryogenics Safety Committee. Special operational safety problems, safety incidents, and general policy were considered. A Division-wide safety meeting was conducted with the assistance of H-1/LAMPF personnel. This meeting covered a review of the safety program, continuing safety problems, and radiation-safety items.

Area A Evacuation Horns

In the previous quarterly report it was mentioned that tests indicated that a different sound was needed for immediate evacuation of the main experimental area in the event of a hydrogen or tritium release. A stuttering Klaxon sound was chosen, and an electronic tone generator was inserted in the area paging system. Through this system, the main area and all the counting houses and electronic trailers will receive the alarm. Also, horns have been placed outside the main building to alert personnel approaching the area.

Accidents

During the quarter, eight injury accidents were recorded, with one resulting in lost time.

Training and Orientation

Five training and orientation meetings were held this quarter. A radiation safety training session dealing with problems specific to LAMPF was given for 56 craftsmen who work at the site from time to time.

An orientation meeting was held for a group of American Cancer Society volunteers who assist with patients at the Radiation Treatment Facility at LAMPF. A tritium safety lecture was given to individuals involved in the operation and surveillance of Exp. 50. Training was given to operating personnel and the experimental group on the use of portable tritium detector instruments. A preconstruction safety indoctrination was held for contractor supervisory personnel concerned with construction of a warehouse/stockroom building at the LAMPF site.

LAMPF Users Group, Inc.

Liaison Office

The HRS Working Group held a meeting in Washington, DC on April 25, 1977, with Charles A. Whitten, Jr. (University of California, Los Angeles) chairing the meeting. The following agenda items were featured: 1) the present and proposed experimental setup of the HRS facility, including a discussion of the current detector system and beam monitors and a presentation of the systems to be used in polarization experiments; 2) the data-taking and data analysis on Exp. 139; 3) the preliminary results on Exp. 4; and 4) the HRS experimental schedule. Minutes of this meeting will be mailed to all members of the HRS Working Group.

Invitations to an EPICS Working Group meeting to be held in Los Alamos on June 21, 1977, were mailed on April 15, 1977. Agenda items are as follows: 1) discussion of initial results with the EPICS spectrometer, 2) estimate of schedule for experiments, and 3) discussion of responses to the PAC's request for proposal updates.

A letter and questionnaire concerning future budgetary shutdowns were mailed to all spokesmen of LAMPF experiments on March 3, 1977.

The Nominating Committee for the upcoming election of officers for the LAMPF Users Group, Inc., was appointed by the Board of Directors and consists of Chairman Herbert L. Anderson (University of Chicago), Robert J. Macek (LASL), W. Kenneth McFarlane (Temple University), Robert A. Naumann (Princeton University), and Robert T. Siegel (College of William and Mary).

LAMPF Program Advisory Committee

The LAMPF Program Advisory Committee will meet on July 27-29, 1977 at Los Alamos. Deadline for the submission of new material will be June 3, 1977. Specific update requests have been made to all HRS and EPICS spokesmen.

The Solid State Physics and Materials Science committees will meet on May 26-27, 1977 to consider proposals related to μ -mesic x-ray analysis, μ SR, and radiation damage. Recommendations will be prepared for the PAC and the Director of LAMPF.

LAMPF Visitors Center

Exclusive of the "casual" visitors this quarter, there were 200 research guests working on LAMPF-related activities or participating in experiments at LAMPF (see Appendix), with 137 guests checking in and 111 checking out.

In response to a request for bids to provide efficiency or kitchenette apartments, LASL is negotiating a contract for 20 kitchenette apartments for priority assignment to LAMPF users. These apartments will be assigned by the LAMPF Housing Office. Direct townsite sublets have been found by the LAMPF Housing Office for 31 summer guests, with 9 requests remaining to be filled. In addition, all of the LAMPF/LASL-leased apartments have been assigned through the summer, including tentative assignment of the 20 kitchenette apartments noted above.

Tours

Organized tours of LAMPF were conducted by LASL personnel for the following:

- El Rito, NM Tech. Voc. Inst. students
- LASL families (3)
- Dodge City Community College
- UNM/LASL Committee on Human Trials
- Univ. of New Mexico Student ASME Chapter
- Univ. of New Mexico Cancer Research & Treatment Center Medical Technicians
- Ft. Lewis College science students
- Particle Beam Symposium attendees
- Univ. of New Mexico science students

- Santa Fe, NM Presbyterian Church
- Univ. of Colorado, Dept. of Mech. Engineering
- New Mexico Attorneys Meeting attendees
- St. Regis College science students
- Advanced Development Conf. attendees
(WNR Facility only)

- Texas Tech. chemistry students
- Industrial Hygienists
- Panhandle State College physics students
- New Mexico School of Mining & Tech. science
students
- Respirator Training Class

APPENDIX

RESEARCH GUESTS AT LAMPF DURING PERIOD FEBRUARY 1, 1977 - APRIL 30, 1977

Douglas M. Alde	Univ. of Illinois	Steven A. Dytman	Carnegie-Mellon Univ.
John C. Allred	Univ. of Houston	Ronald D. Edge	Univ. of South Carolina
James Amann	Carnegie-Mellon Univ.	Patrick O. Egan	Yale Univ.
Konrad A. Aniol	Univ. of Washington	Robert A. Eisenstein	Carnegie-Mellon Univ.
Mahmood Azad	UNM Cancer Center	Donald R. Fenstermacher ..	UNM Cancer Center
Helmuth W. Baer ...	Case Western Reserve Univ.	John C. Fong	UC, Los Angeles
Peter D. Barnes	Carnegie-Mellon Univ.	Sherman Frankel	Univ. of Pennsylvania
Thomas S. Bauer	UC, Los Angeles	Jeffrey M. Gallup	Lawrence Berkeley Lab.
F. E. Bertrand	Oak Ridge National Lab	Wilhelm B. Gauster	Sandia Labs.
Philip R. Bevington	Case Western Reserve Univ.	David R. Giebink	Univ. of Texas
James A. Bistirlich	Lawrence Berkeley Lab.	Shalev Gilad	Tel-Aviv Univ.
C. W. Bjork	Univ. of Wyoming	George Glass	Texas A&M Univ.
Gary S. Blanpied	Univ. of Texas	Kazuo Gotow	Virginia Polytech. Inst.
Marvin Blecher	Virginia Polytech. Inst.	Charles A. Goulding	Florida A&M Univ.
Stewart D. Bloom	Lawrence Livermore Lab.	Charles M. Grassl	Univ. of Wyoming
Felix H. Boehm	California Inst. of Tech.	Mark B. Greenfield	Florida A&M Univ.
Joseph E. Bolger	Univ. of Texas	P. C. Gugelot	Univ. of Virginia
Jonathan S. Boswell	Univ. of Virginia	Alan A. Hahn	California Inst. of Tech.
Richard L. Boudrie	Univ. of Colorado	Maureen B. Hall	UNM Cancer Center
Kenneth Boyer	Univ. of Texas	Isaac Halpern	Univ. of Washington
W. J. Braithwaite	Univ. of Texas	Robert L. Hawley	UNM Cancer Center
Hubert Brandle	UC, Los Angeles	Ryugo S. Hayano	Univ. of Tokyo
H. C. Bryant	Univ. of New Mexico	Virgil L. Highland	Temple Univ.
G. R. Burleson	New Mexico State Univ.	Nathaniel W. Hill	Oak Ridge National Lab.
Jeanne L. Burmester	UNM Cancer Center	Norton M. Hintz	Univ. of Minnesota
Elizabeth Cameron	UNM Cancer Center	Martha V. Hoehn	Florida State Univ.
Roger D. Carlini	Univ. of New Mexico	Kenneth R. Hogstrom	UNM Cancer Center
Rebecca Carrington	Stanford Univ.	Charles L. Hollas	Univ. of Texas
D. E. Casperson	Yale Univ.	Roy J. Holt	Argonne National Lab.
David T. Chiang	Univ. of Washington	Barrie E. Hughes	Stanford Univ.
Terrance P. Cleary	Oak Ridge National Lab.	Vernon W. Hughes	Yale Univ.
Carl F. Cole	Univ. of Southern California	George J. Igo	UC, Los Angeles
Robert K. Cole	Univ. of Southern California	Hikaru Inoue	Hiroshima Univ.
C. Alton Coulter	Univ. of Alabama	Harvey Israel	Private Consultant
Kenneth M. Crowe	Lawrence Berkeley Lab.	Steven G. Iversen	Northwestern Univ.
Frank H. Cverna ...	Case Western Reserve Univ.	Harold E. Jackson	Argonne National Lab.
Colgate W. Darden	Univ. of South Carolina	Van L. Jacobson	Lawrence Berkeley Lab.
Judith M. Dembo	UNM Cancer Center	Mark J. Jakobson	Univ. of Montana
William F. Denig	Utah State Univ.	David A. Jenkins	Virginia Polytech. Inst.
Arthur B. Denison	Univ. of Wyoming	R. H. Jeppesen	Univ. of Montana
Michael J. Devereux ...	New Mexico State Univ.	K. F. Johnson	Temple Univ.
Joey B. Donahue	Univ. of New Mexico	William Johnson	Univ. of Rochester
Mohan Doss	Carnegie-Mellon Univ.	Lloyd W. Johnston	UNM Cancer Center
Minh V. Duong-van	Stanford Lin. Accel. Center	Jan Källne	Univ. of Uppsala

Charles A. Kelsey UNM Cancer Center
 Charles R. Key Univ. of New Mexico
 W. Wayne Kiumison Univ. of Chicago
 Lynn Knutson Univ. of Wisconsin
 Thomas Kozlowski ... Brookhaven National Lab.
 Kenneth S. Krane Oregon State Univ.
 Joseph Z. Kukulka Carleton Univ.
 Gary Kyle Univ. of Minnesota
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