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GLOSSARY OF TERMS USED IN THIS REPORT

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

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 Spectrometer

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 JANUARY 31, 1977

I. SUMMARY

Engineering Support

The klystrons accumulated 81 500 socket hours during this quarter. Nine klystrons and thirty switchtubes required replacement. Three klystrons were rebuilt and thirty-one switchtubes were successfully reprocessed. The new klystron cleaning facility is now in full service.

The EPICS spectrometer frame was fitted with the drive and air-pad system and successfully passed the dynamic load tests. Installation of the two 90-ton spectrometer magnets was completed in January.

To provide room for future installation of the WNR fast-kicker magnet in the switchyard, the slow-kicker magnet was repositioned downstream, and the associated vacuum system was modified.

Work is progressing on the peripheral mechanical details associated with the 450-MHz test cavity (PIGLET). An order has been written for the PIGLET tank, and the copperplating program of dummy drift tubes has commenced. New rotating coil hardware was designed and fabricated to improve the harmonic content measurements of the permanent-magnet quadrupole models. The 450-MHz rf modulator and test stand racks are nearing completion, and the waveguide hardware has been ordered.

Support of the experimental program continued to dominate the group effort. Twenty-three experiments received active design, fabrication, and installation support this quarter.

Accelerator Support

The loss of a 4664 tube in module 1 resulted in 12 to 14 h of processing before the replacement could

be brought up to full power. The only way to reduce this kind of downtime in the future is to keep a spare 4664 rf-processed.

The extensive modification of the 805-MHz tank resonance control system is almost complete. Hardware is now installed in all sectors and the tank resonance temperature is being held to within 0.05 Celsius degrees.

Data from the RG-218 insulation growth test suggest that the insulation expansion is a function of being immersed in oil and of temperature rise.

A study of noise problems in the source resulted in several changes which should improve both phase and amplitude stability. A noisy reference power supply was replaced and the sensitivity of the phase detector was increased. Additional modifications are scheduled.

A heliax line was run in the beam tunnel for transmission of 12-MHz timing signals from the injector to the SY. This line will have lower attenuation and be much more temperature stable than the RG-213 located in the equipment aisle. In addition, a variety of 12-MHz power dividers has been purchased so that the distribution of the 12-MHz timing signals can be expanded as needed by the experimenters.

The fabrication, installation, and checkout of the redundant phase monitor system have been completed and the system is now operational throughout the machine. Additional isolators for the system are on order and the updating of all drawings is in progress.

The modification of all dual-Acme power supplies used on the line is complete. The supplies are now compatible with the LAMPF-standard control and regulator system.

New by-pass shunt systems are being designed for the EPICS spectrometer magnets and have been installed in LEP.

A new prototype amplifier card using a special isolation amplifier is being evaluated for use with

the current shunt in systems where problems exist with common mode voltages.

The writing of a computer test program that will increase the speed of operational tests on the beam diagnostics systems was completed. Design continued on a portable microprocessor-controlled test system that will provide the capability for performing operational tests on the actuators instead of the central computer.

Design continued on a test beam line to be installed in the transport area. This line will allow performance testing of beam diagnostics equipment with the H^+ beam while the H^- beam is being accelerated. The use of this test line for beam studies on present and future equipment will provide for more efficient testing of beam-diagnostic devices.

Extensive mechanical redesign of beam diagnostic hardware has been initiated. To facilitate this effort, beam diagnostics has been reorganized and is now composed of an electrical and a mechanical section.

Accelerator Systems Development

A compromise design for longitudinal tuning of the 201.25-MHz linac was completed, and further progress was made on the determination of new drift-tube positions to produce a linearly varying field distribution in the first tank.

The SUPERFISH cavity design code was used extensively on various problems, and was sent to BNL and Cornell University.

Simulation modeling was used to investigate a number of experimentally observed phenomena in a collaborative effort to understand the detailed trajectories of simultaneous H^+ and H^- beams in the linac. Most of the deviation from axis is explained by the fact that tolerances that would be completely acceptable for single-beam operation must be tightened or compensated for in two-beam operation.

Significant progress was made in the evaluation of a class of equilibrium distributions of particles under the influence of space charge. A particle-tracing code for these studies was written and is operating.

Diagnostic-equipment development continued to receive major emphasis. Procurement of the beam-position monitor system is well under way. Work continued on achieving consistent performance from

the multigain wire-scanner system everywhere on the linac.

The pion range shifter performed flawlessly during the human patient trials. Design work on the second-generation device was essentially completed. Construction of a single-degree-of-freedom force-reflective hydraulic servoarm was completed.

Injector Systems

Both the H^+ and H^- injectors were operational this quarter except for a scheduled two-week shutdown. The construction of the polarized ion injector has continued on schedule and is now almost completed.

The H^+ injector has been run at the 30-mA level all this quarter. An additional beam-impingement fast-protect channel has been installed to provide redundant protection to the accelerating tube. The spare MG set was installed on the H^+ injector during the shutdown and was found to be defective; the original system was then put back into service. Preventive maintenance continues to make on-line downtime minimal.

The H^- injector was run almost exclusively with chopped beam this quarter, and the tuning of dual beams with H^- chopping has continued to be a problem. A system of beam diagnostics for on-line tuning of the chopped beams has been installed in Area B and will be used in tuning up for the next production run. Additional diagnostics are now also planned for the transition region.

The accelerating column was installed on the polarized injector and high-voltage conditioning carried out. Most of the ion source components are installed and initial tests are now in progress on the polarized ion source.

Work has continued on resolving some long-standing problems in data links and computer interfaces in the high-voltage equipment domes. Marginal systems are now being replaced.

Work has also continued on studying emittance damping from the injector through the linac. Studies carried out comparing the damping of both H^+ and H^- beams with the same linac tune imply that, for the current levels now being run, an improvement in brightness of injector beams would result in a corresponding improvement in the

brightness of the linac beams. Thus, development of brighter injector beams would be useful if operating requirements at LAMPF require brighter linac beams.

Electronic Instrumentation and Computer Systems

A new disk controller and one of three disk drives were delivered, installed, and put into operation with the PDP-11/34 that will control the new bulk storage system for the SEL-840 control computer.

A new hardcopy system was installed on one of the operator consoles in CCR. This system enables an operator to press a special button on any of the Tektronix 611 storage scopes on the console and get a print of the information on that scope.

The interfacing chassis for the new master timing unit was installed temporarily on-line to the SEL-840 to check out the communication link with the computer.

The programming effort this quarter was devoted almost totally to improving existing capabilities.

The December/January shutdown provided the opportunity to make a substantial number of modifications and additions to the instrumentation and controls in the experimental area to prepare the facility for the next run cycle.

At the request of the Experimental Area Safety Committee, an addition was made to the existing evacuation alarm system so that all inhabited buildings in the experimental area would have alarms.

Orders were placed for a PDP-11/70 computer system to be used for data analysis, for a LAMPF-standard PDP-11/34 data-acquisition computer for the test channel, and for a number of system enhancements for the new PDP-11/34 in P³-East.

A software design study session was held to plan the next level of enhancements for program Q, the general data-acquisition package which runs on the PDP-11s.

Several computer systems were relocated in an effort to match computer configurations to the complexities of upcoming experiments.

A program to renovate disk cartridges was set up in LEEP; a savings of 50% over new cartridges is expected.

A major effort was mounted to upgrade the beam current monitors used in the experimental areas.

A radiation detector is nearing completion to monitor the exit gate at LAMPF for any radioactive materials leaving the site in vehicles.

Accelerator Operations

The accelerator was in continuous operation during the quarter, with the exception of an 18-day shutdown in December and January. Operating time was divided equally between research and facility development. The machine continued to run routinely with 100 μA of H^+ delivered to Area A and as much as 6 μA to Area B. Machine availability during research shifts averaged 81% for the H^+ beam and 76% for the H^- beam.

Research-quality proton beams to Area A totalled 65 000 $\mu\text{A}\cdot\text{h}$ during the quarter, as measured at the A-1 target station. An additional 338 $\mu\text{A}\cdot\text{h}$ went to Area B. Thirty-five experiments received beam.

Machine time allotted for facility development stressed the improvement of beam-tuning procedures and the determination of physical and magnetic misalignments in the accelerator and in diagnostic hardware.

Machine operation continued to be reliable and moderately stable, although problems encountered with the Δt system caused difficulties during the tuning process and throughout operating Cycle 11. Continuing difficulties in attempting to satisfy various users with the properties of chopped H^- beams pointed up the need for an independent capability to measure those properties.

Operating personnel were active in the area of facility support activities during the 2½-week shutdown of the machine. The switchyard run-permissive interlock system was completely rebuilt, the CCTV distribution system was overhauled, and other maintenance and improvement projects were completed.

Experimental Areas

Work in the experimental areas was focused on production runs at 100 μA during the first half of this quarter and shutdown activities during the second half. The production runs were carried out successfully without any significant loss of beam

time because of experimental area faults. The shutdown was notable in that the first major remote-handling maintenance operations were undertaken at the main beam stop.

Plans to erect a shelter and crane structure at Area A-East are continuing. An architect-engineer will be selected soon. A temporary enclosure has been built over the A-6 beam stop to provide weather protection for remote-handling operations that are currently in progress.

The first phase of the installation of the proton irradiation port (PIP) near the A-1 target in the main beam line has been completed.

The experimental area operations trailer complex is nearing completion. Design work is in progress to convert the crafts building into an experimental support facility.

Shield doors were opened at four target cell areas to allow maintenance activities during the shutdown. Shielding improvements have been made in several places.

Design of improved targets and beam line components has continued this quarter. This effort is backed up by engineering studies and prototype testing. Among the major items receiving attention are new solid-target wheels, a new water-cooled beam window, collimators, new target drive mechanisms, special tooling for remote handling, and the Monitor I manipulator systems.

Extensive repairs and maintenance were completed on the main beams and target systems during the shutdown. Some of these jobs were carried out in low-to-moderate radiation fields by carefully planned hands-on techniques or by semiremote methods using long-handled tools. The required maintenance work at the main beam stop, however, had to be done by full remote-handling techniques because of radiation levels approaching 1000 R/h. The Monitor I manipulator system was used successfully to replace the beam-exit window, a harp, a collimator, and to make a number of vacuum and water seals.

Delivery of the new, two-arm, force-reflecting servomanipulator system is expected in the next few months. A trailer that will serve as a master station for this system is being purchased.

Cryogenic support for experiments continued at a high level. An experiment that used a large quantity of tritium was mounted successfully, and preparations for a second tritium experiment were made.

These experiments required an enormous amount of highly skilled support.

Negotiations are under way to procure a superconducting magnet and polarized proton target cryostat from CEN-Saclay. The auxiliary systems are being prepared.

Beam Line Development

The H^+ production beam intensity continued at 100- μA average. The beam studies effort was concentrated on understanding beam halo measurements in the switchyard, beam emittance measurements at target A-5, and experimental verification of beam spot sizes at the Isorad facility at A-6.

During the December-January shutdown, numerous improvements were made to the primary beam line hardware. These include beam-on-target monitors at A-1 and A-2, a guard ring in Line A-Direct, new harps in Area A-East, improvements to the switchyard AP System, addition of an H^- chopped beam monitor in Line B, and improved EPB current monitors. The harps are now being fabricated with monolithic alumina frames, silicon-carbide wire, and commercially available metal-to-ceramic feedthroughs. In addition, a commercial fast-closing valve was installed between the SY and Experimental Area A, and a vacuum window obtained from NBS was installed in the SY to accommodate high-current test runs.

Planning for polarized H^- beams has begun. A variety of solutions to provide independent orientation of the polarization directions for HRS and EPB have been developed and are being evaluated.

Measurements of the stopped π^- rates in SMC-East have been made. Since these results are lower than calculated by a factor of 2 or 3, additional measurements are planned with BM03 removed.

Large-Spectrometer Systems

Energetic Pion Channel and Spectrometers

The EPICS channel was used for a full program of experiments during the evening and weekend periods. During the day, construction of the spectrometer proceeded. The two large dipoles were mounted in the frame, and alignment of these

magnets was completed. The mapping of the dipoles and quadrupoles was completed, and analysis of the maps is under way. Apparatus is being assembled to make a second higher-accuracy calibration of the beam monitors as well as a measurement of the multiple scattering of muons and pions. Substantial progress has been made in the design of a differential Cerenkov counter capable of distinguishing pions from muons over the whole focal plane of the EPICS spectrometer.

High-Resolution Proton Spectrometer

During the past quarter, Exp. 256 was run to completion and Exp. 139 was initiated. These first HRS experiments have led to an improved understanding of the characteristics of the operating system. The December through February shutdown allowed for continued development and modification of the facility.

Research

This past quarter, initial results were reported from two long-awaited projects: the first spectra from the HRS, and the first observation of pion double-charge exchange. Data were taken for all the even nickel isotopes in the proton scattering survey (Exp. 139) on the HRS. An energy resolution of 80 keV at 800 MeV was obtained with the full phase space from the accelerator and the nominal acceptance solid angle of the spectrometer. From Exp. 25 comes a report of the first, unambiguous measurement of the pion double-charge exchange (DCE) reaction, $^{18}\text{O}(\pi^+, \pi^-)^{18}\text{Ne}$. The transition involved is the $\Delta T_z = 2$ isobaric analog transition from the ground state of ^{18}O to the ground state of ^{18}Ne . The differential cross section $d\sigma/d\Omega$ (0°) was measured at a mean pion energy of 139 MeV by utilizing the LEP channel as both a pion channel and a spectrometer.

The first completed experiment on the HRS was a low-resolution study (Exp. 256) of backward proton, deuteron, and triton production by 800-MeV protons on ^6Li , Be, C, and Ta. The data show that, even at 2-GeV/c momentum transfer, the particle production is "cooperative," with an exponentially

falling nuclear form factor. The analysis of data from Exp. 246, scattering of 50-MeV π^+ from light nuclei, indicates that a single set of Kisslinger optical model parameters will fit elastic scattering on ^{12}C , ^{16}O , and ^{56}Fe and inelastic scattering on ^{12}C (4.44 MeV, 2^+ state). In an experiment on chemical effects in muon capture (Exp. 60), the intensities of the higher Lyman series are lower in deuterium compounds of CD_2 and D_2O than in the hydrogen compounds thereby indicating that the muon angular momentum following transfer is a function of the mass of the hydrogen nucleus from which it transferred.

In radioactivity experiments, cross sections have been measured for the 50- to 400-MeV formation of ^{18}F and ^{24}Na from ^{27}Al , and ^{24}Na from silicon (Exp. 67), and for 21 spallation products following stopped π^- absorption in ^{181}Ta (Exp. 247). A comparison of measured spallation yields for $\pi^\pm$ reactions in copper (Exp. 103) with the VEGAS cascade code shows agreement at 350 and 190 MeV but not at 100 MeV.

Several groups report the completion of the data-taking part of their experiments. The Dalitz decay mode of the π^0 was studied in Exp. 221. Several π^- -induced reactions on ^3He were measured in Exp. 245 by detecting resultant protons, deuterons, and tritons. In Exp. 90, elastic-scattering, single charge-exchange, and inverse pion-phot production data were obtained for both tritium and ^3He at 233-, 253-, and 293-MeV/c incident $\pi^\pm$ momentum. Neutron and cosmic-ray background measurements in the neutrino experiment (Exp. 31) are discussed. Theoretical problems in a scheme for a precise pion-mass measurement, and for a test of the Auger effect in pionic atoms, are described.

Nuclear Chemistry

The WWVB radio receiver, which is to be the new master timer for the Time-of-Year clocks distributed throughout the Nuclear Chemistry Lab., has been received and appears to lock perfectly on the NBS time signal. Programming has been started for the handler to be resident in the PDP-11/40 to talk to the monitor within the PDP-11/03, which is the heart of the new dual-parameter γ - γ coincidence system. Forty thousand words of additional memory, necessary to bring the PDP-11/40 data-acquisition computer to its full 124k-word capacity,

has been received and installed. Because of some heat problems in this computer, additional fans were installed and components were rearranged to promote better air flow. Some user programs have been rewritten to provide greater versatility and to reduce core memory usage.

A number of important problems have been resolved with regard to the pneumatic "rabbit" system. In particular, components involved in the transaction from the hot cell to the energetic neutron station at the A-6 beam stop have had many improvements made on them, such that "rabbits" as heavy as 500 g can be reliably delivered to the station and returned. Also, the control console digital indicator of the stopping location of the "rabbit" has been made operable. Design has been completed and fabrication about half completed on the new in-air target box to replace the radiation-damaged box in the Nuclear Chemistry Cave at the end of Line B. An instrument trailer north of Area B has been equipped for carrying out nuclear chemistry targeting activities on proton Line B.

The major theoretical activities this quarter involve calculations (with the VEGAS intranuclear cascade code) of the yields of residual nuclei from reactions with stopped and fast pions to compare with recent experimental data. The significantly higher values for the measured yields for fast pions over the calculated yields suggest that an appropriate average pion potential inside the nucleus should be included in the cascade code. In the case of stopped π^- reactions, estimates have been made of the relative probability of absorption from different pionic orbitals and these, plus more realistic nuclear densities, have been included in recent calculations of interactions induced in tantalum and copper.

Practical Applications of LAMPF

The pion biomedical channel was operated for 10 experiments during the past quarter which involved visualization studies, radiobiology, microdosimetry, therapy beam development, and patient treatments. For the first time, the treatments (head and neck tumors) required large fields (8 cm by 10 cm) and the dynamic range shifter to spread the beam in depth. *In vivo* dosimetry was

also investigated. Other experiments involved establishing the energy required for the formation of ion pairs by pions, determining the effects of pions on spheroid cell systems, and measuring the absolute pion fluence of the channel.

Realistic tests have indicated that the multiple stringer radioisotope production facility is completely operational and production will commence next quarter. Apparatus has been designed for a proton irradiation port which will allow thin-sample irradiations at very high-current densities in order to induce damage at very high rates simulating that produced by fast neutrons. Preparations for a proton radiography experiment and a muon spin relaxation experiment are well in hand. Considerable effort has been expended in evaluating the use of hyperthermia equipment in the treatment of the "cancer-eye" condition in cattle. Apparent remission rates have increased to ~90% in the most recent tests. The Univ. of New Mexico School of Medicine has approved a protocol for the investigation of a possible correlation between surface bioelectric potentials and breast carcinoma.

PIGMI Program

The PIGMI program at LASL, supported by the National Cancer Institute Division of Research Resources and Centers of the Department of Health, Education, and Welfare, has just completed the first six months of a three-year program to develop technology for the most suitable Pion Generator for Medical Irradiations (PIGMI). The program is progressing well on a number of parallel activities designed to converge during the next two years in the testing of the major innovations in proton-linac technology espoused by the PIGMI program.

Some of the activities reported here are partially supported by the ERDA Division of Physical Research in recognition of the applicability of these activities to the LAMPF program as well as the PIGMI program. In all cases the talents that have been brought to bear on these activities are talents that were selected and trained for the design and fabrication of LAMPF. We remain thoroughly convinced that the PIGMI program benefits handsomely from the close proximity and association to the LAMPF program.

The major accelerator development activities supported by or of interest to the PIGMI program at LASL in the last six months are:

1. Development of the computer program SUPERFISH, the most exciting new tool for linac, klystron, and storage ring cavity design of the last decade.
2. Continued development of the alternating phase-focused (APF) linac structure, including an algorithm for the transition between the APF structure and quadrupole-focused drift-tube linac (DTL) structure, and the selection of the PIGMI prototype parameters.
3. Development of an improved version of the disk and washer (DAW) structure, including parametric studies relevant to the optimum choice of all cavity dimensions.
4. Continued development of the rf manifold theory.
5. Mechanical design of the PIGLET cavity.
6. Procurement and assembly of a 450-MHz klystron power system, and solicitation of bids for a 1350-MHz klystron to be used with the same system.
7. Continued development of permanent-magnet quadrupole lenses
8. Evaluation of copperplating processes for linac applications.
9. Definition of the PIGMI injection parameters and solicitation of bids for a 300-kV injection power supply.
10. Completion of an APF test cavity and a microprocessor-based bead-perturbation system for APF test cavity studies.
11. Design criteria and procurement of a minicomputer system for diagnostics and control of the PIGMI prototype.

Management

Operating costs for this period were ~5% higher than forecast. Fiscal year 1977 operating funds are

still limited to \$18 415 000, pending action by the Congress. Approximately 15% of the capital equipment allocation has been spent or committed. The average number of full-time-equivalent employees chargeable to the medium-energy physics program is 334, slightly less than forecast.

Individual and total man-rem exposures remained at acceptable levels during this report period. Detailed preparations were made for Exp. 50 to be conducted in the LEP channel to measure the γ -ray energy spectrum from pion capture in tritium and other light elements. This experiment requires special safety considerations because of the large quantities of liquid T_2 and H_2 used as targets. In addition, safety reviews were held for 15 experiments, with no unusual safety problems identified. Additional surveillance was provided during shutdown periods to ensure personnel adherence to safety rules and procedures.

The Tenth LAMPF Users Meeting was held at LASL on November 8-9, 1976; there were 239 registered attendees. The officers and members of the LUGI Board of Directors for 1977 were announced. In conjunction with the annual Users meeting the Board of Directors and the Technical Advisory Panel met on November 10, 1976. During this report period a second meeting of these two entities was held at LASL on January 10-11, 1977. Recommendations and deliberations of the Board of Directors and the TAP have been presented to the LAMPF Director.

The LASL administration restored to MP Division the capability of direct leasing of apartments for sublease to LAMPF users and guests. These units will be assigned by the LAMPF Visitors Center with priorities assigned to users with scheduled experiments. During this report period, 149 guest scientists checked into the LAMPF Visitors Center; there were 162 checkouts.

Publications

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D. J. Liska and L. B. Dauelsberg, "Performance of the LAMPF Particle Separator," *ibid.*

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M. W. Johnson, W. U. Schröder, J. R. Huizenga, W. K. Kensley, D. G. Perry, and J. C. Browne, "Measurement of Total Muon-Capture Rates in ^{232}Th , $^{235,238}\text{U}$, and ^{239}Pu ," submitted for publication in Phys. Rev. A.

D. J. Ernst and M. B. Johnson, "Pion-Nucleon Form Factor in the Chew-Low Theory," submitted for publication in Ann. Phys.

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II. ENGINEERING SUPPORT

LAMPF Accelerator

Accelerator Support

The TR-BM-02 and -06 vacuum chamber bellows developed a leak during accelerator operation and temporary repairs were made to permit continued operation. Permanent repair was accomplished during a routine maintenance period by replacing the entire magnet assembly with a spare unit. Subsequent inspection revealed that the leak was caused by the beam impinging on a flange, and sputtered metal contacting the bellows created a leak. While the coils of both magnets were operated satisfactorily, dark brown streaks and charred epoxy indicated that the beam had passed through the beam pipe and through the coil structure. These coils are being reworked.

The three spare 805-MHz quadrupole doublets and beam pipes have been tested and are ready for installation should they be required. Powered tests are now in progress to determine the magnetic center with respect to the mechanical center and to determine the magnetic center shift when the steering coils are energized.

805-MHz RF System

The VA-862A klystrons have accumulated over 893 000 fh with 12 failures, and the L-5120 klystrons now have more than 168 000 fh with 15 failures. Thus, 20% of the original VA-862A klystrons have failed, and 60% of the original L-5120 klystrons have failed. One VA-862A klystron (S/N-105) and four L-5120 klystrons (S/N-2012, -2028, -2033, and -2034) failed during the quarter. Five VA-862A klystrons were received, including S/N-301 which was repaired by the vendor under warranty. To date, 6 of the 10 klystrons on order have been delivered.

The klystrons were operated for 81 500 fh in the quarter. Nine klystrons and thirty-eight modulator triodes were replaced on the accelerator. The LPT-44 modulator triodes have now accumulated more than 1 088 000 fh with 29 irreparable failures. Thirty-six triodes were reprocessed this quarter, but

only thirty-one of these passed the acceptance tests after reprocessing.

Klystron Repair Facility

Three L-5120 klystrons (S/N-2012R1, -2033R1, and -2034R1) were rebuilt during the quarter. All have passed the acceptance tests, although the output systems of the last two klystrons became detuned in the rebuild process; an external iris was used to retune the output circuits. This detuning problem is being investigated. A fourth rebuilt klystron (S/N-207R1) was tested and found acceptable. Two L-5120 klystrons were disassembled and their output windows and waveguide couplers were loaned to SLAC to be used on the SPEAR ring.

The new klystron cleaning facility is now complete and in full operation.

Switchyard

The WNR line slow-kicker magnet was relocated downstream to provide room for a proposed fast-kicker magnet. A new stand was installed and aligned, a modified vacuum system was added, and a temporary beam pipe was installed.

Experimental Lines

Area B

A new stripper box (LB-ST-00) was installed and aligned.

Area C

Miscellaneous alignment services have been conducted in Area C including LC-TV-02, -03, -04, and other experimental devices. A large current monitor with a 24-cm aperture was made for the nuclear chemistry cave in Line C. The core was wound from Mu-metal ribbon on a slotted steel mandrel, hydrogen-fired, and then carefully wound to avoid stressing the laminations. The completed toroid had 1.4-H inductance which is more than any other LAMPF current monitor. The toroid has a

complete steel magnetic shield which will permit operation in the noisy environment.

Weapons Neutron Research Facility — Line D

Preliminary alignment of the three 30° bending magnets (IL-BM-02, -03, and -04) was performed. Because the entire bending magnet assembly will be rotated occasionally, the accuracy of repositioning is of major concern. Periodic alignment checks will be conducted.

The design of the radiation-hard version of LD-BM-00 is complete, and detail drawings of the m.i. coils (the long lead-time item) has commenced.

Energetic Pion Channel and Spectrometer

The two drive units were installed on the spectrometer frame along with the associated plumbing, and the piping system for the seven air pads was completed.

Load tests were conducted on the spectrometer frame prior to magnet installation at 115% of its rated load (Fig. II-1). The frame was driven, several times, over 25% of full travel. Some difficulty was encountered with the control valves; however, new

valves, on order, should rectify this problem. Air-pad failure was simulated, and it was verified that faulty pads could be replaced.

Alignment mounts for the EPICS spectrometer magnets, from the Univ. of Texas, were delivered in early December. Some weld repair was required on the parts prior to installation on the bending magnets BM-05 and -06. Alignment reference targets were positioned on the frame. Installation of these magnets and removal of the jacking tower were finished on January 13, 1977. An abbreviated installation sequence is shown in Figs. II-2 through 5. Figure II-2 shows the jacking tower in place with the jack rod attached to BM-05. In Fig. II-3, BM-05 is being lowered into the spectrometer support frame; BM-06 is shown in its final position above BM-05 in Fig. II-4; and Fig. II-5 shows the two bending magnets installed in the support frame.

The spectrometer detector frame will be completed upon delivery, scheduled for March, of outside-fabricated parts.

Biomedical Beam Line

Installation of the finished cowl covering the last quadrupole magnet in the treatment room was accomplished during scheduled maintenance periods over the last quarter.

A wedge-changing mechanism was added to slit RF-SL-02 to permit remote wedge selection. Design limitations were encountered since the wedges and mechanism had to operate between the two movable jaws of the slit. The system is now in service although a program is in progress to improve the rigidity of the wedge support structure.

Continued engineering and fabrication support were supplied to the Biomedical Facility including design and fabrication of a depleted uranium collimator and its supporting structure, modification of two treatment couches, and the design and fabrication of a graphite detection chamber.

Pion Generator for Medical Irradiations

Several variations of a newly designed PIGLET drift-tube stem seal have been tested for vacuum integrity and compression reproducibility. All seals were found to be vacuum tight on the first try, and

Fig. II-1.

EPICS spectrometer structure with full test loading on it.

*Fig. II-2.
Installation sequence showing jacking tower in place with jack rod attached to BM-05.*

*Fig. II-3.
Installation sequence showing lowering of BM-05 into the spectrometer support frame.*

*Fig. II-4.
Bending magnet -06 is shown in its final position above BM-05.*

*Fig. II-5.
Shown here is final installation of the two bending magnets in the support frame.*

two styles were compressed to within 0.025 mm of the controlled squeeze surface with the calculated clamping load. These stem seals were machined from solid copper stock and annealed. The vacuum tests also verified the need for a stem material that has high strength in the annealed condition. PIGLET drift-tube stems will be fabricated from 4130 steel tubing which will have adequate strength in the 3/4-10 threads to produce clamping loads necessary to compress the copper vacuum seals.

A 1.5-mm-diam copper wire seal has been designed for the PIGLET end flanges which utilizes a retaining ring that maintains precision alignment of the seal and also provides for a controlled squeeze. This type of wire seal will also be used on the rectangular slot opening in the PIGLET tank. Figure II-6 shows the fixture used to stretch the copper wire to the i.d. of the retaining ring, and Fig. II-7 shows a completed wire seal mounted in a retainer.

An order has been written for the fabrication of one complete PIGLET assembly including the 450-MHz vacuum tank, drift tubes, water-cooling jackets, and vacuum manifolds. Quotations are to be submitted by February 15, 1977.

Two dummy drift tubes have been made from mild steel for use as copperplating models. These models will be bright-acid copperplated, stripped, and replated as required to develop plating fixtures and techniques necessary to produce an acceptable

bright-copperplate. Figure II-8 shows a dummy drift tube mounted in a plating fixture designed to maximize air-bubble agitation on the drift-tube surface during copperplating.

A 33-mm-thick ceramic disk with metalized edge has been ordered for use in fabricating an rf vacuum window assembly for PIGLET.

The APF cold-probe cavity and the associated beadpull components (Fig. II-9) are complete and ready to interface with the electronic and control systems.

The 450-MHz rf modulator is 95% complete, and the test stand racks are 70% complete. Wire trays and pipe supports are being installed to provide water, controls, and power to the system. A water load has been designed, and waveguide bends have been ordered to allow the klystron to be connected to either the water load or PIGLET. These parts will be modified at LASL from the standard 90° bends to those required.

Another circular-pole permanent-magnet quadrupole having a 1.60 pole-to-bore radii ratio was fabricated; this increases the number of magnets for preliminary experimental measurements to five.

To improve the quality of harmonic measurement instrumentation, a new flywheel assembly and series of "quick-change" rotating coils have been adapted to existing equipment. Earlier rotating

Fig. II-6.

Fixture for stretching and bonding copper wire seal to retaining ring.

Fig. II-7.

Copper wire seal mounted in retaining ring.

Fig. II-8.

Dummy drift tube with plating fixtures attached.

coils used a single-turn loop. The new coils have five turns, to increase the signal from the relatively small-bore quadrupole magnets.

Flux integration measurements are being conducted on the series of quadrupole magnets to experimentally determine the permeance coefficients of the magnet assemblies. Accurate determination of this parameter is imperative in the design of permanent-magnet circuits. Mathematical approximations can be made for quads that are long relative to the bore (two-dimensional losses), but actual measurements are required for short quads (three-dimensional losses). Severe design requirements are placed on quadrupole magnets in the short drift tubes in the low-energy end of the linac.

Experiment Support

Continued engineering, drafting, fabrication, and field assistance were provided to LAMPF users this

Fig. II-9.

APF cold-probe cavity and associated bead-pull components.

quarter. Twenty-three experiments that received significant support during this reporting period are as follows:

- **Exp. 4 (HRS).** The elevated platform fabricated last quarter was installed next to the HRS scattering chamber. Safety railings were then attached around the platform edge. The users' electronics rack, vacuum pump, and other apparatus were placed on the platform, and the target holder and support structure were aligned.
- **Exp. 27II (EPB).** Design and fabrication of detector chamber support stands, a new support stand for a scattering chamber, modifications to an existing scattering chamber, and routing of instrument cables from the users' trailer to the EPB cave are under way.
- **Exp. 28 (LEP).** Field assistance was given during removal of this experiment from the LEP cave, which was readied to accommodate Exp. 29/54II.
- **Exp. 29/54II (LEP).** Support consisted mainly of mounting the Bicentennial magnet, its spectrometer stand, vacuum chambers, and target holders. Also provided were a power supply for the magnet and modifications to the target (source) holder. Upon completion of this phase of the experiment, field assistance was furnished for its removal from the LEP cave in preparation for Exp. 191.

•**Exp. 50 (LEP).** The support of this experiment was one of the most intense efforts furnished to users. This support centered around the need to provide a tritium-containment enclosure in the LEP cave and a transport platform for moving the users' twin C magnet.

A roof structure with removable sections was designed and installed over the LEP cave. This structure supports the tritium-containment plastic house, and with its removable sections permits overhead access to the cave. An air-pad platform system was designed and fabricated to transport the magnet into the cave; the magnet is now in place and aligned. The use of this air-pad transport system required reworking the concrete floor inside the LEP cave and an area adjacent to the cave where the magnet was assembled since air pads require smooth floors for proper operation.

A track system was designed and built for the tritium target cart. This track is presently installed in the LEP cave.

•**Exp. 65/66 (B).** A special support stand for the users' polarized beam target magnet was designed. This design permits the use of the existing spectrometer stand now in Area B at the 0° collimator position. The design has been approved by the user and is now ready for detailed drawings.

•**Exp. 90 (P^s-East).** Field assistance was furnished for the removal of the experimental apparatus. Of particular importance was the need to gain early access to the rotation mechanism at the pivot point (3-m position) of Kon-Tiki. This mechanism required modification to allow it to be used to support the scattering chamber for Exp. 93 which is to follow. Occasional alignment assistance was also furnished.

•**Exp. 93 (P^s-East).** Field assistance is being provided for the mounting of this experiment. Four stands for detector chambers were designed, fabricated, and installed on the deck of Kon-Tiki. Extension sections were installed on Kon-Tiki for the downstream detector chambers, and the modification of the Exp. 90 rotation mechanism at the 3-m position was completed. This modification permits installation of the users' scattering

chamber at the Kon-Tiki pivot point. Alignment assistance was furnished for locating the four detector chamber stands, the position on Kon-Tiki of the 30D40 magnet, and the location of the users' scattering chamber. The Ames C magnet was furnished and placed in position for this experiment. This magnet was reworked by removing ~6 cm from the bottom of the magnet to lower the aperture center when placed on the spectrometer stand. The hookup of dc cables and coil cooling-water lines for both the 30D40 and the Ames C magnet was completed.

•**Exp. 96 (LEP).** Design was started for detector holders and the target/scattering chamber mount.

•**Exp. 130 (EPICS).** Conceptual design has been completed for a large Cerenko chamber. This multichannel chamber is to be mounted on the down-stream magnet field clamp now on the EPICS spectrometer stand. Further design awaits a review of the design concept and its preliminary cost/effort estimate. Development of a fabrication technique for the large glass mirrors, using the ETL brazing furnace as a forming oven, is under way. Glass is on order, and the graphite forming mold has been received.

•**Exp. 137 (EPB).** An optical bench is being designed with movable supports to permit rapid insertion and removal from the beam line and to provide a remote positioning capability.

•**Exp. 173 (SMC-East).** This experiment required that air movement around the target crystal be minimized. This was accomplished by lining the interior walls and ceiling of the east cave with plastic sheets taped to the shielding blocks. Field assistance was furnished during setup of the crystal spectrometer stand.

•**Exp. 181 (LEP).** Most of the engineering of the π^0 spectrometer stand has been completed. The design-model concept is being followed. Two vertical column assemblies complete with detector-mounting carriages have been received from the vendors. These units are to be assembled and checked out at ETL. Design of the two radius arm carts for the

columns is 90% complete. Drafting is scheduled for completion in about four weeks.

Design of the spectrometer lead-glass support frames is continuing, and drafting is 70% complete. Mounting tubes for the PMT assembly are being fabricated.

●**Exp. 191 (LEP).** Support was furnished to move the users' apparatus from the Area A test channel to the LEP cave. This included placing the floor tracks in the cave for the movable instrument arms and furnishing an anchored floor pedestal for these arms. Assistance was also furnished for the removal of this apparatus in preparation for the setup of Exp. 50.

●**Exp. 200/323 (EPB).** Engineering and field assistance were furnished for the mounting of this experiment. In addition to the apparatus reported last quarter, a linear actuator was designed and built for positioning the laser power meter, and a specially designed bracket and holder for the actuator and meter were set up.

●**Exp. 201 (P³-East).** The design was completed of the floor tracks for the user-supplied instrument arms. This track/arm system will replace the Kon-Tiki stand and floor plates upon completion of Exp. 93 presently in the P³ cave.

●**Exp. 222 (P³-West).** The design and fabrication of the new Cerenkov chamber including the optical system (mirrors furnished by users) were completed. Alignment of the optical system was performed in the ETL alignment lab, and the chamber was delivered to the cave for installation. Alignment assistance was also furnished for other portions of the experimental setup.

●**Exp. 266 (SMC-West).** A special cradle was designed and fabricated for holding two coils in a fixed relationship to each other. This cradle allows the coils to be positioned vertically or horizontally in the SMC beam line. The coils and cradle have been assembled and delivered to the user.

●**Exp. 286 (P³-West).** Design of an actuator mechanism for remote target positioning was completed. Detail drawings for this mechanism are being prepared.

Five of the twelve new water-cooled sections for the Ames C magnet have been delivered, and the remainder are nearing completion. A core modification and all peripheral hardware are complete in preparation for major rework of this popular pool magnet.

Activity Breakdown

Fabrication

The fabrication section effort for this quarter was as follows:

Experiment support	57%
Accelerator support	16%
Klystron/Ion pump rebuild	12%
WNR support	5%
Other (Biomed, PIGMI, etc.)	10%

The following experiments were provided fabrication services and technician support: Exps. 65, 221/222, 29/54II, 142, 60, 245, 50, 93, 140, 180, and 191.

Seventeen H₂ furnace heats were conducted this quarter for brazing and bakeout purposes.

Light Pipe Shop

Forty-one light pipes were completed and eight units were repaired during this reporting period. In addition to fabricating twenty-nine scintillators, four were repaired.

Metrology Lab

The last two of the WNR 30° bending magnets were processed in the tooling dock. Tooling hold locations were inspected and the physical dimensions were measured and recorded. In addition, the magnetic field clamps were aligned, bolted, and doweled in position.

Beam boxes were positioned and pinned on two quadrupole magnets for the injector area. One other magnet, for the polarized ion line, was processed through the tooling dock and was provided with alignment fiducials.

The target and vacuum chamber assembly for Exp. 222 was provided with alignment references in preparation for installation in P³-West.

Wire-Winding Shop

The following is a review of the services provided by the wire-winding shop during the quarter:

<u>Requester</u>	<u>Service</u>
Exp. 96	Fabricated 7 chambers and wound 17 signal planes
Exp. 221/222	Fabricated and wound 7 spare frames
Exp. 201	Wound 12 helical frames
EPICS	Fabricated and wound 2 frames
Line A	Wound 6 harp frames

III. ACCELERATOR SUPPORT

201-MHz RF Systems

An average of 1630 h was accumulated on each of the 201-MHz rf modules. This is 70% of the total time available during the quarter.

One 4616 failed with a control grid short and the 4664 in module 1 failed with a screen grid short after accumulating 12 000 h of filament time. Twelve to fourteen hours were required in processing the spare 4664. This tube had last been run at full power into a dummy load a year and a half ago. For the past six months it had been in the dc-processing fixture, where the filaments were run up and a small amount of dc current run through it periodically. This dc-processing helped for the initial turn-on of the tube but no significant improvement was noted for the conditioning to full power. It appears that these tubes will have to be run periodically at full power in order to have a processed tube available as a spare for the machine.

One 7835 was removed from module 2 as a suspected failure. After the tube was removed, the fault was still present and although the tube was not the cause of the failure, it failed to hipot properly. The tube will be evaluated at the test stand during the next quarter.

The 7835 amplifier in module 2 was taken down and the filament springs were changed during the December shutdown. The springs on the outer conductor appeared to be in satisfactory condition after a year of operation, but the inner springs had lost their temper and were brittle. Improvements to the water system have significantly reduced the problems associated with these springs.

Brakes on the tuning mechanisms for the 7835 cavity in module 2 were added during the teardown and the control box was modified to accommodate the brakes.

An air eliminator has been installed to improve the condition of the cooling water for the rf system.

The heat exchangers used for crowbar resistor oil cooling had accumulated enough debris to restrict water flow and, therefore, cooling of the resistors was marginal. A chemical cleaning of the exchangers removed most of the debris and the cooling is now back to normal.

The vacuum window on Tank 2 was changed as a preventive maintenance measure during the shut-

down. Although it had accumulated 5500 h of running time, it showed no evidence of damage.

Current meters with overcurrent sensing were installed on the hv power supply for the 7835 stands and interlocked to the control system for over-duty protection of the equipment.

The 7651 bias supplies were modified to eliminate a switching transient that occurred at the end of the rf gate, causing the loss of bias for a microsecond.

Resonant frequency measurements were made on Tank 1 in support of the changes being made to compensate for the change in field tilt.

The new ceramic insulator on the IPA cavity was inspected at 2400 h of hv time. No evidence of deterioration due to corona was noted but additional hv time will be needed to determine if the ceramic is a significant improvement over the Delrin.

A 7835 that had been stored since 1968 was run at the test stand. It ran satisfactorily, and no problems were noted. Four 4616s and four 250 000 modulator tubes were tested and processed at the stand. The control system switching for 4664 operation was completed and checked out and the stand should be ready for 4664 operation within the next two weeks. A chassis was built and installed to operate the tuning mechanisms on the 7835 cavity. The stand was shut down for five weeks in order to divert manpower for the December machine shutdown.

Negotiations between LASL and Microwave Associates for testing of a Microwave Associates piece of hardware at the test stand were completed. The testing should take place some time during the next six months.

805-MHz RF Systems

The extensive modification of the tank resonance control system is 95% complete. Hardware for the system is installed in all sectors. The water temperature controllers have been modified so that the setpoint and gain pots are now located on the front panel of the M1 module. The tank resonance temperature is being held to within 0.05°C of resonance. Interchangeability, however, is not yet as good as desired. To improve this situation, precision power supplies and more stable resistors for the temperature sensing circuit have been ordered.

The modification of the quad magnet power supplies to alleviate start-up problems by replacing four

open-style relays with enclosed relays is 33% complete. Since this modification is carried out only when one of these power supplies fails, only a small number of supplies will be modified each quarter.

Extensive testing of the Δt hardware indicates that it is functioning properly. A program was initiated to replace all hard-wired cards with pc cards.

The setpoint pots on the reference supply for the hv power supply system have always been difficult to adjust. To alleviate this problem, all pots were replaced by multiturn units.

The annual preventive maintenance of the hv power supply components was completed.

For evaluation purposes the relatively stiff coax cable running from the accelerator tank to the phase package was replaced in six modules with a much more flexible cable.

New capacitor room fans, which are used for cooling crowbar resistors, have had a very high failure rate during the first few hours of operation. A test stand has been constructed which will be used to burn in new fans for the first 100 h. This should substantially increase the reliability of the units that are installed on the accelerator.

Preliminary data from the RG-218 insulation growth test suggest that the insulation expansion is a function of being immersed in oil and of temperature rise. Expansion in air with increases in temperature is significantly less than that measured in oil.

Other activities included the following:

- 1) The tank resonance water valves in all sectors were checked for looseness of the ball valve, and several were repaired.
- 2) The rerouting of tank power indication to CCR is 90% complete.
- 3) The Belden 8871 hv cable under test at ETL has 11 155 hvh and 9764 h drawing current.
- 4) The recalibration of numerous systems was completed.

Low-Level RF Systems

A study of phase and amplitude stability of the source was conducted during the December shutdown. Recordings of power line harmonics were made and compared with amplitude modulation on the 201- and 805-MHz multiplier outputs and on the drive line. The amplitude controllers seem to be very

effective in removing all amplitude modulation due to power line noise at 120-Hz and below. However, the amplitude controller does not do as good a job on higher frequency harmonics.

Random noise found on the 201-MHz drive line was traced to the dc-reference for the amplitude controller. By replacing the dc-reference with a better power supply, the random noise was eliminated and the 120-Hz modulation was reduced to 75 dB below the rf level.

Phase stability measurements were made between the multiplier outputs and the drive line signals for both the 201- and 805-MHz systems. These measurements showed the 201-MHz system had several degrees of phase modulation, primarily at a 120-Hz rate. The 805-MHz system showed a few degrees of similar modulation which diminished by a factor of 3 when the 805-MHz phase control loop was opened.

An investigation of the phase control loops showed that the 201-MHz loop does not include the buffer amplifier located immediately after the multiplier. Apparently this buffer amplifier is introducing some phase modulation in the system before the phase correction loop, and this modulation is appearing on the 201 drive line. Since the 805-MHz phase is compared and locked to the 201-MHz at a point beyond this buffer, it would also follow any phase shift in the buffer. This explains why the 805-MHz system appeared more phase stable with its phase loop open.

It was also noted that the phase detector used to compare 201 and 805 MHz was rather insensitive and the signal-to-noise ratio was very poor. By increasing the resistance of the detector summing junction it was possible to make the 805-MHz signal track the 201-MHz signal to 0.25° .

There were several different control loops and monitoring systems in the shield room that have not been used in some time. Some of this superfluous equipment was removed during the December shutdown and the rest will be removed during upcoming maintenance periods. All cabling will be rerouted and the RG 213 will be changed to heliax. The 201-MHz and later the 805-MHz buffer amplifiers will be replaced with solid state units that should be more phase stable than the existing units. After these changes are completed another study of phase and amplitude stability will be initiated.

Drawings of the 201-MHz solid state IFAs have been updated and many of the required parts have been received. The first set of pc cards were made and are being checked. Construction of the 14 IFAs required is scheduled to begin during the next quarter.

The 805-MHz solid state IFA has been completely redesigned. More stripline construction is utilized and all variable capacitors have been replaced with fixed capacitors. This design is not only more efficient, but no tuneup of the unit will be required. A prototype is under construction that will be extensively tested during the next quarter.

During the December shutdown a heliix line was run in the beam tunnel for transmission of 12-MHz timing signals from the injector to the SY. This line will have lower attenuation and be much more temperature-stable than the RG-213 located in the equipment aisle. In addition, a variety of 12-MHz power dividers have been purchased so that the distribution of the 12-MHz timing signals can be expanded as required by the experimenters.

Phase and Amplitude Control Systems

The fabrication, installation, and checkout of the redundant phase monitor system has been completed and the system is now operational throughout the machine. Additional isolators for the system are on order and the updating of all drawings is in progress.

The 805-MHz phase subsystems utilizing solid state diodes, which are being evaluated in Sector B, have exhibited a tendency to saturate. Because of this, the Microwave Assoc. Schottkey Barrier diodes in modules 5 and 6 have been replaced with Hewlett Packard Schottkey Barrier diodes. These diodes appear to solve the saturation problem. The stability of these modules will be monitored to insure the acceptability of the new design.

Because of previous problems with the control probe TNC connectors in the 805-MHz tanks, these probes were checked for broken or intermittent connectors. Seven defective TNC connectors were found between modules 25 and 48 and these were replaced by adapting to type N connectors. Separate studies are under way to provide a better cable and connector system for this application.

Radiofrequency power levels from the 805-MHz tanks to the phase subsystems and amplitude control systems were checked and reset to original design levels. This was done on all 805-MHz modules.

Power Supplies

Of the 12 dual-Acme power supplies, 10 have been modified to make them compatible with the LAMPF-Standard control and regulator system. This completed the power supply modification program on the Stopped Muon line. After modification, the two remaining units will serve as spares in the power supply pool.

The second of two new by-pass shunt systems for LEP has been installed and both systems are operational. These by-pass shunt systems have the capability of being tuned for 300-MeV particles.

Transducers for current regulation and monitoring have been installed in the 14 power supplies for the quad magnets associated with the target cell in Area A. These transducers supply a high-level signal that is isolated from the power supply leads. This system will give more reliable and reproducible regulation and monitoring of the magnet current.

The existing by-pass shunt system now employed on the EPICS bending magnets BM01-04 cannot be utilized for the two by-pass systems needed on the spectrometer magnets. A new method for mounting and cooling the hv transistors needed in these by-pass systems has been developed. The heat sinks are being fabricated, and construction of the by-pass shunt systems will start when the heat sinks arrive.

Installation of the four by-pass shunt systems for Line 1L (WNR) is complete, but the units have not been checked out.

All parts for the 2000-A reversing switch rebuilding program have been received but a satisfactory method for silverplating the furnished contact plate assembly has not yet been developed by CMB-6.

The by-pass shunt systems for BM06 and BM08 in the transition region have been rebuilt for a maximum capability of 330 A, allowing the fixed by-pass resistors in the beam channel to be removed.

A new prototype amplifier card using a special isolation amplifier is under evaluation for use with the current shunt in systems where problems exist with common mode voltages.

Beam Diagnostics

Operational tests were run on the beam diagnostics systems linear actuators several times this quarter using the central control computer. Writing was completed on a computer test program that will allow much faster performance of these tests. The design continued on a portable micro-processor-controlled test system that will provide the capability for performing some of the operational tests on the actuators without the use of the central control computer.

A method for faster checkout of harp and emittance signal cables and diagnostic equipment was devised. The method uses cable scan equipment with a digital readout and various adapter boxes and cables.

Work continued on procurement of spare parts, fabrication of checkout equipment, review of all beam diagnostics systems drawings, and writing of maintenance manuals and procedures for beam diagnostics systems. It has become apparent that more time must be devoted to these activities in the future.

Fabrication continued on the new sample-and-hold system that uses the fast wire-scanner amplifiers. Cables were fabricated to connect the system to the analog data systems in the transport and transition region. A checkout bin was built for setup and adjustment of the fast wire-scanner amplifier module and 26 amplifiers were tested. The wiring of the equipment rack was checked. Extensive testing will be performed on this system before replacing the present sample-and hold system.

New ceramic harp boards were ordered to replace all the large boards now in use. The new boards will be wired with 0.0033-cm-diam carbon monofilament wire. All 201- and 805-MHz harp boards will be replaced with these new boards.

Design continued on a test beam line to be installed in the transport area. This line will allow performance testing of beam diagnostics equipment with the H^+ beam while the H^- beam is being accelerated. Two beam boxes have been fabricated and various other equipment has been obtained for the line. The use of this test line for power-handling-capability studies on present equipment and on future designs will provide for setting more realistic beam-power limits on devices and should result in fewer damaged devices.

Gain switches were installed in the remainder of the 805-MHz wire scanner amplifier modules. These switches provide for a gain range of $\times 10$. Switches were installed in the first half of the modules during the last quarter.

A study was conducted to determine the feasibility of replacing the operational amplifier in the wire scanner module with an amplifier more capable of handling the present gain and risetime requirements. Good results were obtained with two different amplifier designs but additional testing is required.

Vacuum Systems

Vacuum support for the accelerator was mainly carried out during the December shutdown. Several modules were let up to air for diagnostic gear replacement or repair and for ion pump replacement. This included two 2400 ℓ/s pumps replaced on Tank 2. The location and repair of a leak in Tank 1 resulted in one full day of downtime.

The installation of a fast valve in Line A, the kicker for WNR, and some tripper work in the SY required moderate support.

Vacuum support in Area A continued to be light, mainly involving pump maintenance and assistance with leak-checking. A new turbopump was installed at the A4 pumping station and some support was required in the evaluation runs of the Alcatel pump at A3.

The usual periodic shifting and assembly of experiments in EP and B lines required moderate support of the vacuum section, but the heaviest support was in Line C with extensive retrofit work involving fabrication and installation of vacuum lines and equipment.

Some light support of WNR line was required involving fabrication of various line components.

Mechanical Support

A major portion of this quarter's effort continues to be directed to general accelerator maintenance, including work on the 201-MHz water systems, tuning slugs, diagnostic hardware, and rf amplifiers. One new tuning slug was completed and another is near completion. A new air eliminator was installed

in the A01 water system, which supplies cooling water to the 201-MHz amplifiers. An emergency boost pump for the 201-MHz crowbar cooling has been designed and procured, and will be installed early in the next quarter. Drive brakes for the 201-MHz 7835 amplifier input and output tuning drives have been completed for all four amplifiers but installation has been completed in module 2 only.

Five WNR diagnostic actuators were completed and delivered to Group P-11.

Design and fabrication of the EPICS cable bridge is complete and the unit is being installed on the spectrometer frame. Final plumbing and electrical services await checkout of the bridge.

Extensive mechanical redesign of beam diagnostic hardware has been initiated. To facilitate this effort, beam diagnostics is now composed of an electrical and a mechanical section.

Reliability

The quarterly study of operations and maintenance reports continues in an attempt to pin-

point those units with high failure rates. Table III-1 lists those units with the most failures during the first quarter of FY-77. All other MP-11 units had ten or fewer faults during the quarter.

The total number of klystron crowbars for the first quarter of FY-77 was 179 or an average of 2.41 per day. On an hourly basis the rate for all 44 klystrons was 2.34 crowbars per 1000 hvh. This represents a decrease from the previous quarter. Of the 179 crowbars, 115 were on the 6 Litton tubes and 64 were on the 38 Varian tubes.

A comparison between the reports for the FY-76 transition quarter and the first quarter of FY-77 reveals a slight improvement in all categories except "Equipment Downtime." The mean time between failures increased from 4.7 h to 5.6 h. When all aspects of the above are considered, MP-11 equipment reliability improved as compared with the previous quarter.

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

TABLE III-1
MAJOR RF UNIT FAILURE-RATE HISTORY

<u>Unit No.</u>	<u>Name</u>	<u>Section</u>	<u>No. of Failures</u>
1147	Modulator Switch Tube	805	40
2001	Quad Magnet Power Supply	805	19
1111	IFA	Low Level	17
1121	Pulse Amplifier	805	14
1146	Klystron Modulator	805	11
2011	Steering Magnet Power Supply	805	11
1177	RF Permissive	P&A	11

IV. ACCELERATOR SYSTEMS DEVELOPMENT

Beam Dynamics

201-MHz-Linac Field Distribution

The compromise design for the 201 linac was completed, and new injection parameters for energy and phase were determined. This new model was then used to generate new phase-scan parameters. The development of a new phase-scan procedure was initiated.

The effort to determine new geometric parameters to produce a smoother field distribution continued. The effort is now directed toward keeping drift-tube lengths the same, but repositioning them to give new accelerating gap lengths. The goal of this effort is to devise a simple algorithm for predicting new gap lengths to produce a field distribution which varies linearly. This algorithm will be tested in SUPERFISH to determine the field distribution produced in a 15-cell structure. This will then allow extrapolation to a 31-cell structure. It will also predict how many drift tubes should be moved.

Documentation of the beadpull work and the Tank 1 study was initiated.

Accelerator Structure Design

Design work continued for PIGMI, using the SUPERFISH code, with studies for both the low-energy end and the parameters of the drift-tube linac. Polynomial fits have been made to several of the generated parameters and work is continuing on the optimization and accuracy of these fits.

The rf cavity analysis code SUPERFISH is used extensively by members of MP-9 and MP-14, and is run on the average several "terminal hours" each day with minor improvements being made, as necessary, to make this work more efficient.

Work and discussions about major new developments in SUPERFISH are in progress on the following subjects:

- a) The possibility to model beam-cavity interactions. This would involve solving cavity problems with distributed current on axis,

calculating the effect of the resulting fields on this current distribution, and iterating on the procedure to determine real cavity-beam interactions.

- b) The accuracy of large multicell problems. It is important to have complete confidence in these very large problem solutions (~16 000 mesh points) so that "big" SUPERFISH may be used for the final calculations on Tank 1 rf-structure modifications.

Visits were made to the AGS Division, BNL, and the Nuclear Science Division, Cornell Univ., to install SUPERFISH on their computer facilities. They are both using this program for storage ring cavity studies.

Transverse Dynamics

Measurements were made by the operations group in both the 201.25- and 805-MHz parts of the linac to estimate the size of transverse oscillations with present tunes, and to search for input conditions which would minimize oscillations. The observed oscillations are large (several mm) and very sensitive to input conditions. It was demonstrated with the simulation models that the experimental results would be expected from the alignment precision of the magnetic elements. The alignment precision is good (<0.125 -mm displacement, <0.25 -mr angular), but the angular tolerance in particular is inadequate when the requirement is to transport simultaneously two beams of opposite charge, each close enough to the axis to avoid introducing halos. Various methods for measuring and controlling the orbits are being considered.

Tanks 3 and 4 steering partials previously determined were used to steer the H^+ beam through the TR on the quad axes, but the attempt was not successful. New partials were taken. It is known that the partials must be accurate to $<10\%$ in order for the least-squares steering to be successful. It is difficult to measure them that well. A computer study of the steering partials as a function of the relative position of the beam with respect to the quads is now being contemplated inasmuch as the quad steering may well affect the partials to a degree greater than our tolerances.

In conjunction with efforts to define the 805 quad axis, EM-11 measurements of the beam in the common portion of the TR have been made to empirically determine the relative axes of the emittance station, the TR quadrupole, and the 805-MHz linac quad axis for the first few modules.

The Δt Procedure

The SIMALAC beam dynamics code for the 805-MHz linac has been used to study various aspects of the Δt procedure. In one study, it was proposed that the correctness of an rf tune be examined by comparing Δt results when different rf amplitudes are used. Calculations were made for both the design linac and the actual linac models. An isolated rf phase error of 5° produced an obvious effect for the design model. A phase error of this size may also produce a noticeable effect on the actual linac model. Further calculations are being made.

In another study, the SIMALAC code was used to investigate 805-MHz linac phase scans. The phase is scanned by moving the reference line phase. Calculated and measured changes in the TOF parameter Δt_c may be in quite good agreement, as shown in Fig. IV-1. The change in the TOF itself is also of the same form. For a good rf tune, the oscillation for $+10^\circ$ on the reference line should be sym-

metric about the x-axis with the oscillation for -10° on the reference line. This may be used to obtain a rapid rough check on the rf tune for the entire 805-MHz linac. A program for the control computer was written to read the indicated TOF signals from the Δt loops as the operator adjusts reference line phase and plots the changes. SIMILAC calculations show that the presence of isolated rf phase errors of 10° may be detected by this method.

Some improvements and modifications were made in the Δt programs.

Horizontal Oscillation Control

The control electrode assembly was installed inside TDQL02 this quarter and tested by applying voltage to a single plate at a time while holding all other plates at ground. Beam-deflection sensitivity at the entrance to Tank 1 with all other transport elements active was ~ 0.005 mm/V. This is about the level expected for the widely spaced, short electrodes used. The results were checked using the POISSON group of codes to determine the electric field for several configurations, and PARMILA for the resulting beam motion.

A developmental high-voltage operational amplifier using power pentodes in the output stage was completed and satisfactorily tested. This unit has a

Fig. IV-1.
Comparison of calculated and measured changes in TOF parameter using SIMALAC code.

risetime of $\sim 20 \mu\text{s}$ and can deliver a plate-to-plate voltage of almost 800 V. Two will be used with preamps to close loops between fast beam-position monitors and the control electrodes in an attempt to control the horizontal oscillations on a pulse-to-pulse basis.

Space Charge Effects

Work continued on the problem of determining equilibrium distributions in rz coordinates. This procedure determined distributions in phase space which are matched between the transverse and longitudinal directions and in which the space charge is taken into account in a self-consistent manner. The model assumed a harmonic oscillator external potential with azimuthal symmetry. Distribution functions considered were of the form $f(\vec{x}, \vec{p}) = nB(H_0 - H)^{n-1}$ where H is the single-particle energy including space charge and H_0 and B are constants. For $n \rightarrow 0$, the distribution is a shell in six-dimensional phase space. Some special cases were calculated in order to compare with previous work. Long bunch cases were done to compare with the one-degree-of-freedom transverse results of Gluckstern, Chasman, and Crandall.¹ The case $n = 0$ with a long bunch length was also compared with the well-known Kapchinskij-Vladimirskij distribution, and behaved as expected.

Results were obtained for some realistic examples. It was found that if the total oscillation energy and number of particles in the bunch were held fixed, then the $n = 0$ distribution has the smallest radius but is closest to the space-charge limit when compared to the other distributions with higher n values. Another analysis held the transverse emittance (that contains 100% of the particles) fixed and looked at the maximum radius and number of particles in the bunch for various distributions. This is a type of accelerator acceptance study in which space charge is taken into account. It was found that distributions with lower n values were superior in holding a large number of particles.

Work began on a particles tracing code named HOT, using a harmonic oscillator external potential and a sum-over-particles space-charge-force calculation. This approach was chosen to separate out the "pure" space-charge effects as much as possible from effects caused by the variation along the

axis of the external restoring forces. Although the sum-over-particles space-charge calculation is time-consuming for many particles, the tracing needs to proceed only a short distance down the accelerator before space-charge effects can be seen since changes in the distribution due to the alternating gradient structure are absent. Only a small number of particles need to be traced if accuracy is not important (for investigating core of beam only, not the halo). Also, collision effects which are present when small numbers of particles are used are not important if the initial distribution is not too far from thermal equilibrium. Variation in the external forces along the accelerator can easily be incorporated into the tracing code to study the effect on emittance growth due to acceleration. The effect of the alternating gradient structure will be studied either by choosing the proper variation of the force constants along the accelerator in the particle-tracing code or by using PARMILA. So far, the tracing code has been checked by tracing one of the previously calculated equilibrium distributions with no acceleration. It was found that the phase-space distribution does in fact remain unchanged. Turning off the space-charge forces during tracing does cause the same initial distribution to change as it moves down the focusing system.

An accelerator applications workshop at LLL was attended, and the results of the space-charge studies to date were discussed.

Permanent-Magnet-Modeling Computer Program DIRECT

A new computer program DIRECT, which uses the same method of solving simultaneous difference equations as SUPERFISH, is being developed. This program, which will be able to model very general magnetostatic problems in two dimensions, including permanent-magnet materials, will be the primary tool in a design study of permanent-magnet quadrupoles.

Beam-Halo Analysis

Progress continues on the problem of reconstructing distributions from wire-scan profiles. The

data from a single scan are employed in determination of a "core" for the beam, at that cross section, which is of Gaussian form:

$$\rho(x,y) = A e^{\alpha(x-x_0)^2 + \beta(x-x_0)(y-y_0) + \gamma(y-y_0)^2}$$

Analytic techniques have been developed for obtaining the best (in the discrete, least-squares sense) parameters A , α , β , γ , x_0 , and y_0 — this reconstruction procedure is rapid since its cost is approximately that of solving one set of four linear equations in four unknowns. The complement of this core is currently being investigated, numerically and analytically, and then an analogous core/halo decomposition will be sought for xx' phase space using data obtained from consecutive wire scanners.

Long-Term Stability Development

The event recorder software was modified to wrap around in its recording space. Formerly the program quit recording when the space was full. Now the current event is recorded over the oldest event, so that the most current data are always available. The event recorder is being used to study the H^+ injector arcdown rate.

The rf stability plot software was modified such that the signals from the new module-to-module phase packages for modules 25 to 48 may be plotted.

Back-up files of Δt programs and data were created on magnetic tape. These files may be reloaded in the event of a control computer catastrophe. The procedure has been documented.

Operations-Support Development

Work continued on the various data bases employed in support of operations maintenance and equipment reporting. A new data base, AREA A JOBS, has been written for experimental area management, and is ready for data and testing.

Diagnostic Equipment Development

Beam-Position Monitors

Procurement is still under way of components for 60 fast beam position monitor electronic systems.

Beam-Profile Instrumentation

New shielded cable was installed for the multigain wire-scanner amplifier, and rack connections were modified. The new cables caused difficulties with many of the old amplifiers, so they were filtered more heavily. Some of the difficulty arose from cable with out-of-spec capacitance, but it was found that the performance of the multigain system was still not consistent from module to module over the whole machine.

A digital-to-analog amplifier offset circuit was designed, tested, and installed at module 3. The circuit provides the capability of using the multigain wire-scanner amplifiers in the high-gain positions for phase scans. The offset circuit and amplifier were tested and used to take some data; however, offsetting was accomplished with a local command box because the binary computer interface has some technical problems which have not yet been resolved.

Another effort was directed at the development of a device consisting of 40 carbon fingers which can be inserted into the beam in steps which allow a direct measurement of the x-y current density distribution. The required sensitivity of the apparatus was checked and we found that only a single-gain amplifier was necessary for the measurement. Construction of a prototype is in progress.

Δt Hardware

Updating of Δt drawings continued. New phase shifters were procured for installation and testing in Δt . These phase shifters have better temperature coefficient characteristics than those now in use, but they are not as linear nor do they have as favorable a power rating.

New phase-limiting rf amplifiers were installed throughout all the Δt locations except the final gain stage in systems 1 and 2, where high-power output amplifiers will be installed.

Various methods of looking at the longitudinal microstructure of a beam signal are being investigated. Some data has been gathered from the Δt loops. Some bandwidth data for the Δt loop has been taken on the wire-test jig to 2.6 GHz. Other signal pickup devices and testing methods are being investigated.

Emittance-Measurement Equipment

Design for a "fixed" slit EM-3 jaws has been submitted to drafting. This design allows the jaws to be adjusted to give a slit width of 0.025 cm to 0.25 cm in both planes and provides a tungsten surface wherever maximum cooling cannot be provided.

Consultations with MP-11 have been carried out with regard to new emittance collectors, an emittance-collector testing station, and thermal hardening of the phase-scan gear.

Beam-Diagnostic Software

An analysis program for the 805 wire scanners has been written and is nearly debugged. This code is a developmental type code which initially is to be used to assess its value to operations. It has the capability to correct wire-scanner centroids for beambox alignment errors, both displacement and rotation, and for actuator-beambox mounting uncertainties.

New Beadpull Apparatus

The controller for the beadpull in PIGMI has been completed and bench tested under both local and microprocessor control. The unit has drive capabilities for hysteresis-synchronous motors and uses optical limit switches.

Software to monitor the standard microprocessor control panel and operate the hardware, both control and data acquisition, has been written and test-

ed. An operational test on the PIGMI cold-probe model will soon be carried out.

Miscellaneous

A report on the Teletype Monitor system software for the LASL/Fermi Crate microcontroller has been written.

Collaborative Programs

Injector Arc-Pulse-Modulator Controller

A circuit was designed and prototyped for controlling the output current of the new arc-pulse modulator.

Biomed Hardware

The prototype range shifter was used on human patients during November-December 1976. The system functioned satisfactorily in all respects with no failures occurring in either the mechanical hardware or the MPU system. The only addition made to the system was the inclusion of a pulsation dampener to reduce pressure pulses in the long supply lines.

The improved range-shifter head design was essentially completed this quarter providing up to 20 cm of stroke with a 2-cm thickness. A design review resulted in a planned reduction of stroke to 17 cm pending proof that a higher density absorbing fluid such as ethylene glycol can be used without deteriorating the system. This will allow the shape of the tank to be made even more conical for greater convenience of use during treatments. At the same time, it is planned to go to continuous command functions rather than histograms which will reduce tracking speeds at the bottom of the stroke. This will alleviate displacement problems of the fluid sandwiched between the two windows and possibly allow an even further reduction in minimum thickness.

A preliminary design has been completed for a servocontrolled collimator adapted to a collar-mount on the base of the range shifter. This design is still under review.

Hydraulic Servoarm

The pressure control servovalves arrived this quarter and the construction of the single-degree-of-freedom force-reflective model is complete. Work is now progressing on the control system electronics.

A LaGrange analysis of the six-degrees-of-freedom system was started to complement the stress-analysis work being carried on by WX-8.

EPICS Separator

The new 400-kV power supply for the EPICS separator is still under construction and some parts

and interface information have been delivered to the manufacturer. Delivery of this unit is expected next quarter.

REFERENCES

1. R. L. Gluckstern, R. Chasman, and K. Crandall, "Stability of Phase-Space Distributions in Two-Dimensional Beams," Proc. 1970 Proton Linear Accel. Conf., FNAL, Sept./Oct. 1970, p. 823.

V. INJECTOR SYSTEMS

H⁺ Injector

The H⁺ injector was on-line all this quarter except for a two-week scheduled shutdown. The injector has functioned normally at the 30-mA beam level.

An additional fast-protect channel has been added to this injector for accelerating-tube protection. This channel monitors beam impingement on the exit-beam pipe from the accelerating column and interrupts the beam when excessive current is observed. Since this pipe is smaller than the accelerating-electrode apertures, it provides a redundant protection for beam impingement on the accelerating column.

The palladium leak in the H⁺ equipment dome has required more frequent bakeouts during the past quarter and, from an operational standpoint, this was becoming a nuisance. The leak was thoroughly outgassed and operating pressure on the inlet side was increased from 4 to 12 psig. No further problems have occurred in its operation since these measures were taken.

The bouncer unit was removed from its oil tank for inspection in preparation for upgrading the corresponding unit on the H⁻ injector. The anode power supply and resistor network were checked for spare part inventory. This unit has been in service for over 10 years with only minimal parts failure to date.

The motor generator in the H⁺ injector was overhauled after 18 months of service. The new spare MG set was installed during the two-week shutdown but was found to be defective, so the original MG set was put back into service after overhaul was complete. Negotiations with the vendor are now in progress to rectify this situation.

An effort has been started this quarter to correct some long-standing problems in the operation of the light links and computer interface systems in the equipment domes. The light links have been checked out and improved LED units have been installed in some channels to correct low-gain problems. Investigation of ground loops in the computer circuits and channel crosstalk is continuing and optical isolators are being considered to improve these data links.

H⁻ Injector

The H⁻ injector was operational all this quarter except for a scheduled two-week shutdown. This injector has been running at the 0.5-mA level although dual-beam operation has limited accelerated beams to 0.2 mA.

Work has continued in studying problems of satellite contamination in the chopped beams. Some improvement has been achieved with the use of additional aperturing in the injector beam lines. On-line chopped-beam diagnostic systems are now being installed in the TR which will permit chopped beams to be tuned prior to production runs.

The intermittent interlock problem in the H⁻ equipment dome was found to be due to improper functioning of the 24-V power supplies, which power the control channels and interlock chassis; they have been replaced by supplies of a more rugged design.

The bouncer unit for the H⁻ injector was removed and will be rebuilt and tested off-line in preparation for higher peak-current operation. The EHT7 switch tubes are no longer available and they will be replaced by 7668 tubes. This unit will then be almost identical to that now in use on the H⁺ injector and could be used as a spare on this injector if necessary.

One ion pump was changed this quarter in the H⁻ dome and has been rebuilt.

Polarized Ion Injector

The accelerating column was installed this quarter and initial high-voltage tests were carried out. Sparking on the drive lines limited conditioning tests to 670 kV. Corona shields are now being installed to correct this problem.

The polarized injector is nearly ready for beam extraction. All vacuum housings have been installed and final alignment has been made. The cracked weld in the spin-filter solenoid vacuum housing has been repaired, but a new housing will be fabricated to prevent future trouble. A cryogenic refrigerator has been installed in the argon charge-exchange cell.

The magnetic field-mapping of the spin-filter solenoid and argon-cell solenoid has been completed. The axial field within the spin filter is uniform within ± 0.2 G over the critical region. The 1.608-GHz rf cavity which operates within this field has been tested for rf power distribution within the cavity and meets specifications. Frequency stability is within ± 0.5 kHz for a 24-h period.

The light-link system used to communicate between the 750-kV injector and ground level has been tested. This system incorporates new amplifiers having a bandwidth of 1.0 MHz and increased gain, new types of LEDs and photodiodes, and a redesigned optics system. Interfacing changes between

the receiver diodes and the RICE multiplexing system have reduced the amount of electronics necessary for reliable transmission.

All beam transport magnets have been installed and aligned. The transport vacuum system is complete and ready for final welding except for the spin precessor magnet vacuum box. This item should be received from the shops department shortly.

The system for rapid spin reversal is still being designed. Present plans are to use an adiabatic spin-reversal system in order to eliminate beam-position movements resulting from spin reversal. This system should be ready by June.

The status of all assemblies for the polarized source is presented in Table V-I.

TABLE V-I
STATUS OF POLARIZED ION SOURCE COMPONENTS

	<u>Design Completed</u>	<u>Drawings Completed</u>	<u>In Shop or to Vendor</u>	<u>Received from Shop or Vendor</u>	<u>Installed</u>	<u>Tested</u>
Duoplasmatron Ion Source	x	x	x	x	x	x
Duoplasmatron Vacuum Housing	x	x	x	*	*	*
Cesium Cell	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	*	
Precessor Magnet	x	x	x	x	x	
Transport Quadrupoles	-	-	x	x	*	
Transport Diagnostic Element						
Ion Pumps	-	-	x	x	*	x
Ion Source Stand	x	x	x	x	x	x
Ion Source Gas Systems	x	x	x	x	*	*
Injector Dome	x	x	x	x	x	x
Injector C-W Power Supply	x	x	x	x	x	x
Injector MG 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.

At the present time, the first polarized beam is scheduled for Cycle 13 beginning March 27. There are no present problems which would indicate any delay in achieving this goal.

Injector Development

Emittance damping studies were continued this quarter although the difficulties in making absolute emittance measurements still remain unresolved. With the present linac tune, the emittance measurements for the H^+ beam can be characterized by:

$$E_{out} = K + \alpha E_{in}$$

where

E_{out} = beam emittance at the exit of the 201-MHz linac,

E_{in} = beam emittance at the entrance of the 201-MHz linac,

α , K = constants independent of emittance.

For present linac tune, $K \sim 0.2$ cm-mr and $\alpha \sim 0.22$. For the beams now being run (1.7-mA-peak),

the contribution from the constant term predominates. For beams with design current (17-mA-peak), the damping term αE_{in} will dominate, and implies a normalized emittance growth of 2.6 in the linac. This growth is similar to that observed in other linacs.

Corresponding measurements have also been started for the H^- beams running with the same linac tune. The first results indicate that the emittance damping is essentially the same despite the fact that the H^- beam is a factor of 40 less bright than the H^+ beam. Work is continuing to establish this behavior. This conclusion would imply that an improvement in the brightness of the injector beams should result in a corresponding improvement in the brightness of the linac beams at these current levels.

Work continues on the development of a controller for the new arc-pulse modulator. The prototype controller now functions as expected except for a ringing transient on the turn-on of the modulator.

A used vacuum analyzer has been obtained and is now being set up in the vacuum laboratory to study vacuum contaminants in accelerating tubes and in proposed pumping systems. These tests are part of an evaluation program to obtain a better roughing system for the accelerating columns and to study the dependence of the column sparking on vacuum contaminants.

VI. ELECTRONIC INSTRUMENTATION AND COMPUTER SYSTEMS

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

Computer Control System

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

Control Computer

The new disk controller and one of the disk drives were delivered, installed, and put into operation with the PDP-11/34 that will control the new bulk storage system for the SEL-840 control computer. When the remaining two drives are delivered, the system will have a capacity of 40-million, 24-bit words. The file-handling software of DEC's RSX-11M operating system will be used to reduce the programming required for this upgrade of the disk system. The initial system generation for this software was successfully completed. The SEL-840 to PDP-11 hardware interface was designed, assembled, and partially checked. The chassis consists of a DR11B DMA interface, four quad-sized cards, and five CASH cards. Installation and checkout of this interface and integration with the computers are scheduled for next quarter.

The December/January shutdown offered an opportunity to correct a number of computer faults which have been aggravating operations from CCR. The pc cards in the mainframe and shared memory were reseated to eliminate suspected poor contacts. A failure in CAMAC crate No. 1 was traced to a poor termination and corrected. CAMAC crate No. 2 on the SEL-840 was repaired so the status display would work properly. The two magnetic tape

drives were given a complete electrical and mechanical alignment to correct tape-reading problems. The Extended Arithmetic Unit in the SEL-840 was repaired. An integrated circuit was replaced in the ROM of the IDS PDP-11/10. An intermittent problem in one of the CCI controllers was corrected.

A recurring problem with the block transfer channel (BTC) was studied. During periods of high I/O activity, the interrupt which signals the end of the transfer of a block of information is lost. Recovering from the lost interrupt creates further I/O activity that compounds the problem. Several modifications were made to the computer logic in an effort to correct the fault but, so far, none has been entirely satisfactory, and the investigation continues.

Control Consoles

The new hardcopy system was installed in one of the operator consoles in CCR. This system enables an operator to get a 22- by 28-cm black and white print of the information on the face of any of three Tektronix 611 storage scopes on the console simply by pressing a special button on that scope. Previously, copies were available from only one scope, which the operator had to select in advance. This development required numerous electronic and mechanical modifications to each scope and to the hardcopy unit. Work was started on the next set of three 611 scopes; these will be installed on console No. 2. Two new hardcopy units were ordered so that all consoles will have this capability.

The shell of the third operator's console was moved into place in CCR after all drilling and cutting on the console for the communications system was completed. The appropriate floor cutouts were made for cooling air and electrical cable access, and the ac power distribution system was installed. The console is now ready for the installation of various devices.

Work continued on the function button panel, mainly on the control software. The diagnostic program for the panel was completed, and all facets of the interface were tested. Since this diagnostic uses the same control structure and procedures as those in the operational software, the final checkout with the bus controller should progress rapidly.

Microprocessor Developments

The 8080 development machine which was built last quarter was checked out. As part of this effort, the development machine was interfaced to a TI Silent 700 Data Terminal which includes a magnetic-tape cassette system. This allows assembled programs to be output onto the tape cassettes from CCF over dial-up phone lines. The program on tape cassette can then be transferred from cassette into the RAM of the development machine for use in program development. This eliminates having to use the paper-tape system, which is cumbersome and slow. The development machine is being used to check out the hardware and software interface between the function button panel and the GPIB controller.

Several modifications were made to the hexadecimal debug and trace package (HDT). As soon as HDT was applied to interrupt-driven software, it became apparent that having the capability for a single breakpoint (trace) location was a serious limitation. Any unexpected interrupt would cause the loss of software control with no indication as to which interrupt had occurred, why, or what the software had done. This problem was overcome by giving HDT the capability of placing up to eight breakpoints in the program under test. One breakpoint can then be placed at the vector locations for each of the seven interrupt levels in the 8080. This feature proved to be extremely helpful in diagnosing both hardware and software problems during tests on the function button panel.

The new version of HDT was modified to run on the microprocessor development machine. Changes were made to accommodate the memory-mapped I/O for the serial output port and the change in format for the status register. Also, because of the faster clock, the software delay loop was changed.

A RAM test program was written for the new development machine. It includes zero-one tests, rotating pattern tests, and a unique address test for the block of RAM (user-specified) being tested. It provides a readout of all failing locations, the data it was trying to store, and the erroneous data read back. During the unique addressing test, it provides the address which was intended to be changed as well as any address that was changed.

Master Timer

The interfacing chassis for the new master timing unit was installed temporarily on-line to the SEL-840 and checked out. After reliable communications were established with the computer, the chassis was removed because all further testing can be done on the bench. The rack in which the unit is to reside was installed in CCR. The timing modules (23 each) were checked out along with their host crate.

A RAM test program was designed, written, and tested for the new Master Timer. The program includes zero-one tests, a rotating pattern test, and a unique addressing test for all addressable RAM locations. The programs to control the new Master Timer were written and assembled. Debugging of these programs is in progress.

Accelerator Interface System

During the checkout of the CAMAC Serial Link between the control computer and the Transition Region, a malfunction in the Jorway, Model 74, Type L-1 Serial Crate Controller was identified. If a demand message was generated immediately after a command message having extra space bytes, a longitudinal parity error would occur if the total number of space bytes generated was an even number. A collaboration with Jorway engineers, via phone, led to a solution of the problem, and the company issued a service bulletin to Model 74 users. Several additional modifications were made to the LAMPF Serial Driver to correct problems and to improve timing tolerances in the unit. The Serial CAMAC Link was down for about a week because of a power supply failure in the CAMAC crate. The software development for the serial system is continuing.

The prototype Microcontrolled Data Link was modified from downline loading of the satellite PDP-11s and returned to operation. Work continues on the two-wide pc version of the MCDL.

Additional binary command (on/off) channels were needed to control instrumentation in the 805-MHz portion of the accelerator. Wiring diagrams and instructions were formulated and sent, along with materials, for the fabrication of 36 J00-to-RICE I/O cables to expand the number of command channels.

Several manweeks of concentrated activity were spent in repairing data system equipment. The spare inventory of good replacement modules was near zero before the situation was rectified. An RG-108 cable to the module 53 RICE was shorted about 600 m from CCR. The short was located with a time-domain reflectometer. A malfunction in the RIU memory card for module 55 was diagnosed and corrected.

The responsibility for the repair of most of the NIM control modules will be shifted to another group. The new person in charge will be given all of the spare parts, cabinets, testers, etc., required to do this job. The people previously responsible for this work will now aid in the repair of most of the RICE, RICE I/O, and ADS pc cards. As part of this shift in responsibilities, a trailer is being outfitted to be an electronic lab. Lab benches, cabinets, shelves, etc., were obtained and are to be installed. This lab will become the center for data system maintenance activities.

Computer System Software

A modest effort was directed toward the maintenance and improvement of the SEL-840 system software. The following accomplishments are worthy of note. The system program which writes all other programs on the disk was modified to keep track of the time and date of the last initialization. In this way, a record is kept of those programs which get changed. Additional error checking was written into the Assembler. A dump option was added to the nonresident error handler. An indication of fast-protect errors was added to the timed analog data-take sequence. Corrections were made in the extrapolation procedure for the rapid data bank updater, in the time-to-run calculation and completion tests of the analog command subroutine, and in the Drop program to keep the correct status of dropped resident programs.

Six new general-purpose system subroutines were written. Two were for character manipulation, two provide FORTRAN interfaces to the system magnetic tape I/O handlers, one allows scrolling lines on the CCI scope, and the last provides a simplified interface to the system error-logging program.

An index was developed for the systems manual to make it easier to find documentation relating to a given problem area.

Accelerator Application Programs

The software support for accelerator operations was almost totally devoted to improving existing capabilities.

The magnet-setting program MAGSET was upgraded as an outgrowth of the several discussions with users. The display program was changed so that the number of magnets that can be plotted on the storage scope was increased from 9 to 16. A new cycle code was added so that magnets will either be cycled to zero or go directly to their setpoint, depending on where they were on their hysteresis curve. This will make it easier for the operator to set up magnets after they have already been cycled. Because many of the problems in setting magnets are a result of incorrect information in the Master Magnet Table, a new program was written to display the information for a specified magnet on the storage scope. This will help in diagnosing a large number of problems. A recurrent complaint that MAGSET was causing magnets to trip off was traced to a hardware malfunction.

A major change was made in the Beam Spill Monitor display program and its updater. A data file containing the operator designators of the channels used in the display was created. This file eliminated the complicated method of handling data and permits the acquisition of information directly from the channel tables, thereby keeping the data current.

Work was completed on a series of programs to automate the reporting of beam statistics at the end of each run cycle and at the end of each quarter. As confidence is gained in the information compiled by these programs, the workload on the operations staff will be reduced.

The beam current monitor program was modified to include a record of the times that: 1) the computer was running, 2) the A-5 target was in the beam, 3) the H⁺ injector was on and operating at 120 Hz, and 4) the H⁻ injector was on and running at 120 Hz.

A program was written to allow an operator to assign a knob to a stepping motor from the keyboard

by giving the LAMPF-standard operator designator rather than the channel address.

The LD₂ target program was improved by the creation of a data file containing the names of solid targets, thus making it easier to revise the display when the targets are changed.

Software for the low-momentum component detector was merged into the SY harp program. A typical display of this data is shown in Fig. VI-1.

A program was written to calculate changes in the currents of the TR magnets required to produce a given beam position and angle at a specified emittance station. The calculation is based on empirically-determined-steering partial derivatives. The scope of this program is expected to evolve to include more magnets and a wider variety of emittance stations as the process is better understood.

When a computerized procedure fails, there is often no indication of the mode of failure. It could be the program, data-acquisition system, or hardware being controlled. To identify or eliminate at least one source of the problem, the disk images of the computer programs for two of the major procedures (Δt and linac wire scanners) were written on magnetic tape, the tape being considered the master file. If either of these procedures fails, the first step

is to validate the programs on the disk by comparing them with the version on tape. A program was written to perform this comparison and detect any discrepancies.

Stripper programs were modified to allow positioning the stripper either with respect to a center-position indicator or a Run Permit-position indicator. This option, which will be checked during the next run cycle, should allow operation in cases where the center-position indicator malfunctions.

Software was provided in the Line B/C PDP-11/10 to allow readout of the toroidal current monitors for Lines B and C.

Numerous other programs received attention to correct minor errors or deficiencies. Among them were the programs for the linac wire scanners, the wire-scanner-emittance calculation, Δt , the rf turn-on, the RICE calibration test, the timed-analog data plotter, the chart recorder, the transmission monitor, and the SY wire scanners.

Experimental Area Controls and Instrumentation

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

Switchyard

A new fast-acting vacuum valve was installed in the extreme downstream end of the SY with appropriate cabling and sensors for the protection of the harps in Area A.

The controls required for operating two new actuators for the Halo Scraper (LAHL05) were installed.

A new water-cooled vacuum window (LAVW01) was installed in the Line A-Direct beam line.

Three new 50-A, 24-V dc power supplies were installed in the north set of racks in the SY to replace four 16-A power supplies which will be used elsewhere.

The fast wire-scanner system (FWSS) was modified by adding several 10-V power supplies.

Fig. VI-1.

Display of data from the new low-momentum component detector. This graph shows that a portion of the beam was lost from the acceleration process at an energy equivalent to module 22.

The wire scanners in Lines A, B, and X now have their own common power supply for the position-indicating voltage so that standard Type II motor drivers can be used. The spare test coax cable for all of the wire scanners (cable C) was terminated in a patch panel for easier access and testing. The collection field power supply was reinstalled in the SY.

The control panels required for the modification to the Run-Permit system were set up for another group to implement and install during the shutdown.

Cables were pulled for the future guard-ring device for Line A.

The Line C device LCSZ02 was redesignated as a new LX stripper, LXST06. The computer controls for this device were moved from CAMAC to RICE.

The shunt controls for LABM03 were added to the existing shunt control racks.

Area A

Several modifications and improvements to the controls and instrumentation in Area A were implemented during the shutdown. The complement of analog channels allowed in module 66 was doubled to 128. A thermocouple gauge was installed on the A-4 vacuum system to replace a device which gave unreliable readings. A power supply with a floating ground was used to remedy a problem in the thermal switch string of the target cell triplet. A design was completed for the leak detector circuit; the associated drawings for the readout controls and the wire schedule were prepared. Some electrical noise problems in the module 65 ADS were corrected with capacitors. The wiring and documentation were updated for the latest modification to 3ASV03 which is associated with the Alcatel turbopump. The system is ready for checkout when Line A is returned to vacuum. The wiring was completed to provide a computer reset capability for the ground fault detector chassis, which are being fabricated. A new chassis drawing showing this interact wiring was prepared.

Following the completion of Exp. 90, all of the control cabling associated with the alarm system was removed from P³ and rerouted to the LEP area for Exp. 50. The electronics for the tritium alarm panel were redesigned to provide the capability of

disarming individual alarm conditions on a selected basis. A single control restores all alarms to the armed condition. These modifications were installed and completely checked out.

The power supplies and blower modules for the CAMAC crates associated with the PDP-11/10 satellite computers were replaced with new units that are more reliable and simpler to maintain.

Work started on the controls for the new HAP unit. Circuitry on the HAP cart to control the hydraulic pumps, etc., is 50% complete. All of the control cables associated with *both* T.O.S. arms have been built. Cables required for in-plant checkout have been sent to T.O.S. along with the mating connectors and hardware.

EPICS

Several modifications and additions were made in the controls and instrumentation for the EPICS area. The scattering chamber control chassis were installed. Controls for the new beam plug were wired and documented. A sketch for the fuse and zener diode layout in 1PJB01 was prepared.

A remote shaft-encoder system was designed and installed. This work involved the fabrication of a power supply module, a remote readout for the counting house, and cables. Drawings and wire schedules were prepared to document the system.

Work began on the spectrometer frame controls. A rack was constructed and wired for 24-V dc control power. The coax cables between the patch panels and the frame were designed and ordered. The thermal switch wiring for all three quadrupole magnets on the frame was completed.

A recurring problem in the computer data-acquisition system was traced to an improperly wired LAM-grader plug for one of the CAMAC crate controllers.

LEP, SMC, P³, and Test Channel

A CAMAC Branch Highway cable was installed between the P³-East and P³-West counting houses and tested.

The remainder of the power supply controls for the SMC were moved to the new control racks. The checkout of the controls through the computer is

80% complete and will be finished when the electricians get the last power and reversing switches installed.

Considerable effort was expended to get the Yale trailer connected to SMC Cave B. The patch panel and coaxial cabling for data-acquisition signals were designed and sent out for fabrication. The package of timing signals was specified. A CAMAC Branch Highway was installed and tested.

Beam Stop Area

The optronic system was removed as a source for the stringer limit switches and replaced by a new system. Three stringers are now in reliable operation.

Part of the wiring was completed for the monitoring of temperatures in the collimator and window being installed at A-6. The remainder of the wiring will be installed when information needed to complete the wiring diagrams is supplied.

Lines B and EPB

A new sieve stripper was installed in Line B. This device is activated by an air cylinder similar to a TV phosphor or isolation valve.

The controls for the isolation valve of the turbopump in the Nuclear Chemistry cave were modified slightly.

The coax patch panels in Equipment Room B were greatly improved by the rearrangement and addition of the coax cables in one concentrated area.

Another 12 coax cables were added from Line B to the lower level of Equipment Room B for the chopper-amplifier experiment.

A 24-V, 125-A dc power supply was installed to operate the Line B wire scanners. This unit makes it possible for all six wire scanners to be operated simultaneously.

Line C and HRS

The December/January shutdown provided the opportunity to make a substantial number of modifications and additions to prepare the facility for the next run cycle.

The following changes were made in the vacuum system:

- A cryopump was added between LCBM04 and -05.
- Ion pump LCIP04 was replaced with a new turbopump.
- A 208-V outlet was installed near LCQM11 for a mechanical pump.
- The blower vacuum pump was moved from the third level to the ground-level scattering chamber.
- A new turbopump was installed on the third level.
- A small mechanical pump was added in the beam stop vacuum line to replace LCIP08 and -09.
- Two vacuum ion gauges were installed in CCH with a special 91-m cable to beam line.

The following coax cables were installed:

- Twenty-four RG-223 from CCH to Equipment Room B.
- Ten new low-noise RG-21-145, twenty-four red hv RG-58, and twenty-four RG-213 signal cables from CCH to scattering chamber.
- Twelve red RG-58 hv cables and twelve RG-213 signal cables from CCH to the third level of the HRS frame.
- Twelve remaining 256-ns delay lines in CCH.

The following work was performed on the HRS magnets:

- A control 24-V dc power supply was added in each of the two HRS bending magnet power supplies.
- Relays were installed in the HRS bending magnet power supplies for automatic operation of the magnet warning lights.
- A magnet warning light was added to HSBM02 on the third level.
- The quad magnet and the two bending magnets on the HRS frame were interlocked to the cooling-water pump "on" relay contacts.

Some of the diagnostic instrumentation was rearranged for more convenient operation.

- The operation of the NMR mux located on the second level of the HRS frame was remoted to CCH. A special interface was designed and built to facilitate local operation.
- Similarly, the operation of the ISIC multiplexer located in CR control rack R01 was remoted to CCH.

- Position readouts for four Line C ISICS, six HRS NMR probes, and two HRS SZ scanners were added in CCH.
- New controls were provided for phosphors LCTV02 and -09.
- The 24-V dc control voltage power supply for the Line C scanner system was replaced with a 350-A power supply.

Several miscellaneous tasks were completed.

- A 440-V outlet was installed for the scattering-chamber vacuum-blower package.
- Several 110-V outlets were added on first and third levels of the HRS frame and along Line C.
- Control circuits for the turbopumps were merged with vacuum "OK" interlocks.
- The 24-V dc control power supply in CCH was changed to two 50-A power supplies.
- A 24-V dc power supply was installed in the CR for the HRS water-pump system.
- The control racks for HRS bending magnets, H_t windings, and multipole magnet were moved from Equipment Room B to the second level of the HRS frame.
- The controls of the steering magnet regulators in Line C were repaired.

In an effort to standardize the DVM systems in Area C, the CCH HP-3490A DVM was retrofitted with the remote-control option. A third HP-3490A DVM was ordered to be used as a spare for the DVMs at Line C and CCH. In the near future, the signals in the Line B (RICE-controlled) DVM system will be incorporated into the Line C (CAMAC-controlled) DVM system, and the Line B DVM system will be removed, thus obviating the support of a one-of-a-kind DVM system.

Communications

The LAMPF communications system continued to grow and evolve. In response to requests, the following installations were completed: four new permanent intercom stations, one temporary station and one speaker for Exp. 50, a new station in the LEP area, a temporary station and speaker in the new Terminal building, four new speakers in Area C to solve a reverberation problem, a new station in the SY, and another in Sector B.

The maintenance of the system involves a wide range of tasks. When static was reported on the CCR line, it took five days to trace the problem to a defective intercom station in the ISORAD area. Four days were required to troubleshoot a problem on the ICR line caused by a power outage which burned out two amplifiers and one speaker. Defective equipment was replaced in the SY, Areas B and C, CCR, the TR beam tunnel, and the Injector area. In addition to responding daily to failure reports, all areas are swept once a month to search for broken equipment or degradations in performance.

The task of documenting the wiring for the communications system in the experimental area is almost at a standstill because the wire-run specialist from ENG-4 was withdrawn.

New headsets for use in areas of high noise were investigated. At least one promising commercial product was located.

Experimental Data-Acquisition System

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

Experimental Area Computers

The initiation and monitoring of procurement actions for computer equipment for data acquisition and analysis was a major activity this quarter. Approvals were received and orders were placed for a LAMPF-standard PDP-11/34 data-acquisition computer for the test channel and for a number of system enhancements for the new PDP-11/34 in P³-East. Bids were received for a PDP-11/70 to be used to analyze data. A final configuration was selected for this system and the order placed. Software packages for all three of the above systems were ordered. A large disk system for the Terminal computer is scheduled for delivery next quarter.

One of the advantages of standardizing on a single line of computers is that systems can be reconfigured to meet new requirements. The task of seeing that different experiments get the computer

equipment they need when they need it was an important activity this quarter.

MP Division is cooperating with the LASL minicomputer systems group in writing specifications for a standard RK05 equivalent disk system for general use at LASL. This effort to standardize will lead to lower initial costs and reduced maintenance costs.

Data-Acquisition Software

The development work continued on the general data-acquisition package Q which runs on the PDP-11s under the RSX-11D operating system. Most of the work this quarter was in the character of consolidating past gains and very little new code was produced. Eleven problems were reported by Q users, most being in the nature of suggestions and requests for more capabilities. In the course of identifying and correcting one disabling bug, a weakness was discovered in the technique of distributing new program modules which contain error corrections. The technique was revised to avoid the problem in the future.

A software design study session was held in Santa Fe to plan the next level of enhancements for program Q. A total of ten programmers participated — two from LBL, four LAMPF users, and four from Group MP-1. The focus of the design effort was on new histogramming and display software. Work on the design documents is still in progress. They will be ready for review early next quarter.

In preparation for the study session, work was completed in the "standards and conventions" document for Q programmers. Since it is hoped that users will contribute software to the Q program, this document will guide users to produce code that fits in with the structure and philosophy of the whole system.

During January, new Q systems were generated in rapid succession for EPICS, Exp. 50, and Exp. 266. While the production of these Sysgens has become considerably more automated, the fact remains that each must be considered as an individual case, i.e., configuration, other uses of the system, and machine scheduling all affect the operation. In the process of generating these systems, a set of system notes and supporting disk packs are produced for each system. With these tools, any of the Q

programmers can restore or work knowledgeably with these systems.

The collaboration with LBL continued toward the goal of making Q available under RSX-11M as well as under the current RSX-11D systems at LAMPF. During the course of three trips to LBL during November, the 11M and 11D Q-disks were merged and their production fully automated. A number of new compatibility problems were uncovered during this process. A report documenting these incompatibilities is in preparation.

The new histogramming package was completed except for the split-screen and dynamic-scatter plot options. It is scheduled for use by several experiments that start on the next beam cycle. Figure VI-2 shows a sample plot consisting of a simulated spectrum overlaid on a simulated background. Work continues on the two special plotting options. This software runs under RSX-11D as well as RSX-11M. A document describing the present histogram system was prepared and distributed to a number of Q users.

Several improvements were made in the option to replay data-acquisition tasks under Q. A message is now output at the end of a run which indicates the number of tape records containing parity errors and the number of events of each type which were distributed to the user during that run.

Fig. VI-2.

A sample display from the new histogram software showing a simulated spectrum overlaying a simulated background.

The magnet control software for the SMC was converted from DOS to RSX-11D. Because the power supplies have been changed, current controls must be measured and supplied to the system. This work will be completed as the magnets are brought on-line.

Some work went into improving and implementing a CAMAC test language system which runs interactively under RSX-11D. This project is still in the design stage.

The task of providing software support to users on a 24-h basis continued this quarter. Generating RSX-11D systems, consulting on the Q program, helping to find hardware and software faults, and advising experimenters on the use of the software system required the equivalent of three full-time programmers. Although this activity leaves little in the way of resources for new programs, the interaction with users is beneficial in developing a better understanding of the users' problems and the software capabilities required for the future.

Computer Maintenance

During the quarter, there were about 360 service calls for computer maintenance, a 30% increase over previous quarters. This increase resulted from moving computer systems to new sites to match the computer configurations to the complexity of upcoming experiments. The Terminal computer was moved from CCR to the Terminal building. The LBL computer was moved from P³-East to a trailer for Exp. 50. The P³-East computer was moved to the SMC. A new PDP-11/34 was set up in P³-East along with the Oregon State Univ. PDP-11/10, which was moved from a trailer. This relocating of computers will not be a common practice, and the number of service calls should drop accordingly as the systems stabilize in their new environments.

Considerable effort went into the data base, COMAINT, associated with the computer maintenance operation. Some of the computer configurations were altered as part of the moving, and this information had to be put into the data base.

In an effort to improve the technical capabilities of the maintenance personnel, a seminar on DEC's RSX-11D operating system was presented. The knowledge gained from this training will make the

field engineers more effective in diagnosing system problems.

LAMPF Electronics Equipment Pool

The LEEP is becoming an effective stocking point for user supplies. The inventory presently includes disk cartridges, front and top loaders, magnetic tape, DECwriter paper, and Versatec paper. Recently, RSX-11 and FORTRAN manuals were added. The next items will be toner for the Versatec plotter and polaroid film.

LEEP personnel took the initiative recently to establish a comprehensive disk cartridge renovation program. A new disk cartridge sells for \$70. The cost of a replacement platter is \$25. With the necessary equipment, it is possible to recondition a disk cartridge for about \$35. This represents a 50% saving compared to the cost of a new cartridge. The equipment needed is a cleaner, which is on hand, an alignment jig, which is being fabricated, and an optical inspection device which the computer maintenance group is buying. The final step in the renovation will be to reformat the cartridge and check it for proper operation. Personnel are available for this process. Hopefully, this project will be operational by next quarter.

In the near future, a total of 10 Diva disk drives will be installed at LAMPF. An order was placed with Randomex for their automatic disk pack cleaner which will accommodate the packs used on the Diva system. This cleaner will supplement the present cleaners and will provide total cleaning capability for all cartridges and packs used at LAMPF.

During this quarter, an automatic cable tester was delivered. In a few milliseconds, this instrument will check 100 conductors for short circuits or open connections between the two ends. Its primary use will be to test CAMAC branch highway cables, but it can be used for any multiconductor cable such as PDP-11 Unibus. To put the instrument in use, an adapter box containing the appropriate connectors must be fabricated and wired. This work will be completed early next quarter.

The connectors for the digital panel printers arrived. The cables were fabricated to give a hardcopy capability for all the multichannel analyzers on site.

As reported last quarter, pulse delay cables packaged in a compact box have proved to be a very popular item. The LEEP inventory presently contains 38 such boxes providing 6 cables each with 64-ns delay. These boxes were assembled by LEEP personnel. LEMO, USA, has shown an interest in supplying a similar style box. Negotiations are in progress for a product built to LAMPF specifications.

In response to an inquiry about NIM prescalers, one manufacturer indicated that his company could supply a dual-channel unit for \$850 or a single-channel unit for \$450. Both would be packaged in a one-wide NIM module. A minimum input frequency of 100 MHz was guaranteed, but the vendor was reasonably confident that the product would operate in excess of 200 MHz. As proposed, the modules would have one input and seven synchronous outputs. The outputs would include one equal to the input frequency and six more divided down in decode steps. This proposal will be reviewed at the next LEEP committee meeting.

A new instrument was introduced recently by LeCroy Research Systems which may be of interest to many users. Called a meantimer, the device attempts to solve a timing problem in experiments where scattering angles are large. On these occasions, large scintillators are required and the phototube output pulse may vary by several nanoseconds, depending on where the particle struck the detector. This instrument accepts two pulses from phototubes attached to both ends of the scintillator, equalizes the transit time, and provides an output pulse at a fixed time independent of where the impact occurred. The need for this device will be considered at the next LEEP meeting.

Special Instrumentation

Beam Current Monitors

The beam current monitors (BCM) in the experimental areas are crucial to present and future plans for beam line protection. The present model is adequate for accelerator operation at 100 μ A but will have to be upgraded to support operation at 1000 μ A.

A series of meetings was held to identify the deficiencies of the present BCM. It suffers from: 1) noise spikes from power supply SCRs, 2) long-term toroid inductance changes, 3) amplitude errors from a variety of sources, and 4) excessive toroid lead resistance due to the required length of cable run through the shielding from toroid to pre-amp. Moreover, the four gain ranges do not track nor are they acceptably linear. Noise and signal measurements showed that the series calibrate loop which runs through all the BCMs introduced excessive noise.

The result of the discussions and measurements was a plan for developing a new BCM. The salient points of the plan are as follow:

- 1) New electronics will be designed and a prototype model built for test and evaluation.
- 2) The new electronics will include an input resistance cancelling circuit in the pre-amp; a V/F converter; one digital output, optically isolated and with 0.1% accuracy; and one analog output, also optically isolated and with 1% accuracy.
- 3) The new electronics will be tested in a representative environment in Area A.
- 4) The V/F converter in the new electronics will be biased in such a way as to provide a pulsed digital output from the V/F converter with zero signal input. This will move the normal operating point away from the non-linear zero voltage point on the transfer function curve.
- 5) If the implementation of the electronics described above is successful, all software handling the BCM outputs must take the offset described in 4) above into consideration so that it is not apparent to the user.
- 6) An attempt will be made to do away with the series calibrate loop if it can be established that the electronics are reliable and consistently accurate.

Work on the electronics has progressed rapidly. Several potentially useful circuit concepts were analyzed by mathematics, computer synthesis, and breadboarding. A prototype of the BCM front-end electronics is under construction and will be available soon for testing on-line.

Fast Wire-Scanner Amplifier

At the request of a beam line physicist, an analysis was made of a multipulse integration mode for the fast wire-scanner amplifier (FWSA). Both the analysis and subsequent field tests indicated that the signal-to-noise ratio improved at the expense of time. A simple modification to the FWSA can provide this capability, if desired.

A second modification was developed to provide a gain-range latchback feature to the computer from the FWSA.

Certain stability problems with the FWSA amplifier were investigated in collaboration with other groups. This investigation resulted from efforts to use the high-gain capability of the FWSA at locations along the accelerator where the wiring had been changed to minimize noise pickup. The new wiring introduced capacitances that led to an overall positive feedback in the FWSA. The problem can apparently be corrected by proper grounding techniques.

Cryogenic Pressure Servo

Although the Cryogenic Pressure Servo chassis has not been field-tested yet, work began on a series of modifications designed to make it function under a new set of system parameters. After these modifications were completed, tests showed that the automatic trip-point circuit interacted with the closed-loop control. This fault was corrected, and work began on the preliminary documentation, after which the unit will be relinquished for field tests.

Vacuum Loss Detector

In a continuing effort to support the Vacuum Task Force, version two of the vacuum loss detector was modified by the addition of a "100-V present" relay interlock circuit. The unit suffered one failure during tests — an apparently random failure of an input stage. The unit was submitted to drafting for schematic documentation.

Portal Monitor

A radiation detector system is being developed to monitor the exit gate at LAMPF for any radioactive materials leaving the site in vehicles. The modifications to the guard station and the evacuation of the roadway were completed, and the cable was pulled in mid-January. The detector and electronics will be installed and checked out the first week in February. A phone line is available to carry the alarm to CCR. The alarm panels are under construction and will be installed the first week in February in the Health Physics office and in the CCR.

Experimental Area Evacuation Alarm

The Experimental Area Safety Committee requested an addition to the existing evacuation alarm system so that all inhabited buildings in the experimental area would have alarms. Several alternatives were considered, both to meet the immediate requirements placed upon the system by the tritium experiment (Exp. 50) and for long-term usage. The short-term solution is as follows:

- 1) Replace the existing PA system amplifiers in Area A with more reliable units that also have battery backup and alarm oscillators.
- 2) The oscillators will be triggered by the evacuation alarm system, and the noise will go out over the existing PA speakers.
- 3) The operation of the PA system will be unchanged.
- 4) A daily operational check will be required.

The new equipment was ordered and should be available for installation by mid-February. If a permanent evacuation alarm system is required for Areas A, B, and C, then a stand-alone system that is not part of the PA system should be considered. This redundancy would be attractive since both systems could act as a PA system.

Auditorium Equipment

The heavy use of the MP-Division auditorium puts a big load on the electronic equipment. After

five years of operation, the original microphone equipment became erratic and was replaced by two new systems which, thus far, have been trouble-free. The old systems were left in place and can function as backups as soon as the manufacturer reconditions the microphones.

The transparency projectors were replaced with units in which the light passes up through the master rather than being reflected. The new ones give a sharper, less distorted projection.

VII. ACCELERATOR OPERATIONS

General

The accelerator was in continuous operation during the quarter with the exception of an 18-day shutdown in December and January. Operating time was divided equally between research and facility development.

The machine continued to run routinely with 100 μA of H^+ delivered to Area A and as much as 6 μA to Area B. Machine availability during research shifts averaged 81% for the H^+ beam and 76% for the H^- beam.

Experimental Program

Research-quality proton beams to Area A totalled 65 000 $\mu\text{A}\cdot\text{h}$ during the quarter, as measured at the A-1 target station. An additional 338 $\mu\text{A}\cdot\text{h}$ went to Area B. Thirty-five experiments received beam, as shown in Table VII-I. This tabulation does not in-

clude the beam used for facility development or tuneup activities.

Facility Development

Machine time allotted for facility development continued to stress the improvement of standardized beam-tuning procedures. Systematic searches were made to determine optimum beam positions and angles at the entrance to the drift-tube linac. Beam-oscillation amplitudes arising from physical and magnetic misalignments in the 201-MHz tanks were determined. The alignment of the straight portion of the transition region was measured with respect to that of the 805-MHz accelerator, using the beam and installed diagnostic gear. Beam trajectories were used to measure and correct wire-scanner alignment errors. Steering partials were determined for appropriate steering elements to permit rapid adjustment of beam position and angle at all of the emittance stations. The procedure for determining phase and amplitude setpoints for the 201-MHz

TABLE VII-I

QUARTERLY REPORT OF BEAM PROVIDED FOR EXPERIMENTS

Experiment No.	Channel	Shifts (8 h)	$\mu\text{A}\cdot\text{h}$	Experiment No.	Channel	Shifts (8 h)	$\mu\text{A}\cdot\text{h}$
7	SMC	10.5	6 400	222	P ³	6.0	3 690
37	SMC	42.5	27 500	234	LEP	61.0	43 900
60	SMC	11.0	7 500	236	Biomed	6.5	3 370
67	LEP	4.0	2 730	243	AB-Nucchem	2.5	48
86	TTA	91.0	65 000	245	EPICS	47.0	33 700
90	P ³	49.5	31 800	247	LEP	5.0	3 450
105	AB-Nucchem	2.0	43	256	HRS	16.0	3
111	BSA-RAD	0.5	165	262	AB-Neutron	58.0	180
133	EPICS	28.5	20 300	263	AB-Neutron	1.0	4
139	HRS	44.0	5	264	AB-Neutron	56.0	174
142	SMC	6.0	4 090	267	ISORAD	68.5	30 400
161	BSA-RAD	0.5	243	270	Biomed	2.0	1 160
173	SMC	21.0	13 100	271	Biomed	13.0	6 400
191	LEP	23.5	16 600	272	Biomed	8.0	4 270
197	EPB	59.0	3	273	Biomed	4.5	2 340
200	EPB	17.5	2	274	Biomed	23.0	11 800
215	Biomed	8.5	3 690	275	Biomed	23.0	11 000
221	P ³	37.0	23 100				

tanks and bunchers was rechecked and new criteria were determined.

Operating Experience and Downtime Accounting

Machine operation continued to be reliable and moderately stable. However, problems encountered with the Δt hardware and software, used for determining amplitude and phase setpoints in the 805-MHz linac, made the tuneup process for operating Cycle 11 extremely difficult and the task of maintaining beam quality through that cycle especially trying. A frequently recurring, but highly elusive, malfunction of the control computer slowed progress during machine development experiments. Continuing difficulties in attempting to satisfy various users with the properties of chopped H⁻ beams pointed up the need for an independent capability to measure those properties.

A summary of accelerator downtime during the 106 research shifts is given in Table VII-II.

Accelerator Support Activities

Operating personnel, released from their normal duties during the 2½-week shutdown of the machine, were, as usual, highly productive in support activities. The switchyard run-permissive interlock system was completely rebuilt. The CCTV distribution system was overhauled: all cable runs are now 75- Ω with the exception of those between Area C and counting house C, and all cable runs are now buffered via distribution amplifiers. All activation-protection (AP) power supplies were modified for more precise voltage measurement. The power supplies and station unit bins for doubling the AP systems throughout the machine were built and installed, and cabling was installed and terminated to improve wire-scanner signal-to-noise ratios. Cables were procured and installed to provide for 10 additional binary command and data channels in each of 44 RICEs in order to accommodate the remote gain-changing capability requested for the new wire-scanner amplifiers. The computer-controlled beam current monitor calibration system was

TABLE VII-II
QUARTERLY SUMMARY OF MACHINE DOWNTIME

Category	Downtime (h)	Percent of Total
201-MHz amplifiers and transmission lines	19	10
805-MHz amplifier systems	39	20
Vacuum	24	13
Magnets and magnet power supplies	16	8
Interlocks	15	8
Injectors	9	5
Water	3	2
Computer control and data acquisition	15	8
Reference source	3	1
Beam stops, plugs, targets, strippers, scrapers	5	3
Beam diagnostics	2	1
Timing distribution systems	--	--
Miscellaneous (utilities, etc.)	39	21
TOTAL	189	

extended to include all current monitors on Lines B and C. Steering magnet wiring was changed throughout the 805-MHz linac to provide horizontal and vertical steering capability in all modules. Water-leak detectors were installed in the transition region. Water-cooling passages in the post couplers on all 201-MHz tanks were backflushed. Interlock

circuits for all 805-MHz linac tank and magnet water pumps were changed to include contacts from the pump power contactors. Six recently installed 805-MHz phase-shifter packages were calibrated. Terminal strips for all run-permissive interlock systems were checked for unauthorized jumpers.

VIII. EXPERIMENTAL AREAS

Facility Operations

Planning and preliminary design work are proceeding for the shelter and crane structure for Area A-East serving target stations A-5 and A-6. Design criteria have been completed and are in final review. Advertisements have gone out requesting architect-engineer proposals. A 30-ton bridge crane has been obtained as excess property from Fermilab. A request for proposals to recondition and install this crane is now being prepared.

Preliminary studies have been made and cost estimates developed for a proposal to locate an isotope separator facility on Beam Line B between Experimental Area B and the Line B beam stop.

The proton irradiation port (PIP) has been installed, utilizing the fast-rabbit penetration just ahead of the A-1 target in Beam Line A. Design of the sample insertion and removal mechanism is completed and fabrication is in progress.

The experimental area operations trailer complex is nearing completion. Major work left to do includes the installation of communication and instrumentation cables to connect this facility to the operating systems, and completion of the status information racks in the Area Manager's office.

A steel structure with canvas sides was built over the Line A beam stop area (A-6) to provide protection from winter weather. The protective roof from Target Station A-5 was used to form a temporary shelter over A-6. This shelter is large enough to house the remote maintenance equipment and allow access of a mobile crane. At the end of the shutdown, the roof will be replaced on top of A-5, while the side frames of the structure will be left in place until the proposed Area A-East facility is built.

Final design work is in progress to convert the crafts building located just south of Area A to an experimental support facility. One-third of this metal building was modified as a target laboratory some time ago. The balance of the building, an area 12 m by 12 m, will become a cryogenic laboratory and a nonradioactive assembly shop to support secondary lines and experimental systems.

Shielding

The major shielding effort during the report period was related to the scheduled December-January shutdown.

A new hydraulic pump package and additional hose systems have been purchased and assembled. We now have sufficient equipment for two complete moving systems.

Shielding on the north face of the A-1 shield at EPICS was removed for access to the outside of the A-1 target mechanism and to the fast-rabbit tube. Steel shielding and the tube plugs were extensively modified to accommodate the proton irradiation work. A steel plug, fabricated in two sections, was completed and installed outside the A-1 target mechanism. This plug, ~1-m thick and 2-m square, will reduce the radiation leaks along the target mechanism shield.

A new shield plug between the shield doors at the top of the A-5 target station has been fabricated. This plug can be stacked around the target mechanism vertical penetration and will provide an added 1 m of iron and 0.6 m of concrete above the target area.

The special shielding blocks ordered for the deck covering at ISORAD were delivered and installed. This provides an additional 0.5-m-thick concrete cover over the existing steel shielding at the stringer housing and transfer vault of the ISORAD facility.

About 32 tons of excess lead ballast was obtained from the U.S. Navy. This scrap lead was shipped directly to a commercial lead company where it was cleaned and formed into standard lead bricks. This provided us with a supply of good lead bricks at considerable saving.

Extensive radiation surveys have been carried out in Area A in search of radiation leaks during beam-on times. A few leaks were found and are being corrected. In addition, two personnel-exclusion gates have been installed.

Cooling-Water Systems

As of January 31, 1977, the water specific resistivity of the five radioactive water systems was as follows:

Water System	MΩ-cm
X02	~ 9.0
X03	~10.5
X04-6	~13.6
X05	~ 0.9
X07-8	~14.0

Several system changes and additions were started during the major shutdown which was scheduled during this quarter.

The Rover cooling system, which is used to cool the auxiliary magnets in Area A, was moved from its location in Area A to the A-4 stubout. This will reduce the floor vibrations in the SMC cave in preparation for crystal spectrometer experiments. The move will also provide room for future expansion of the stopped muon experimental caves.

The pump motors for systems X02 and X03 were replaced and sent out for overhaul.

All Area A flow switches were cleaned.

Small leaks were repaired in the A-1 and A-2 target cells. The A-1 leak was located on an insulator fitting on EPICS bending magnet BM01. The A-2 leak was on a fitting upstream of the clamp on collimator CL02. Remote-handling methods were used to effect this repair because of high residual activation levels.

In addition to these maintenance items, the design was started for a system to dispose of tritium-contaminated water by evaporative dispersal to the existing radioactive exhaust stack. This system will allow the continual disposal of contaminated water to prevent unmanageable buildups of tritium in the cooling-water systems.

The design for the spare pump heat exchanger was completed and a bid package was prepared in anticipation of a fabrication contract for this system.

Radioactive Air Exhaust System

An additional duct was added to the fume hood in the Area A machine shop to allow this hood to be operated independently from the radioactive exhaust system during routine soldering and welding operations. It is still available for contaminated welding and soldering as well.

Preliminary design has begun on a means of sealing the gaps in the Area A shielding in an effort to

reduce or eliminate the background of radioactive air emanating from the target cells. This air, while not a safety hazard, has caused high background rates in detectors during 100-μA run cycles.

Installation of a permanent copper air-sampling manifold has begun. This system will allow the Health Physics Group to continuously sample airborne radiation in Area A.

Main Beam Lines and Target Cells; Remote Handling

New design work has been a major effort during this quarter. Among the design items are the following:

- **A-2 Target Wheel.** A new, solid-graphite target wheel was designed and manufactured at LASL (see Fig. VIII-1).

Fig. VIII-1.
Solid graphite A-2 target wheel.

- **A-6 Collimator/Window.** A new water-cooled window and collimator were designed and fabricated at LASL (see Fig. VIII-2).
- **A-2 Collimator.** Detail drawings have been released to the LASL Shops for fabrication; the expected completion date is March 15, 1977.
- **Double Wrenches.** Seven new double wrenches have been designed for remote assembly/disassembly of vacuum flanges. Detail drawings have been released to the LASL Shops for fabrication.
- **A-5 Target Mechanism.** A new target mechanism is being designed by L. Wilkerson, Group WX-4.
- **Line C Beam Plugs.** Two new switchyard beam plugs have been designed.
- **A-2 Spin Drive.** Preliminary design of a new chain drive concept has been completed. Component testing is under way.
- **Television Mounting Mechanisms.** Designs of six major pieces of equipment have been released for fabrication. Finished components will be installed on Monitor.

Fig. VIII-2.
A-6 water-cooled vacuum window.

- **Hydraulic Test Fixture.** Design drawings for a special hydraulic test fixture for servoarm development are completed. Parts are being fabricated in the LASL Shops.
- **TeleOperator Systems, Inc. (TOS) Manipulator Arms.** Design drawings for the vertical-adjustment assembly are complete.

A number of repairs were made to main beam-line components and target cells during the shutdown that started in mid-December. The following major maintenance items were performed:

- The graphite target at A-5 was replaced with a similar target which was reworked to prevent cracking caused by thermal expansion.
- New steel shielding was fabricated and installed at A-6 to facilitate remote rigging operations.
- The A-6 beam stop was moved eastward to allow isotope production up to Stringer 6.

Remote operations at the main beam stop, where levels approaching 1000 R/h were encountered, were a major activity during the shutdown. The Monitor I system (Fig. VIII-3) was set up in a temporary enclosure which was constructed over the beam stop. Below is a summary of the activities that were performed by remote control:

1. **Shielding.** Lower-level steel shielding was rigged for removal and reinstallation with Monitor I, i.e., installation and removal of eyebolts and slings were done remotely. Lifting was accomplished with a motor crane.
2. **Cooling-Water Connections.** Six cooling-water connections (Swagelok fittings) were removed and reinstalled with Monitor I. Also, some of the manifold threads were restored remotely by chasing with a specially made die.
3. **Measurements.** Many measurements were performed remotely to determine clearances for new components.
4. **Rabbit Tube Modifications.** Complex modifications were made to a rabbit tube clamp to provide clearance for the new water-cooled window. Typical Monitor I operations involved three-dimensional measurements and accurately controlled saw cuts, using a modified portable bandsaw.
5. **Harp Replacement.** Harp 6A-HP-01 was removed and replaced. No vacuum leaks or other difficulties were encountered.

*Fig. VIII-3.
Monitor I remote-handling system.*

6. **Window Replacement.** The air-cooled window was removed and the new water-cooled window was installed. Considerable modifications of interfering components were necessary.

Engineering and conceptual design in support of the target development and remote-handling programs are important continuing activities. Some of the current engineering efforts are as follows:

- **Special Tooling.** A general evaluation of special tooling and handling equipment for Area A remote operations is being performed by R. L. Tanner, Consulting Engineer. To date, this study indicates that about 25 additional special tools of varying complexities will be required.
- **A-2 Spin Drive Mechanism.** A full-size model of the new chain-drive design has been operating at ambient temperature and pressure for ~500 h. A scale model has been operating in vacuum at 540°C for ~2000 h.
- **Monitor.** Conceptual designs for updating Monitor I and implementing Monitor II have

been completed. This effort also includes the layout of the remote-handling master station and a preliminary study of the control system to be installed between master and work stations.

- **A-6 Water-Cooled Window.** Heating, temperature distribution, and stress calculations were performed to optimize the new design for high beam current. The completed window was helium leak- and pressure-tested before installation. Deflection measurements were also made at various locations for comparison with calculated values. A design report has been written.
- **A-5 Target Analysis.** Temperature and thermal-expansion analyses of the present target were made to determine the cause of a cracking problem in the ATJ graphite. A report covering this activity has been issued.
- **A-2 Target Wheel.** Temperature distribution and thermal stress calculations were made as a basis for the new target wheel design. The new wheel was operated for 48 h at ambient

temperature and atmospheric pressure before installation. A design report has been issued.

•**Future A-5 Target.** Preliminary heating calculations for a new water-cooled A-5 target are being performed by G. E. Cort, WX-4.

•**Hydraulic Servoarm Development.** The pressure control servovalves arrived during this report period and the construction of the single degree-of-freedom force-reflective model is complete. Work is now progressing on the control system electronics.

Several new items of remote-handling equipment are being acquired. The most important of these is the two-arm force-reflecting servomanipulator system that is being manufactured for LAMPF by TOS. It is estimated that the first arm will be completed by March 15, 1977. The second arm will be finished about six weeks later.

A purchase order has been initiated for the procurement of a trailer in which to house the remote-handling master station.

A small television camera (~4.4-cm-diam by 40-cm-long) has been purchased for special remote-handling and inspection operations.

Secondary Beam Lines

During this quarter, work continued to improve and update the secondary beam lines. During the time in which usable beam was targeted in Area A, beam-line components caused channel downtimes of <1% in SMC and <0.5% each in P³ and LEP.

Hardware for computer control of P³, LEP, and SMC has been received, and the software package is being prepared.

A new vacuum valve for SMC has been installed and checked out. Bending magnet BM03 has been removed from the beam line in preparation for beam studies at the start of the next run cycle. Carpet installation in the SMC Counting House is completed. Modification of the dual-Acme magnet power supplies is completed. All SMC supplies now have LAMPF-standard regulators. Engineering and floor support have been given to Exps. 7, 173, 206, 240, 266, 288, and 292 in the SMC caves.

A new current bypass shunt for LEP BM04 has been installed and checked out. Extensive engineering and floor support have been given to Exps. 29/54, 180/191/140, and 50 in LEP.

A movable jaw assembly in P³ became inoperable during Cycle 11. It has been removed, and repairs will be made soon. A vacuum leak in the P³-East beam plug has been repaired.

In the Line B tunnel, a new beam box has been installed to contain a sieve stripper for fine control of the EPB beam intensity, and its controls have been readied. Vacuum repairs have been made to an EPB beam plug, and an ion pump was replaced. The vacuum system in the EPB cave has been reworked since Exp. 197 was removed. A new ion chamber has been built and installed. The setup of a shielded counter telescope in the Line B tunnel for the monitoring of H⁻ chopper contamination has been completed. It will be tested during the next run cycle.

Cryogenics Support

The use of tritium for two experiments in Area A was a major concern of the Cryogenic Section during this quarter. Experiment 90, after considerable effort devoted to target fabrication, was run successfully with tritium and was dismantled without incident. Experiment 50 will use tritium during the next quarter. The cryogenics hardware is essentially completed. New target flasks have been fabricated and installed on the target apparatus. The gas-handling system has been refurbished and checked. New operating procedures have been written and operators have been trained.

A liquid neon target has been requested for Exp. 50. Several parts will be furnished by LBL and the remainder will be supplied by LAMPF. The target assembly is completed, as is the installation of associated system components. Only final testing of the system remains.

A liquid hydrogen target system for Exp. 222 was installed and operated in P³-West. Preliminary data dictated changes in the vacuum chamber, which have been accomplished. The system is again ready for operation.

The target flask for Exp. 201 has been tested and a small leak has been repaired. The vacuum chamber, supplied by the Univ. of Virginia, has been repaired and tested. An 80 K heat shield system is being built. A stand for the system is in design.

For Exp. 27/194, a stand that will allow quick insertion of a cryogenic and a solid target into the EPB beam is being built.

A target flask with very thin, flat walls, capable of being aligned to 0.02° rotation, has been designed for Exp. 96.

Two new target flasks for Exp. 262 have been built and tested; a leaking flask has been replaced.

Plumbing improvements on the pump carts for the standard 10-W refrigerator systems have been designed and are being performed. Two leaking compressors have been repaired. A pumping station for target-flask testing is on order. Plans for construction of a cryogenics laboratory are under way.

Polarized Proton Target Development

A nuclear magnetic resonance (NMR) detection system will be used to measure and monitor the target polarization. A design, essentially the same as the one that was used on the P-Division polarized target, has been chosen. Fabrication and testing of

the tuner and detector circuits are completed. Orders have been placed for most of the remaining components of the system (rf amplifiers, power divider, etc.). The existing rf signal generator is inadequate and will be replaced.

We are undertaking negotiations with CEN-Saclay to obtain a 25-kG superconducting magnet and polarized proton target cryostat.¹ A request for quotation has been sent to the French government for this system. Designs for the ^3He gas-handling system, ^3He pumping system, and microwave system are in progress.

REFERENCES

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IX. BEAM LINE DEVELOPMENT

H⁺ Beam Development

Line A Tunes

Procedures for tuning Line A were documented and supplied to MP-2 Operations for tuning of the Cycle 11 100- μ A production beam. Necessary modifications and training will continue into the next quarter.

The effort to achieve a tune of A-5 to A-6 transport that would make the A-6 spot size essentially independent of the A-5 target position was transferred from calculational models to experimental measurements on the proton beam.

Beam Studies and Measurements

Halo Measurements. More halo data using the halo plates (HL) and wire scanners (WS) were taken and all previously taken data were reduced. At times we find the WS and HL data track closely over 10^3 dynamic range; at other times we find large departures. Interest is now on understanding this response and, if possible, equalizing the instruments. Tests are planned to observe effects of wire bias and clearing fields. Use of the halo plates will also be improved by the addition of loss monitors mounted directly by the HL beam box.

Figure IX-1 shows data from a particular run plotted on a probability scale. A straight line is also shown passing through the 16 to 84 percentiles, which of course would fit a perfect Gaussian beam profile of the same $\pm 1\sigma$ width as the measured beam. To provide a condensed view of all the data, a simple figure of merit, percent halo, is defined and tabulated (Table IX-1). The percent halo is defined as the excess of measured beam size at the 0.05 percentile relative to the size of the Gaussian fit to the 16 to 84% size and extrapolated down to 0.05%. Construction by graph of the excess is also shown in Fig. IX-1.

Table IX-1 indicates that one may expect beams 30 to 60% broader at the 0.05% level than computed by a Gaussian continuation of the 1σ size.

Fig. IX-1.

Proton beam distribution, horizontal axis.

Phase-Space Measurements at A-5. Previous work encouraged us to pursue the possibility of developing an on-line system using the A-5 and A-6 harps and the SEL-840 to measure beam-profile sizes and compute the phase space at the A-5 target location. Until now, the harp profiles had to be measured by hand, because of pattern recognition problems, to get a consistent set of beam-spot sizes for use in calculating the phase space. This quarter, harp data were taken to study the pattern recognition problem for possible on-line computer calculation of spot sizes. The missing harp wires and the poor quality of some of the harp data prior to February 1977 have prevented use of on-line techniques. Hand-measured data were used successfully to test the on-line calculation of the phase space by the SEL-840 using the CCR console interfaces.

TABLE IX-I
PERCENT HALO BY DATE ^a

DATE	LA-HL PLATE	SIZE AT 0.05%		HALO %
		Gaussian Extrapolation	Measured Excess, mm	
10-18	1X	7.2	4.4	61
	1Y	6.4	2.2	34
	3Y	6.5	3.8	58
10-29	1X	4.7	1.4	30
	1Y	3.3	1.3	39
12-12	1X	5.6	3.2	57
	1Y	3.9	2.3	59
	3Y	4.7	1.6	34
H ⁺ 12-12	1Y	8.5	5.2	61

^aAmount of halo is defined as excess in beam size at 0.05 percentile over Gaussian extrapolation from 16 percentile. H⁺ beam except as noted.

Spot-Size Measurement at A-6. In collaboration with Group CNC-11, two aluminum foils were irradiated at A-6 using the Isorad stringers. One foil was exposed to the main proton beam with the A-5 target out of the beam, the other with the A-5 target in the beam. The exposures were for five minutes. The target-in exposure was at an average beam current of 55 μ A as measured by the 6A-CM-02 current monitor; the target-out exposure was at 77 μ A. The aluminum foils were allowed to cool for 48 h during which time x-ray films (Kodak RP/TL) were placed on top of the foils and removed after different time intervals. The x-ray films were developed, but at each level of exposure the film showed no distinctive spot that could be associated with the proton beam. It is not clear whether the proton beam spot filled the target foil area or the neutrons from the beam stop activated the foil rather uniformly.

The two aluminum foils (10.2 cm by 7.6 cm) were cut into 0.6-cm-on-a-side squares, providing both a horizontal and vertical scan of each foil. Two gamma activities, ²²Na and ⁷Be, were counted for each foil. To get sufficient counts, each square was count-

ed ~12 h. The spot sizes in both dimensions for both target-in and target-out showed the vertical FWHM was near the dimension of the foil (7.6 cm), and the distribution could not be determined. The horizontal profile for target-out was a little better as the edge squares had 17% of the peak counts. Again, the shape of the distribution could not be determined. The target-in data did not drop below 25% of the peak counts. The corners of the foils were counted with the hope of determining the background or tails of the distributions. The corners had between 10% and 33% of the peak counts. There is no discernible difference between the ²²Na and ⁷Be data. Since the threshold for (n, α 2n) is 25 MeV for producing ²²Na, and there is no reasonable decay chain for producing ⁷Be, then the spallation products from ²⁷Al by 800-MeV protons must account for the ⁷Be activity. The conclusion, therefore, is that the spot size at A-6 during Cycles 9, 10, and 11 filled the foil area. Because of the need to wait for the decay of nuclides with low thresholds for neutron activation in order to measure the nuclides with higher thresholds and longer half-lives, the foil technique is not practical for measurements at A-6.

After the aluminum exposures, several pieces of Megarads dosimetry film (Kodak LR-132) were exposed to the proton beam at A-6. Several pieces of film were exposed to different known amounts of beam covering four orders of magnitude of radiation dose to the film. From these data, a relative calibration of the film [$\ln$ (Dose) vs film density] was obtained using a densitometer. Two additional pieces of film were exposed: one for A-5 target-in and one for A-5 target-out. The films were scanned using the densitometer for both horizontal and vertical profiles. The calibration curve was used to convert film density to dose which is proportional to the number of protons passing through the film. The Megarads film is apparently more sensitive to protons than to the neutron flux at A-6 since the neutron flux is expected to be rather uniform in the backward direction, and the films show definite peaks in the vertical and horizontal scans. The scan meshes were 3 mm. The shapes of the profiles are well defined to the eye, but again the spot sizes appear to fill the film area. The FWHM sizes are the sizes of the film (10.2 cm by 7.6 cm). The Megarads film has several advantages over the foil irradiations in that short irradiation times are used and, hence, the activation of the target holder is reduced, the Megarads film activity decays to <10 mr/h in 24 h, and it can be read on the densitometer at that time.

Instrumentation and Controls

Beam-on-Target Monitors. The electronics have been installed and the signals connected to the CCR computer. The linearity of the signal was checked against the toroid signals and found to be quite good. The response of the monitors as a function of beam position on the targets was also measured.

The present system provides a time-averaged signal proportional to the proton beam striking a production target. A digital signal will soon be made available to experimenters so it can be counted at their experiment location.

Guard Rings. A new secondary emission guard ring has been installed in Line A-Direct to provide protection for the vacuum system during tuning of the linac. It is expected that this device will show

low sensitivity to secondary particles scattered from the beam stop compared to its sensitivity to the primary proton beam. We plan to confirm this property and develop a protection system during the next two running cycles.

Beam Transmission Monitor. Groups MP-1 and MP-13 are continuing to work on the beam-current transmission monitor to improve program reliability and operator interface. One recent change was to remove the "threshold" level test on current monitor LA-CM-02; below threshold, transmission was not checked. It was determined that this test was not necessary and, in addition, was not fail-safe in cases of loss of data from this current monitor. However, the basic timing data (rf gate) is checked from two sources to reduce the chance of an erroneous time base causing high currents to look like low currents, with consequent loss of protection. The transmission monitoring period, previously fixed at 1 s, can now be set from CCR down to 1/30 s. When a transmission trip occurs, a new program is available which provides a full storage scope display of the program parameters as frozen at the moment of the trip. One of the beam line hardware faults recently detected by the transmission monitor system was the wobble in the A-2 target.

A-2 Current Monitor. A new radiation-hardened toroid (see LA-6553-PR, p. 64) was installed at the A-2 profile monitor, to replace the original 10-cm-bore current monitor which was exhibiting increased droop. There are now two of these all-inorganic current transformers installed, the one at A-1 having a Hymu-80 core, and that at A-2 having a Mu-metal core. They will be watched for possible radiation effects on the initial permeability of the cores.

The investigation of the original cores is still awaiting uncasing of these toroids — a hot-cell operation because of the activity level.

Harps. Sufficient monolithic 30-cm-bore harp boards are now on hand to equip all harp positions in the main beam line. Now painted with a silver-platinum ink (to withstand the long firing cycle),

these boards exhibit sufficiently high thermal conductivity (because of the high density of the alumina) to require tinning before the attachment of the silicon-carbon wire or feedthrough leads.

Commercial ceramic-to-metal 80-wire feedthroughs have been procured. Two are already installed on a Line A harp. With minor modifications, these will be used to replace the m.i. feedthroughs used previously.

Replacement harps for 5AHP01, 5AHP02, and 6AHP01 were completed this quarter. The harp cable connector edge cards were also replaced to improve the reliability of connection. All new replacement harps will have the new silicon-carbon wire, and we hope that gain variations between wires will be minimized with the more uniform surface areas.

High-Level Dosimetry. Study of the calibration of the various dosimetry materials used at LAMPF has shown that Kodak's LR-132 Megarads film apparently does not respond to low dose rates (~ 1500 r/h). The matter is largely academic, as this tetrazolium-salt film is no longer marketed. There is now no commercial source for a film dosimeter suitable for monitoring component doses, or direct beam spot "photography."

Activation-Protect (AP) and Loss-Monitor (LM) Systems Development. Several changes have been made during the December-January shutdown to improve the AP system in the SY. The average signal from the phototube is now available from the station units up to the start of integration to the trip level. This signal goes through the ADS and can be displayed at the CCR consoles. A new AP and LM pair (LA-AP-05 and LA-LM-05) was added to Line A in the SY in front of magnet LA-BM-03. In Line X, LX-AP-04, -05, and -06 were moved closer to the beam line. Two AP units in the SY (LA-AP-01 and LA-AP-10) have been modified to allow the phototubes to run at higher voltages. The trip current in the AP station unit has been increased by a factor of 10^3 which should allow the use of scintillator oil in previously empty cans and higher tube voltages for the same level of sensitivity to beam spill.

Halo Plates. The x and y halo plates formerly located at LA-HL-03 have been moved downstream of the Line A dogleg to a new location designated LA-HL-05 as shown in Fig. IX-2.

Instrumentation Roadmaps. A new instrumentation roadmap (Fig. IX-2) was made for the SY to reflect the changes made during the December-January shutdown.

Vacuum Improvements

A new fast-closing vacuum valve has been installed in the downstream end of the SY to protect the Area A harps from sudden pressure rises induced in the upstream experimental areas. This valve closes in less than 25 ms after a pressure rise is sensed by either of two ionization-type detectors located ~ 40 m upstream. This distance is sufficient to ensure that the valve is fully sealed before a shockwave can reach it from the upstream direction. The valve and electronics controller are fail-safe to a high degree and have been interlocked to Run-Permit and Fast-Protect to prevent beam irradiations of the valve. The valve is expected to close ~ 1000 times and to withstand $\sim 10^9$ rad before refurbishing is necessary.

A high-current four-foil window was obtained from NBS¹ and installed in the Line A-Direct beam line just upstream of the SY beam stop LA-BS-01. This window handles a 1-mA beam of 100-MeV electrons in the NBS accelerator. Although the present LAMPF water system does not allow the full design intensity, it will be adequate for $500 \mu\text{A}$, and, meanwhile, a cooling system will be provided which matches the window's requirements. The components of the window are shown in Fig. IX-3.

H⁻ Beam Development

Polarized Beam

Means for providing polarized beams simultaneously to more than one user are being explored. For polarization vectors not perpendicular to the bend plane, independent ways of rotating the polarization to provide compatibility between HRS

Fig. IX-3.
Components of the NBS water-cooled window.

and EPB have been developed and are under consideration at the present time.

Instrumentation and Controls

Wire Scanners. All the SY and Line B wire scanners received preventive maintenance and repair. Three broken signal or clearing-field wires were replaced; in LX-WS-9 the clearing-field wires were removed and 0.025- by 1-mm stainless steel signal wires were installed.

Stripping Foils. Damaged stripper foils were replaced at LB-ST-01. One of the V-shaped foils (two are used to give a variable aperture) is shown in Fig. IX-4. The heated spot due to beam impingement may be seen surrounding the apex of the V, and numerous holes in the aluminum are presumed to be caused by air-driven sand and other debris admitted to the vacuum system.

Chopper Monitor. A TOF system has been designed and installed in Line B for chopped-beam diagnostics. The system will consist of four small scintillators and two small Cerenkov counters mounted as a telescope and looking at LB-ST-01. The six counters should allow for sufficient flexibility in determining a coincidence that will optimize the system. A 200-MHz octal prescaler has been designed and will be used in conjunction with the chopped beam. In addition, an rf synchronizer module is being fabricated and will be used for rf timing.

Fig. IX-4.
Damaged stripper foil from Line B.

EPB Current Monitors. The movable EPB ion chamber has been remade. It has approximately the same dimensions as the old one but the noise figure has been improved: it now has $<10^{-12}$ -A inherent noise; the electronics will include an improved fan-out; and buffered TTL outputs will eliminate interaction between the experimental areas and CCR. In addition, the Faraday cup, ion chamber, and secondary emission monitor will now have two outputs supplied to the experimental area and will terminate the EPB patch panel. A fixed-position ion chamber has been designed for EPB and is intended to be located immediately in front of the Faraday cup.

Fast-Valve Triggers. The fast-valve hv distribution system has been designed and fabricated. It will be used to close the fast valves, other than the VAT valve, and will serve as the sensor for the spark plugs.

Beam Transport Calculations

A brief study was done for Group CNC-11 to examine the addition of quads at the end of Line B to improve the optics for a proposed on-line mass separator. It was found that an 8Q16 doublet downstream of LB-BM-08 would give a very favorable spot size for the mass separator, even with the LD₂ target in use upstream. Installation of the doublet would require extensive cutting of existing steel shielding and therefore would involve considerable time and money. Magnets and power supplies, however, are available.

Secondary Beam Line Development

During August, measurements of the pion beam at the East leg of the SMC were made as part of a feasibility study for Exp. 173. Using a 5- by 5-cm copper target, a rate of $2.4 \times 10^4 \pi^-$ stops/($\mu\text{A}\cdot\text{s g/cm}^2$) was obtained with a background rate of 0.014 counts/s in a 2-keV window. The rate was found to be three times higher in the front of the two quadrupoles (QM23, QM24).

In December, the apparatus, including the crystal spectrometer, for this experiment was set up. A 10-by 10-cm copper target was used, which it was hoped, would give a factor of 3 increase in the stopping rate. The actual measurement, however, was $1 \times 10^4 \pi^-$ stops/($\mu\text{A}\cdot\text{s g/cm}^2$); the background had increased to 0.08 counts/s. These measurements were compared with the calculated rates which had indicated that a rate in the range of $4 \pm 2 \times 10^4$ might be expected from the experimental setup. The current feeling is that the difference between the August and December measurements was due to problems with normalizing the "1-in-10 pulse" and possibly failure to correct properly for accidentals. The discrepancy between calculations and measurements may be due to dispersion of the beam by magnet BM03 which is set to handle the normal 67°

bend and is poorly positioned to handle the 37° bend of the π beam.

Further measurements are planned to determine if it is possible to obtain the stopping rate needed for these experiments [$1 \times 10^7 \pi^-$ stops/(s g/cm²)]. It is clear from the calculations that the experiment will have to wait for at least 200 μA . It is not clear that it will be feasible even at 300 μA if the lower limits of the estimates are borne out by measurements. The background problems (fast neutrons predominantly) can presumably be solved by more shielding.

Magnet Assembly and Measurement

Modifications to the new assembly area located at Bldg. SM-253, are still not complete. However, reconditioning of spare SY indirectly cooled m.i. magnets has continued. Three water leaks which developed in the SY were repaired. These leaks were due to erosion caused by high water velocities, as were the previous three. The velocity was increased by a local obstruction (soft-solder) in the cooling tube. Steps have been taken to reduce the maximum water velocity in these magnets from 4.5 m/s to 2.5 m/s.

The following magnet measurements were made and analyzed during this period: field maps of four C8IV63/16 bending magnets for WNR and the twin C-magnets for Exp. 50 (see Fig. IX-5); JGdL and harmonic analysis on a quad magnet 6Q22M/5, three 805 doublets, and the quads EA-QM-01, -02, and -03. The measurement section also provided some assistance to Group Q-11 in connection with a down-hole solenoid.

REFERENCE

1. S. Penner, "Handling High Power Electron Beams," IEEE Trans. Nucl. Sci., NS-14, 3, 12 (1967).

Fig. IX-5.
Three-dimensional representation of one-half
of the vertical field component in the two Exp.
50 magnets.

X. LARGE-SPECTROMETER SYSTEMS

Energetic Pion Channel and Spectrometers

Channel Operations

Two experiments received beam time during this quarter. Experiment 245, (π^- , n) reactions from ^3He and ^4He , received the bulk of the time, and angular distributions were obtained for both targets from 50 to 300 MeV. Experiment 133, π^+ and π^- channeling by the ANL group, was completed. In this experiment, the channeling of π^+ and π^- was clearly observed. The EPICS channel performed better than anticipated as angular resolution better than 1 mrad (FWHM) was obtained.

During the shutdown, maintenance was performed on BM01. A water leak in the external plumbing was repaired and a thermal switch on the coil for this magnet was replaced. Radiation levels on the order of 100 mR were found in the vicinity of the magnet. A two-week shutdown made it possible to do all the required work without use of remote-handling equipment.

Spectrometer Construction

The mounting of the EPICS spectrometer dipoles was accomplished during the December shutdown. This operation, which was performed by an outside contractor, took approximately four weeks. A special jacking tower was used to lift the 90-ton magnets into position on the spectrometer frame. This jacking tower was purchased by LASL and can be used if ever the magnets need to be dismounted for repair.

After installation, the dipoles were aligned by the MP-8 alignment crew. The adjustable magnet-mounting fixtures (which were fabricated by the Univ. of Texas at Austin shops) performed as designed, and the alignment operation went smoothly.

The final shield wall around the EPICS cave was installed. The utilities bridge for the spectrometer was delivered and assembly of this bridge was started.

Quadrupole Mapping

The three spectrometer quadrupoles for EPICS have been shimmed and mapped. Five fields have been mapped, ranging over ~ 0.9 to 7.9 kG for Q1 and Q3, and 1.1 to 9.6 kG for Q2. The maps were then transformed into harmonic content as a function of position along the quadrupole axis. The unwanted harmonics in each quadrupole were shimmed at the middle field, corresponding to a central momentum of ~ 390 MeV/c until they were 0.1% or less of the quadrupole harmonic.

Figure X-1 shows the results of shimming performed on Q2 at the central field of -5.6 kG. The results are all normalized to the central field quadrupole harmonic. Noted on the figure are contributions from the pole edge (PE) and the field clamp (FC), to which the shims were attached, extending ~ 2.5 cm toward the poles. For the case illustrated, the integrated octupole harmonic is $\sim 0.01\%$ of the integrated quadrupole, and the duodecapole $\sim 0.07\%$.

The quadrupoles are now being prepared for installation into the spectrometer frame. Further analysis of the maps is being undertaken in which the effect of the residual harmonics on the quadrupole triplet optics will be investigated.

Analysis of the Spectrometer Dipole Maps

In conjunction with the MP-13 magnet-mapping crew, all mapping on the 60° EPICS spectrometer dipole magnets (BM05 and BM06) was completed during the period September 1 through December 1, 1976. A total of 66 maps was made comprising almost 750 000 data points. The analysis of the maps took place in roughly three steps.

In the first step, each map was individually analyzed by a program called RAPMAP which performed a series of tasks: 1) each coil ($B_{y1}, B_{y2}, B_{y3}, B_x, B_z$) in the cart in each scan (one complete trip of the coil cart in and out of the magnet) is corrected for integrator drift; 2) each coil in each scan is normalized to its corresponding value at a predetermined position in the scan located approximately in the central field region of the magnet and measured by a NMR probe; 3) all three B_y coils

Fig. X-1.

Normalized $N = 2$, $N = 4$, $N = 6$ harmonics as a function of position through the magnet.

are normalized to one another; 4) all scans are normalized to one another by the NMR probe measurement made for each scan; 5) the magnet power supply drift is corrected for in each scan; 6) all scans are normalized to a NMR probe measurement of the central field (B_y) in the exact center of the magnet; and 7) the B_y contributions to the B_x and B_z coils are removed. No unusual problems were encountered

during the analysis which would require remeasurement.

In the second step, each magnet entrance and exit was mapped at three different planes (between the pole faces, the central plane, and as close to the pole faces as possible) at three different field settings (2, 10, and 17 kG). Each corresponding set of three planar maps is analyzed by a program called MFIT which 1) fits the three maps to a set of harmonic polynomials that are solutions to Maxwell's field equations, 2) compares the resulting fit with a corresponding theoretical fit for error checking, and 3) generates a map corresponding to the fitted field of the magnet along the central plane. At present, only BM05 has been analyzed in order to provide a test case prior to the analysis of BM06. The most difficult task presenting itself at this point is to choose an adequate set of mesh points and corresponding harmonic polynomial order to fit the magnet fringe field. In anticipation that the current grid size in the maps (1.3 by 2.5 cm) would prove to be inadequate, each plane at the 10-kG setting was mapped with an additional two maps, offset to provide a new grid size of 1.3 by 0.8 cm.

Finally, each pair of central maps corresponding to a particular field of a given magnet was interfaced with a program called MOTER. This program allows the user to analyze a magnet transport system by a Monte Carlo ray-tracing simulation. Currently, only BM05 has been interfaced with MOTER in order to determine the accuracy of the fringe field fit re-created by MOTER as compared to the fit generated by MFIT. Effort is now being placed on optimizing the fringe field fit in both MFIT and MOTER. The information will then be used to complete the analysis of BM06 and its interface with MOTER. As soon as the data become available, the quadrupole triplet measurements will be incorporated into MOTER.

EPICS Channel Tuneup

Preparations are in progress to measure the pion fluxes, beam composition, and character of the EPICS channel. In addition, multiple-scattering measurements will be made on some low-Z targets.

A schematic of the detection array is shown in Fig. X-2. The four delay line chambers (DLC) are

Fig. X-2.

Experimental detector and monitor arrangement for EPICS tuneup.

the ones to be used in front of the EPICS spectrometer to determine the incoming particle trajectories. Scintillators S1, S4, and S5, positioned at the target spot for the spectrometer, will be used to define the incoming beam. These scintillators will also be used as particle identifiers by using dE/dx losses and TOF measurements with the 40-ns chopped proton beam. A removable copper absorber before scintillator S6 will allow measurements of proton energies up to 180 MeV.

The ion chambers (IC) will be used to monitor the beam intensity. An aluminum absorber between them will absorb high-energy protons which are not stopped by the total thickness of the previous detector arrays. Scintillators S7 and S8 will also be used, in an integration mode, to monitor the beam intensity. All the phototubes will be gated off between beam macropulses.

To calibrate the beam monitors with an absolute accuracy of $\pm 3\%$ or better, three methods will be used. One method, using the low-intensity continuous chopped beam, is direct counting of the beam while integrating the output of the ion chambers. The second method, using the low-intensity 1-in-10 mode beam, consists of counting the beam during the low-intensity pulse and extrapolating to the high-intensity pulse by using the integrating

scintillators. The third method consists of counting events from π^+ elastic scattering and using the known cross sections to deduce the incident flux. For these cross-section measurements, S1, S4, S5, and S6 will rotate out of the beam direction to detect protons at an angle of 22° ; S1 and S4 will define the solid angle. Three additional scintillators will be stacked at 123° to detect the coincident pions.

For the modeling of the multichannel disk Cerenkov counter, to be used at the exit of the EPICS spectrometer, a better knowledge of the large-angle (tail) region of multiple scattering on low-Z materials is needed. Measurements with an accuracy on the order of 1 mr and 1% or better data on the Gaussian portion of the distribution will be made on targets such as ^6Li , ^7Li , ^9Be , ^{13}C , and hydrogen. To minimize nuclear interactions, a reasonably pure muon beam will be obtained using μ^+ of the same momentum as 67-MeV pions along with TOF and energy measurements.

Multichannel Cerenkov Counter for EPICS Spectrometer

Design. The Monte Carlo ray-tracing design of a multichannel Cerenkov counter for identifying pions in the large phase space of the EPICS pion spectrometer (Fig. X-3) is essentially complete. The parameters of the counter have been improved and firmed up over the last several months. A schematic (plan view) of the optics is shown to scale in Fig. X-4. These include a 5-cm-thick liquid radiator with a 0.32-cm-thick quartz exit window, two water prisms with 1-cm-thick quartz windows, two sets of spherically concave 0.635-cm-thick plate glass mirrors (front surface aluminized), and two arrays of 5-cm quartz-faced photomultipliers with aluminized aluminum light collectors.

Since the Cerenkov light separation for the π - μ groups is as small as 25 mr at 300-MeV pion energy, it is necessary to bin the particle trajectories both horizontally and vertically. This is accomplished by tagging the particles passing through the Cerenkov radiator with wire chambers positioned both before and after the radiator, which also reduces the effects of multiple scattering by a factor of 2. Because of the large beam divergence in the vertical or dispersion plane, and the large momentum acceptance in that

Fig. X-3.

MOTER output of spectrometer phase space at 1 m downstream of the focal plane with trapezoidal/Gaussian approximations superimposed.

plane, it is practical to set up an array of photomultiplier light collectors (to be correlated to the particle trajectory bins) only in the horizontal plane, preferably on each side of the focal plane with a coincidence requirement.

An 80-bin array of light collectors is shown in Fig. X-5, corresponding to six vertical by six horizontal particle angle bins. The shaded region represents the light collectors used in an "OR" coincidence for the particle trajectory $\Delta\theta = (+50,0)$ mr, $\Delta\phi = (-15,0)$ mr. These 15 signals would then be taken in an "AND" coincidence with those from the other side of the focal plane. The offset of each row is due to the different particle momenta corresponding to the different vertical angular bins. Multiple scattering and chromatic dispersion (corrected in first order by the prism) limit the advantage of a larger number of light bins, and a total of 160 is already a barely manageable number. A more economical

Fig. X-4.

Top view of proposed multichannel Cerenkov counter showing optics and pion-muon light rays for a given particle trajectory.

arrangement of 30 light collectors on each side (three vertical by four horizontal particle bins) is shown in Fig. X-6, and the ability of these two arrangements to reject muons is summarized in Fig. X-7. Utilization of one-half of the focal plane reduces the muon contamination to about one half of the values shown. The values indicated in Fig. X-7 include a margin of safety of $\sim 30\%$, and as all the optical constants and absorption losses are known measured quantities, the pion-muon separation with 98% coincidence efficiency is $\sim 150:1$ at 300 MeV, 600:1 at 250 MeV, and rapidly improves thereafter with decreasing energy (also see below).

Over the useful energy range of 50 to 300 MeV it is necessary to use five different radiator liquids, because of the variation of the Cerenkov light cone angle with particle velocity. The index of refraction of only the highest-energy liquid (actually the most critical situation) is reasonably well known over the wavelength region of interest (2000 to 5000 Å). For the lower-energy liquids, the known index of refraction at 5000 Å was used along with an estimated extrapolation down to 2000 Å. Precise measurements of all the necessary indices and absorption coefficients are currently in progress at the National Bureau of Standards, and will become available in February. Once the data for the 300-MeV liquid FC-75 has been checked, the final design of the counter

Fig. X-5.
The 80 photomultiplier array with the 15 OR'D photomultipliers for the particle trajectory $\Delta\theta = (+50, 0)$ mr, $\Delta\phi = (-15, 0)$ mr indicated by the shaded region.

Fig. X-6.
The 30 photomultiplier array with the 9 OR'D photomultipliers for the particle trajectory $\Delta\theta = (+50, -50)$ mr, $\Delta\phi = (-25, 0)$ mr indicated by the shaded region.

can be turned over to the engineering group for drafting and construction. The proposed counter is shown in Fig. X-8.

Several remaining refinements are currently being incorporated in the ray-tracing code: Rather than to allow the muons the same phase space as the pions, the pions are being allowed to decay in the last several meters before the focal plane, while allowing some 10% of the particles to be muons from the region of the target. The possibility of using an anticoincidence signal from the muon bins in order to improve the π - μ separation as well as the noise rejection is being investigated. The Rossi multiple-scattering theory is being replaced with the more exact Moliere theory, which has a narrower distribution but more persistent tails. The exact tracing of

Fig. X-7.

Muon rejection ratio for the 80-light bin and 30-light bin designs as a function of pion energy.

reflection losses of the linearly polarized (in the favorable direction) Cerenkov light is being included, which becomes elliptically polarized after reflection from the mirror and down through the light funnels.

High-Resolution Proton Spectrometer

All Line C TV phosphors have been replaced with more durable chromium-doped aluminum phosphors. New phosphors designated as LCTV2 and LCTV9 have been installed. LCTV2 is placed at the focus after LCQM2 and allows for visual observation of the first Line C focus and any steering produced by the LCQM1-2 doublet. LCTV9 is located about 2 m after the target and allows for monitoring of beam angle on target.

Ion pumps LCIP03-7 have been replaced with one cryopump, two turbomolecular pumps, and a two-

stage blower. The cryopump is located between LCBM04-5, the first turbomolecular pump is after LCBM05, the second turbomolecular pump is placed after the twister, and the blower is on the scattering chamber. This scheme allows for a gradual pressure gradient from the scattering chamber (10^{-3} torr) to LCIP02 (10^{-7} torr) and the end of Line X. The beam dump has been taken off IP07 and put on a large roughing pump. These changes resulted in a vacuum system which requires little attention and is insensitive to small leaks.

Initial operation of the HRS system this quarter indicated that Line X strippers LXST01,4,5 did not offer the appropriate selection of foils for optimum simultaneous operation of Lines C, B, and EP. During the shutdown period the stripper selection was optimized. In addition, beam scanner LCSZ01 (situated near LXST05) was converted to a stripper offering the same selection of foils as does LXST01. This stripper may be used instead of LXST05 and allows stripper changes without the need to turn off the H^- beam.

Initial problems with the secondary emission monitor (SEM) after the scattering chamber were traced to bad vacuum inside the SEM as well as improper grounding. The SEM has been put on its own ion pump. The SEM and the two ion chambers IC1 and IC2 now derive their high voltage from batteries rather than power supplies.

The failure of LCQM13-14 to properly focus the beam at the dump was traced to the wrong field polarities in these magnets.

During Exp. 139, an energy resolution of 100 keV was typically observed for elastic and inelastic scattering from $^{58,60,62,64}\text{Ni}$ and ^{208}Pb . Because this resolution was sufficient for the experiment, little time was devoted to fine tuning the resolution because the goal was to obtain the first angular distribution using the HRS.

Initial measurements of the relative solid angle of the HRS as a function of momentum-out-of-scattering-plane angle were made by sweeping elastic peaks across the focal plane by varying the magnetic fields in the spectrometer.

Measurements of the relative solid angle of the HRS as a function of angle in the scattering plane were made utilizing the fact that the kinematic shift for $p + H$ elastic scattering is so large that the full energy spread across the focal plane corresponds to a scattering angle which is very small compared to the

Fig. X-8.

Three-dimensional sketch of proposed multichannel Cerenkov counter showing the basic optics.

acceptance angle of the HRS: the HRS was set to focus various energy bands for $p + H$ corresponding to different scattering angles (0.25° increments) within the aperture of the magnets, and in this way the relative solid angle as a function of scattering angle was mapped out.

Further tests of the scattering chamber sliding seal mechanism demonstrated that a vacuum of 10^{-4} torr could be maintained as the spectrometer angle was changed.

The desire to be able to have many targets inside the scattering chamber at once has led to the design of a target wheel assembly which holds up to 36 targets of dimensions 4 cm by 10 cm. The wheel is mounted on the present target ladder post and is

driven by a precision Geneva mechanism — stepping motor control. The assembly is presently being fabricated in-house and should be available for use in a few cycles.

A new detector system consisting of four 60-cm delay-line chambers has been constructed for positioning near the focal plane of the HRS (see Fig. X-9). The first (DL1) and fourth (DL4) chambers have ~ 1 -mm resolution in the analyzing plane and will be used to obtain focal plane position and out-of-plane scattering angle. The second chamber (DL2) has 4-mm wire spacings (as contrasted to 1 mm for the DL1 and DL4 chambers) and will be used as an absolute position calibrator for the DL1. The second chamber has about 1-mm resolution in

Fig. X-9.

Schematic representation of new detector system situated near the focal plane of HRS.

DL1: X, 60 cm, 1 mm SPACINGS
(CATHODE)

Y, 12 cm, 3 mm SPACINGS
(ANODE)

DL2: X, 60 cm, 4 mm SPACINGS
(ANODE)

Y, 12 cm, 1 mm SPACINGS
(CATHODE)

DL3-4: SAME AS DL1

VETO 1-2: 0.32 cm by 13 cm by 18 cm

S2: 64 cm by 9 cm by 76 cm

the other plane and may be used to determine scattering angle to 0.5 mr. The third chamber (DL3) is identical to the DL1 and DL4 and is used for redundancy.

A new 9-cm by 76-cm scintillator (S2) is positioned after DL4 and will be used in coincidence

with S3 and S4 and an "or" from the delay-line chambers to provide the event triggers. In addition, TOF between this scintillator and S3-S4, which are located about 2 m away, will be sufficient for TOF particle identification in most experiments. Two new 13-cm by 18-cm scintillators designated Veto 1 and 2 are placed at the position of the focal plane (along the 35° line) masking the edges of the delay-line chambers and the 75-cm scintillator to define a sharp momentum acceptance for the data acquisition system.

Several new computer programs have been written for the PDP-11/45 which make experimental setup and data analysis easier. The HRSKIN code calculates relativistic two-body kinematics using a mass table and provides the pertinent information for setting up the spectrometer and the analysis program. Program LIGHT tabulates dE/dx , range, and light output for various particles incident on scintillators or Cerenkov materials. Program LANDAU calculates the Landau-Vavilov distribution for particles incident on thin foils. The DETSIM code calculates the output of detector systems so that the particle identification response of a system of scintillators and absorbers may be predicted. Program BOX allows on-line drawing of boxes on two-dimensional plots of data; the limits of the boxes are output so that cuts may be placed on particle identification data. The peak-fitting routine PEKFIT has been rewritten to correct a number of bugs and to cut down on its core requirements.

XI. RESEARCH

Results of Experiments

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

It has long been recognized that the pion double-charge-exchange (DCE) reaction could be a very useful tool in nuclear structure research. In the simplest description, the (π^+, π^-) reaction is assumed to proceed through a two-step process whereby two neutrons (protons) in the nucleus are changed to two protons (neutrons). Thus, with this reaction one might expect to identify $\Delta T_z = 2$ isobaric analog states and nuclei off the line of stability (particularly proton-rich nuclei). Since the reaction involves at least two nucleons, it should also be quite sensitive to nuclear ground-state correlations. Although numerous experiments have been performed over the last 12 years in an attempt to detect nuclear transitions to specific final states, none has yet convincingly demonstrated such a transition. This report describes the first such observation, an unambiguous measurement of the pion DCE reaction $^{18}\text{O}(\pi^+, \pi^-)^{18}\text{Ne}$ made by a LASL- Univ. of South Carolina-ANL collaboration. The transition involved is the $\Delta T_z = 2$ isobaric analog transition from the ground state of ^{18}O to the ground state of ^{18}Ne .

The differential cross-section $d\sigma/d\Omega$ (0°), at a mean pion energy of 139 MeV, was measured by utilizing the LEP channel as both a pion channel and a spectrometer. In this experiment, the pion DCE targets were placed at the channel midpoint immediately following the momentum collimator. As shown schematically in Fig. XI-1, the first half of the channel was tuned for a π^+ beam, with a point focus at the channel center, while the second half of the channel was tuned with opposite polarity as a π^- spectrometer at a fixed 0° scattering angle. During the experiment, the incident pion flux was about 4×10^7 π^+/s and was monitored by recording the integrated current of the primary proton beam used to produce the pion beam. With the DCE target mounted at the channel midpoint, the second half of the channel approximately functions as an energy-loss spectrometer with a momentum acceptance

$\Delta p/p = \pm 5\%$ and a solid angle $\Delta\Omega = 6.7$ n.s.r. The detection apparatus located at the end of the spectrometer, shown in detail at the bottom of Fig. XI-1, served to identify outgoing particles and to define their position on the spectrometer focal plane.

Measurements of the π^- spectra were taken for three different spectrometer energy regions. The combined results with central spectrometer settings of 130 MeV, 124 MeV, and 112 MeV, all for a 139-MeV π^+ beam on the DCE target, are shown in Fig. XI-2. Spectrometer acceptance and relative detector efficiency at the different settings have been unfolded from the spectrum shown. The peak from the DCE isobaric analog transition $^{18}\text{O}(\pi^+, \pi^-)^{18}\text{Ne}$ is clearly separated from the DCE continuum, which begins at ~ 4.5 -MeV excitation in ^{18}Ne and corresponds to a pion energy of 126 MeV. Data were also taken for an ^{18}O target and are displayed in Fig. XI-2. Since the Q-value for DCE on ^{18}O is 25.2 MeV, this target provides a realistic background measurement for the $^{18}\text{O}(\pi^+, \pi^-)^{18}\text{Ne}$ reactions: all of the nonpion DCE sources of background are present for

Fig. XI-1.
Schematic layout of the LAMPF Low-Energy Pion Channel and DCE Spectrometer.

Fig. XI-2.

Combined π^- for three spectrometer settings. The DCE isobaric analog transition to the ^{18}Ne ground state is clearly separated from the continuum. The dashed line shows a small background, as measured with an ^{18}O target.

pion energies around 130 MeV. It is evident from Fig. XI-2 that the background in the region of the DCE peak is quite small and flat. After subtracting

this small background, we obtain a net number of 242 ± 17 events under the peak at 130-MeV π^- energy. Folding in a pion detection efficiency of 36%, obtained by sending a 130-MeV π^- beam through the spectrometer, we get a 0° differential cross section for the DCE reaction $^{18}\text{O}(\pi^+, \pi^-)^{18}\text{Ne}$ of

$$d\sigma/d\Omega (0^\circ) = 1.78 \pm 0.30 \mu\text{b/sr}.$$

The quoted error is dominated by systematic uncertainties in knowledge of the pion flux and detector efficiency.

Early calculations of pion DCE on ^{18}O gave cross sections considerably higher than the upper limits seen in experiments on other nuclei. In anticipation of this experiment, there have been several recent predictions^{1,2,3} which have attempted to improve upon the earlier work. These calculations are based upon some form of multiple-scattering theory, and each has had reasonable success when applied to pion-carbon elastic scattering above 100 MeV. Consequently, it is interesting to compare them to the results of this experiment. Table XI-I lists the available results for $T_\pi = 139$ MeV. All calculations used the free pion-nucleon scattering amplitudes as input and assumed transitions between pure $1d_{5/2}$ states. It is apparent from Table XI-I that there is qualitative agreement between theory and experiment; in particular, our results are bracketed by the several theories. From this first measurement of pion DCE it is already clear, however, that the measured magnitude of the cross section, besides providing constraints on the theoretical analyses,

TABLE XI-I

COMPARISON OF OUR EXPERIMENTAL RESULT WITH
RECENT CALCULATIONS BASED UPON SOME FORM
OF MULTIPLE-SCATTERING THEORY

Theory Experiment	$\sigma_{\text{tot}}(\text{DCE})$ (μb)	$d\sigma/d\Omega (0^\circ)$ ($\mu\text{b/sr}$)	Ref.
1. Glauber Approximation	0.9	2.2	1.
2. Fixed Scatter Approximation	4.1	5.7	2.
3. Optical (LaPlacian)	0.7	0.6	3.
(Laplacian with correlations)	46.0	38.0	
4. This experiment		1.78 ± 0.30	

also is large enough to allow pion double-charge exchange to be used as a spectroscopic tool for the investigation of nuclear structure.

A Neutrino Experiment to Test Muon Conservation (Exp. 31)
(Yale Univ., LASL, Saclay, SIN, National Research Council of Canada)

Measurements of beam-associated backgrounds at 5 m of iron shielding have been completed, and the final shielding, to give a total of 6.3 m, has been installed. Measurements of cosmic-ray backgrounds have also been made.

A beam-associated neutral event is defined as an event which occurs inside the Cerenkov counter during a beam pulse and which is not vetoed by a 20-μs anticoincidence pulse from the surrounding scintillators. Events outside the beam spill are measured as well, and a subtraction is made to correct for cosmic-ray events. A computer-controlled CAMAC ADC system gives total energy information on the Cerenkov events. True neutrino events will be in the energy range 20-60 MeV. The background events are measured from 30-100 MeV instead because of pileup problems from 20-30 MeV at reduced shielding; these background events are referred to as "prompts." All events are expressed in terms of mA·s of protons on the beam stop. With the biomed target out, but no requirements on the upstream targets, we find

$$\text{prompts/mA}\cdot\text{s} = (3.70 \pm 0.20) \times 10^{-2} .$$

All errors are statistical. With the biomed target in, we find

$$\text{prompts/mA}\cdot\text{s} = (3.14 \pm 0.21) \times 10^{-2} .$$

This gives ratios, biomed out to biomed in, of

$$\text{prompts, out/biomed in} = 1.18 \pm 0.10 .$$

From this we conclude that we do not see any events coming directly from the biomed target. (We expect this ratio to be slightly greater than unity because the energy of the beam arriving at the beam stop is somewhat less when the biomed target is in.)

Measurements have been made of neutral cosmic-ray backgrounds from 20-60 MeV. This rate, scaled to include only beam-on time, is 2500/day. We have investigated what types of events these are, and have isolated two major contributions; muon decays in the last part of the roof, with the electron producing a photon which goes through the anticounters and converts in the Cerenkov counter; and muon bremsstrahlung in the roof, with the muon missing the antis, but the photon going through and converting in the counter. These will be referred to as μ-e-γ and μ-γ events, respectively. A small contribution is due to gaps and inefficiencies in the anticounter system. We have measured the μ-e-γ and μ-γ rates through the top, and have assumed that the rest of the events are μ-γ events coming through the sides. This gives the following results (errors are not shown):

1) gaps and inefficiencies	40 events/day (scaled)		
2) μ-e-γ	530	"	"
3) μ-γ (top)	1000	"	"
4) μ-γ (sides) (assumed)	930	"	"
	<hr/>		
	2500 events/day (scaled)		

We then installed 3.8 cm of lead above the top antis, and 1.9 cm of lead around the sides (with some gaps). This is expected to reduce the μ-γ events by a large factor, but to have only a small effect on the μ-e-γ events. We found the following:

1) gaps and inefficiencies	40 events/day (scaled)		
2) μ-e-γ	340	"	"
3) μ-γ (top)	20	"	"
4) μ-γ (sides) (assumed)	400	"	"
	<hr/>		
	800 events/day (scaled)		

We assumed that the small attenuation of μ-γ events through the sides is due to the presence of gaps in the lead shield. We intend to install a total of 3.2 cm of lead around the sides, filling in the gaps, and to install a second layer of anticoincidence counters outside the lead, which should reduce the μ-e-γ events by approximately an order of magnitude (by detecting the incoming muon). We hope that the anticoincidence system will be complete and working well by the end of the summer.

Chemical Effects in Meson Capture (Exp. 60) (LASL, Princeton Univ.)

In order to obtain information on the role of chemically bound hydrogen in the capture and subsequent transfer of negative muons to heavier elements, we have measured the muonic x-ray intensity patterns of carbon in $(\text{CH}_2)_x$ and $(\text{CD}_2)_x$ and of oxygen in H_2O and D_2O . In both cases the relative intensities of the higher Lyman series members are significantly lower in the deuterium compounds (Fig. XI-3). This evidence is consistent with the picture that the muon angular momentum following transfer is a function of the mass of the hydrogen nucleus from which it transferred. We have not yet succeeded in devising a satisfactory mechanism for this interesting isotope effect. We have some evidence from another experiment that a $p\mu$ atom formed from hydrogen bound in a molecule may migrate away from its formation site to an adjacent molecule. However, on the time scale involved it is not immediately evident that the lower velocity of a $d\mu$ atom should make a noticeable difference. Since

Fig. XI-3.

Relative muonic x-ray intensity patterns of deuterium and proton forms of polyethylene and water.

most of the muonic hydrogen atoms formed are not likely to have deexcited significantly from their atom-sized state by the time they make a muon transfer encounter with a higher-Z atom, the $p\mu:Z$ -nucleus distances at transfer will generally be comparable and large, and thus a realistic treatment will probably have to involve the dynamics of the three centers during the encounter, including suitable averaging of $p\mu$ trajectories and n, l states.

The other (recent) experiment referred to above compares the muonic x-ray spectra of fluorine in C_6F_{14} and in a $\text{C}_6\text{F}_{14} + \text{C}_7\text{H}_{16}$ mixture. The intensities of the higher Lyman series members in the hydrogen-containing mixture appear to be greater than in the pure fluorocarbon. The uncertainties in the data are large, but early analysis indicates that the effect is real. Since the extra strength of the higher Lyman members indicates that some of the fluorine atoms are receiving their muons by way of transfer from $p\mu$, this result is evidence that intermolecular transfer of muons has occurred. We had found some evidence of a similar effect in earlier experiments with CCl_4 , CH_2Cl_2 , and $\text{CCl}_4 + \text{C}_6\text{H}_{18}$ mixtures, but the experimental uncertainties were too large to permit a firm conclusion.

Development of Pion Beam Monitoring Techniques (Exp. 67) (LASL, BNL, ANL)

The second and last phase of this activation experiment is nearing completion. In a previous quarterly (LA-6553-PR, p. 94) some preliminary excitation functions were shown and a description was given of the experimental procedure employed to measure the cross sections of some practical pion beam monitoring reactions, $^{27}\text{Al } \pi^\pm {}^{18}\text{F}(110\text{m})$, $^{27}\text{Al } \pi^\pm {}^{24}\text{Na}(15\text{h})$, and $\text{Si } \pi^\pm {}^{24}\text{Na}$, all relative to the $^{12}\text{C}(\pi^\pm, \pi\text{N})^{11}\text{C}$ reactions.⁴ These cross sections have been measured over the useful pion energy range available at LAMPF, 50 to about 400 MeV. Our semifinal results are shown in Figs. XI-4, XI-5, and XI-6. The smooth curves are handdrawn and serve merely to guide the eye. The errors associated with most of the experimental points are estimated to be $\pm 10\%$ or less, except for values below 100 MeV where errors are substantially larger, primarily because of errors in the carbon cross sections. Only some representative error bars are shown.

Fig. XI-4.

Excitation functions of the reaction $^{27}\text{Al } \pi^{\pm} \rightarrow ^{18}\text{F}$.

Fig. XI-6.

Excitation functions of the reaction $\text{Si } \pi^{\pm} \rightarrow ^{24}\text{Na}$.

Fig. XI-5.

Excitation functions of the reaction $^{27}\text{Al } \pi^{\pm} \rightarrow ^{24}\text{Na}$.

It is of interest to note that without exception, for both aluminum and silicon targets, the π^- reactions

yielding the neutron-rich product, ^{24}Na , have higher cross sections than the π^+ reactions, and conversely the π^+ reactions yielding the neutron-deficient product, ^{18}F , have higher cross sections than the π^- reactions. This observation reflects the strong influence of the pion-absorption process. With aluminum targets the ^{18}F cross sections do not fall off as rapidly at lower energies as those of ^{24}Na from π^+ reactions because ^{18}F is produced by absorption of both π^+ and π^- while ^{24}Na production from π^+ absorption is highly improbable (three protons must escape from the compound system, ^{27}Si , without loss of neutrons). The situation is similar for the production of ^{24}Na from silicon targets, except in this case the low-abundance ^{28}Si and ^{30}Si isotopes contribute to ^{24}Na production by π^+ absorption. While the influence of the (3,3) pion-nucleon resonance is noticeable in these excitation functions, its effect is considerably "washed out." Despite the variations in these cross sections with pion energy these beam monitor reactions have been usefully applied in at least six pion-activation studies to date. These results will be presented and discussed at the March meetings of the American Chemical Society.

Scattering, Charge-Exchange, and Inverse Photoproduction of $\pi^\pm$ on ^3He and ^3H (Exp. 90) (LASL, UCLA, Univ. of Virginia)

This experiment was completed at the end of Cycle 11. Data for both tritium and ^3He were obtained at 233-, 253-, and 293-MeV/c incident pion momentum for $\pi^\pm$. Elastic-scattering, single charge exchange, and inverse pion-photoproduction data leaving the residual nucleus in the ground state were obtained to test multiple-scattering models in few-body systems as well as time reversal through comparison with the corresponding photoproduction experiment of Saclay. Beam phase space, particle contamination, and energy were also measured at each momenta. The data at 293 MeV/c are now being analyzed to extract elastic-scattering angular distributions and determine efficiencies of the recoil counter for the neutrals part of the experiment.

Spallation Yield Distributions from Fast Pion Interactions with Complex Nuclei (Exp. 103) (LASL, BNL)

Cross sections have been determined by Ge(Li) γ -spectroscopy for about 24 gamma-emitting spallation products resulting from 100-, 190-, and 350-MeV π^+ and π^- reactions with copper. We reported preliminary cross sections for about 14 of these products from 190-MeV π^+ and π^- irradiations in an earlier quarterly (LA-5959-PR, p. 58). In the recent work we have remeasured the 190-MeV π^- cross sections at a substantially higher pion flux and with the resulting improved statistics. We find good agreement with the previous results.

The data are presented in Table XI-II. Our experimental errors are estimated to be $\pm 15\%$, except for cross sections derived from very low γ -ray intensities marked by asterisks ($\pm 25\%$) and daggers

TABLE XI-II

CROSS SECTIONS (mb) FOR FAST PION REACTIONS ON COPPER (VEGAS + DFF Calculated Values in Parentheses)

Nuclide	100 MeV		190 MeV		350 MeV	
	π^+	π^-	π^+	π^-	π^+	π^-
3.3-h- ^{61}Cu	33.1 (48)	28.4 (39)	23. (27)	28.9 (28)	14.5 (20)	14.9 (13.5)
36-h- ^{62}Ni	2.58 (4.5)	0.826 (1.4)	2.5 (7)	1.4 (4)	1.26 (3.3)	1.1 (2)
18-h- ^{65}Co	3.98 (6)	1.71 (1.9)	3.2 (9)	1.95 (5)	2.11 (4)	1.24 (2.5)
78-d- ^{66}Co	23.7 (22)	15.4 (13)	30. (30)	17.8 (24)	14.4 (15)	13.7 (11)
271-d- ^{67}Co	54.6 (36)	48.1 (29)	57. (52)	53. (48)	31.2 (25)	27.6 (18)
71-d- ^{68}Co	56. (32)	68.5 (38)	67. (41)	68. (45)	34.7 (21)	31.3 (29)
1.6-h- ^{61}Co	3.76 (2.2)	13.1 (8)	6.2 (6)	11. (8)	4.6 (2.5)	6.03 (3)
8-h- ^{62}Fe	0.406 (1)	0.158* (0.2)	0.37* (1)	0.16* (0.1)	0.25 (1)	0.15 (0.2)
45-d- ^{60}Fe	----- (0.84)	7.44 (5.7)	2.7† (2.9)	6.3 (5.6)	2.4† (1.2)	3.4 (2.6)
5.6-d- ^{62}Mn	13.4 (21)	9.33 (8.5)	12. (23)	10. (15)	10.3 (16)	8.33 (11)
312-d- ^{64}Mn	35.8 (17)	54.1 (22.5)	42* (27)	52.5 (33)	27.1 (16)	34.5 (18)
2.6-h- ^{66}Mn	3.51 (2)	11.9 (8)	4.9 (5)	10. (11)	3.46 (3)	7.32 (4)
22-h- ^{60}Cr	0.333* (0.38)	$\leq 0.2†$ (0.03)	0.43* (0.95)	0.25* (0.3)	0.49 (1.4)	0.25* (0.44)
42-m- ^{60}Cr	3* (4.6)	1.89* (0.8)	3.3* (8)	2.3* (2.8)	$\approx 4*$ (7.5)	2.5* (4)
28-d- ^{61}Cr	34.4 (23)	34.8 (17.5)	0.42 (33)	38. (25)	29.6 (27)	24.5 (22)
16-d- ^{60}V	9.14 (9)	5.47 (3.6)	12. (15)	10.2 (8)	12.4 (17)	10.2 (11)
44-h- $^{44}\text{Sc}^e$	2.5 (1.5)	1.8 (0.7)	5.3 (5.3)	4.4 (3.3)	6.9 (6.9)	6.4 (6.4)
59-h- $^{44}\text{Sc}^m$	2.16† (1.1)	4.5 (2.7)	4† (4.4)	6.4 (6)	5.52 (6.7)	7.3 (10)
84-d- ^{46}Sc	0.96 (1.1)	2.08 (3.5)	1.6 (2.9)	3.2 (7.2)	1.91 (4)	3.31 (8)
44-h- ^{46}Sc	0.17* (0.2)	0.84* (3)	0.53 (1.4)	1. (3.7)	0.55 (2)	0.95 (4)
12-h- ^{42}K	----- (0.14)	----- (0.46)	----- (0.84)	2.14* (1.1)	1.62 (2.4)	2.2 (4.2)
22-h- ^{41}K	-----	-----	0.4* (0.4)	0.75* (1.1)	0.55* (1.5)	0.92 (2.3)
1.8-h- ^{41}Ar	$\approx 0.08†$ (0.03)	----- (0.03)	----- (0.14)	0.23† (0.39)	0.22* (0.7)	0.51* (1.3)
$\Sigma(\text{mb})$	304. (234)	311. (208)	312. (303)	310. (286)	223. (205)	208. (180)
R(obs./calc.)	1.30	1.50	1.03	1.08	1.09	1.16

($\pm 50\%$). Values calculated using the latest ISOBAR version of the VEGAS intranuclear cascade code are given in parentheses. In general, the calculated values agree quite well with the measured results for 190 and 350 MeV, but not for 100 MeV. The most obvious disagreement occurs for the high-yield products, $^{57,58,61}\text{Co}$, ^{54}Mn , and ^{51}Cr , at 100 MeV.

The ratios of the measured cross sections $\sigma_{\pi^-}/\sigma_{\pi^+}$ are generally greater than unity for neutron-rich products and $\sigma_{\pi^+}/\sigma_{\pi^-}$ greater than unity for neutron-deficient products at all three energies, indicating the importance of pion absorption even at the higher energies. These ratios are similar at 190 and 350 MeV where pion inelastic scattering is a strong contributor. At 100 MeV, absorption is apparently the dominant reaction mode and these ratios are noticeably enhanced from those at the two higher energies. These results will be presented and discussed at the Washington meetings of the American Physical Society.

It is noteworthy that the larger total cross sections for the measurements at 190 MeV still persist at 100 MeV. This is in agreement with the total pion cross section results for iron, tin, and lead (large-A targets) reported by Carroll *et al.*⁵

Proton Scattering Survey on HRS (Exp. 139) (LASL, Northwestern Univ., Univ. of Minnesota, Univ. of Oregon, Univ. of Texas, UCLA)

This experiment received its first beam during Cycle 11 and data were taken for all of the even isotopes of nickel. Most of the cycle was spent on facility development such as calibrating beam current monitors, spectrometer solid angle, and hardware associated with the scattering chamber. The particle identification system worked well up to average beam currents of ~ 40 nA. Figure XI-7 shows an on-line spectrum at this current for a spectrometer setting of 1 GeV/c which allows p, d, T, ^3He , and ^4He . The ordinate is the minimum of the geometric means of scintillators S_3 and S_4 for an $S_3 \cdot S_4 \cdot S_6 \cdot S_8$ coincidence requirement. There were no ^3He or ^4He particles observed for more than 10^6 protons. An energy resolution of 80 keV at 800 MeV was obtained with the full phase space from the accelerator and the nominal acceptance solid angle of the spectrometer. A typical on-line spectrum at $\theta_L =$

Fig. XI-7.

Corrected time-of-flight for ~ 5 -m separation between S_6 and S_3 vs the minimum of the geometric mean pulse heights of S_3 and S_4 . There are $>10^6$ protons in the proton volume. Although ^3He and ^4He are kinematically allowed and would fall within the boundaries of the plot, none are observed. The average proton beam current here was ~ 20 nA for a 170-mg/cm^2 target thickness.

25° for ^{60}Ni after peak-fitting the ground state 0^+ (FWHM = 107 keV) is shown in Fig. XI-8. The other strong peaks are the 2^+ and 3^- (FWHM = 107 keV) located near the center of the focal plane). The first attempt at an angular distribution resulted in data from 16 - 25° and some problems with the scattering chamber. These should now be remedied and we expect to attempt a full angular distribution during Cycle 12.

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

The data taking for this experiment was completed in Cycle 11 with a total of 351 h of beam time. Data were taken with three different target thicknesses to eliminate photon conversion as a

source of electron-positron pairs and with two different copper converter thicknesses to permit the normalization of the data. It was found that accidental coincidences were more of a problem than anticipated; the various accidental coincidence rates were directly scaled to facilitate their subtraction. In addition, data were taken at three incident beam intensities to enable us to verify that accidental coincidences are being treated correctly.

Preliminary results will be presented at the Washington meetings of the American Physical Society.

Study of the (π^-, n) and $(\pi, \pi p)$ Reactions in $^3,4\text{He}$ and Heavier Nuclei by Detecting Recoiling Deuterons and Tritons (Exp. 245)

(LASL, Univ. of Virginia, Northwestern Univ., Univ. of Texas at Austin, Carnegie-Mellon Univ., New Mexico State Univ., Uppsala Univ.)

In this experiment, we have studied charged particles (p, d, t) from π^- induced reactions in ^3He . The detector was a simple device of a wire chamber and plastic scintillators with which p, d, and t could

be nicely separated (see Fig. XI-9) and which provided adequate angular and energy information. A cryostat was used to provide liquid ^3He and ^4He targets.

For the purpose of calibrations, we measured elastic pion scattering for which accurate cross sections are available. The beam-monitoring system was calibrated by measuring the yields of $\pi^- + p$ scattering in the energy range $T_\pi = 89$ to 290 MeV; the target thicknesses were checked by measuring the yields of $\pi^+ + {}^3\text{He}$. This will allow the determinations of absolute cross sections of an overall accuracy of $\sim \pm 10\%$.

Experiment 245 has received beam time during Cycles 9, 10, and 11. The data analysis was started directly after the production period and it is nearing completion for the data on the two-body final states. For the ${}^3\text{He}(\pi^-, n){}^2\text{H}$ and ${}^4\text{He}(\pi^-, n){}^3\text{H}$ reactions we have extended angular distributions ($\theta_{\text{c.m.}}^{\text{c.m.}} = 16$ to 150°) at six incident energies ($T_\pi = 50, 100, 150, 200, 250,$ and 290 MeV). At a few angles, data are available at each 25 MeV which will provide for excitation functions at fixed momentum transfers. For the (π^-, n) reaction we have thus reached the goal of carrying out a comprehensive study in the domain of the (3,3) resonance. The reaction ${}^3\text{He}(\pi^-, \pi^0){}^3\text{H}$ was

Fig. XI-8.

Proton spectrum for ^{58}Ni at $\theta_{\text{LAB}} = 9^\circ$ showing one delay-line segment with ~ 15 MeV of excitation. The elastic peak has $> 50\,000$ counts and the first 2^+ state has ~ 1000 . The first-order resolution observed on this on-line plot was 100 keV for 800-MeV incident protons.

Fig. XI-9.

Density plot of mass vs energy loss in plastic scintillator.

observed in the forward hemisphere for the highest incident energies where the triton is ejected with sufficient energy to be detected ($E_t \gtrsim 30$ MeV). The kinematics region of observation is, of course, limited although we shall be able to obtain partial angular distributions (such as covering $\theta_\pi \approx 65$ to 145° for $T_\pi = 290$ MeV). The analysis of the two-body final states should be completed in a few months and then we shall try to extract information on multibody final states, e.g., $(\pi, \pi p)/(\pi, \pi d)$, which also were observed in the experiment.

Studies of π^+ Scattering at 50 MeV from Light Nuclei (Exp. 246)

(Carnegie-Mellon Univ., LASL, Univ. of Virginia, Univ. of Colorado, New Mexico State Univ.)

The analysis of the data for extraction of the 50-MeV π^+ elastic scattering cross sections on ^{12}C , ^{16}O , and ^{56}Fe as well as for inelastic scattering to the ^{12}C (4.44 MeV, 2^+) state is nearly complete. The new ^{12}C data show $\sim 30\%$ larger cross sections at back angles when compared to our previous measurement⁶ but the position of the minimum and the qualitative interpretation of the data remain unchanged. The ^{12}C best-fit parameters b_0 and b_1 for a Kisslinger model optical potential when used to calculate angular distributions for ^{16}O and ^{56}Fe yield predictions in good agreement with the measured elastic differential cross sections. A similar calculation for inelastic scattering to the ^{12}C (4.44 MeV, 2^+) state using a macroscopic E2 deformation parameter $\beta = 0.56$ is also in good agreement with the measured angular distribution. The analysis of the remainder of the data for elastic scattering on ^{28}Si , ^6Li and the detailed comparison of ^{12}C and ^{13}C are currently in progress.

Distributions of Products from Interactions of Stopped π^- with Several Medium- and Heavy-Mass Nuclei (Exp. 247) (LASL)

Relative yields have been determined by activation methods for 21 radioactive spallation products resulting from the interaction of stopped π^- with ^{181}Ta targets. Two exposures, one for two hours and

one for four hours, have been carried out at the LEP channel. The pions were stopped in the 1.4 g/cm^2 tantalum foils by slowing down 80-MeV π^- with appropriate graphite degraders; the experimental methods used and the spallation-product yields for copper targets were reported in a previous quarterly report (LA-6553-PR, p. 95).

The preliminary spallation-product yields from tantalum are given in Table XI-III. These yields are normalized to unity for the ^{175}Hf yields. On the basis of an earlier low-intensity run where the number of π^- stops was counted with a scintillator telescope, we estimate the absolute percentage yields per pion stop for ^{175}Hf is $10 \pm 2\%$. The relative yields calculated with the latest version of the VEGAS code for stopped π^- interactions are also given in the table. These calculated results show higher yields for the large ΔA products than do the measured

TABLE XI-III

RELATIVE SPALLATION YIELDS FROM STOPPED NEGATIVE PIONS ON TANTALUM

Nuclide			Measured	Calculated
16-h	^{170}Hf	I ^a	0.41	0.34
12-h	^{171}Hf	I	0.51	0.63
1.9-y	^{172}Hf	I	0.67	1.1
24-h	^{173}Hf	I	0.74	1.2
70-d	^{175}Hf	I	1.00	1.00
52-m	$^{177}\text{Hf}^m$	I	0.0066	≤ 0.45
29-d	$^{179}\text{Hf}^m$	I	0.027	≤ 0.001
1.4-d	^{169}Lu	C	0.33	0.58
2-d	^{170}Lu	I	0.25	0.71
8.2-d	^{171}Lu	I	0.33	0.81
6.7-d	^{172}Lu	I	0.34	0.86
512-d	^{173}Lu	I	0.36	0.63
142-d	$^{174}\text{Lu}^m$	I	0.23	≤ 0.49
6.6-d	^{177}Lu	I	0.055	0.07
57-h	^{166}Yb	I	0.048	0.08
31-d	^{169}Yb	C	0.39	0.99
4.2-d	^{175}Yb	I	≤ 0.046	0.01
30-h	^{165}Tm	C	0.023	0.07
7.7-h	^{166}Tm	I	0.008	0.14
9.3-d	^{167}Tm	C	0.19	0.46
93-d	^{168}Tm	I	0.015	0.15

^a The I or C refer to independent yield or cumulative chain yield.

results, indicating the model places more excitation energy into the interaction than actually occurs.

Measurement of p, d, t Production in Backward High-Elasticity p-Nucleus Interactions (Exp. 256)

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

This experiment, the first on HRS, was successful in acquiring useful data with about six shifts of tuneup and six shifts of running. The tuneup time was spent largely on developing a sufficiently clean trigger to enable measurements down to the nanobarn level. Both for triggering and TOF in the relativistic range, the most useful development was inclusion of the "jaw" counters between HSBM01 and HSBM02. A new scintillation counter was added close to the front delay-line chamber, near the spectrometer focal plane. This counter provides a useful extension of the TOF path and has a smaller acceptance for background events than the originally planned back counter sets. The most persistent experimental difficulty appears to be in measurement of beam current and correction for system dead times (often 50%).

Data were taken on targets of ${}^6\text{Li}$, beryllium, carbon, and tantalum at spectrometer angles of 100° and 158° , the largest angle which appeared to be safely attainable at that time. At 100° , protons off ${}^6\text{Li}$ were clearly detected out to 1000 MeV/c, close to the elastic limit. Further processing of the computer tapes will be necessary to separate valid from background events at the elastic limit, 1052 MeV/c.

The data at the high momenta show that the cross section *per target nucleon* for backward p, d, t production *increases* with nucleus atomic weight, which is an antiperipheral behavior, and in fact shows that even with momentum transfers of 2 GeV/c, there is a "cooperative" effect among nucleons in the struck nucleus. A model has been proposed with a spectator-like residual nucleus recoiling with negligible excitation, emitting a virtual p, d, or t that receives sufficient energy from the beam proton to emerge as the observed real particle. This model, with several simplifications in the kinematics, is capable of putting data points from

all nuclei at one angle on the same exponential line with the abscissa interpreted as the exchanged virtual momentum k . Figure XI-10 shows the results from 100° in this reduced form. A possible interpretation is that the Fermi distribution of momenta within the nucleus is parallel to this observed line, i.e., the high-momentum portion of the nuclear wave function is proportional to $\exp(-k/k_0)$, $k_0 = 85 \text{ MeV/c}$.

Fig. XI-10.

Relative cross section per nucleon for inclusive proton scattering from nuclear targets at 158° . The abscissa k is a function of incident momentum p , scattered momentum q , and target atomic weight M , and is computed assuming a nucleon-exchange mechanism with the residual unexcited nucleus recoiling with the kinematically possible minimum momentum k . This transformation basically gives a recoil factor $1 + m_p/M$ which equalizes per-nucleon cross section.

Proton Scattering from $^{12,13}\text{C}$, $^{58,60,62,64}\text{Ni}$, and ^{208}Pb (Exp. 139)

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

Elastic and inelastic scattering data from 800-MeV proton bombardment of $^{12,13}\text{C}$, $^{58,60,62,64}\text{Ni}$, and ^{208}Pb have been obtained using the HRS over the laboratory angular range $15\text{--}25^\circ$. Figure XI-11 shows a typical energy spectrum for $p + ^{208}\text{Pb}$ at 25°_{lab} . The energy resolution was typically 100 keV, although under particularly stable operating conditions an energy resolution of 80 keV was observed for the nickel isotopes with full phase space from the accelerator and the nominal acceptance solid angle of the spectrometer. Preliminary angular distributions and extended energy spectra ($E_x \leq 25$ MeV) have been obtained. Besides providing data which help us understand the systematics of the HRS, it is hoped that this data will be useful for exploring nucleon density distributions through better application of existing theories.

Preparation of Experiments

($p, \pi^\pm$) Reaction to Discrete Final States

(Exps. 10 and 233)

(LASL, Northwestern Univ.)

The final layout for these experiments has been completed. Two large Cerenkov counters have been installed as part of the HRS particle-identification system (PIDS) and will be tested during Cycle 12 as part of the facility development. Two smaller Cerenkov counters have been built and their support frames are now under construction. While pions have been observed with HRS, there has been no systematic checkout of the complete system, which will be ready for testing by summer.

Theory

A scheme has been devised for measuring the pion mass to a few parts per million using the attenuation of a pionic x-ray line chosen to lie on an absorption edge. The method would require a) an absolute energy measurement to several parts per million of

Fig. XI-11.

Typical energy spectrum for proton scattering from ^{208}Pb at 250°_{lab} .

the absorption edge profile — this is probably achievable with several months of effort using a double-crystal spectrometer; and b) a calculation of the electron screening correction to better than a few percent, which should not be difficult to attain. The pion beam requirements are relatively modest. However, there seems to be at present little scientific interest in knowing the pion mass so precisely, and so the scheme is not being pursued further at this time.

A novel method of testing our knowledge of Auger processes in mesonic atoms was devised and will be applied to pionic atoms in Exp. 304. The method exploits the fact that the pionic $9 \rightarrow 8$ transition can eject a K^- electron for $Z \lesssim 72$, but not for $Z \geq 72$; this affects the Auger rates emptying the $n = 9$ level, and hence $9 \rightarrow 8$, $9 \rightarrow 7$, etc., x-ray intensities, producing an intensity step as a function of Z . The foregoing assumes fast electron refilling of the vacancies produced in earlier Auger transitions; if any electron vacancies exist at the time of the $9 \rightarrow \dots$ transitions, the step will be shifted and broadened. Thus observation of the step tests the fast refilling idea and calculations of the Auger process in a way that is relatively independent of the uncertainties of the "initial distribution," i.e., the population distribution in ℓ at some high n used to start a cascade calculation.

An investigation of the role of dynamic electron screening in mesonic atom and nuclear gamma transitions has begun. For the case of E1 transitions, the

screening effect for photon emission can be related to the Rayleigh scattering amplitude (in agreement with an earlier classical calculation by Chamberlin⁷ and, in a form convenient for calculation, to the photoelectric cross section. The effect on electron emission appears to be much more difficult to calculate with any precision. The effects can be large, especially for low-energy transitions and for those cases where the nuclear (meson) transition energy is close to a discrete electron transition energy.

Programming for Experiments

An off-line analysis program was developed for Exp. 222, "Measurement of the Decay Rate for $\pi^0 \rightarrow e^+e^-$." The program was used following the December test run to plot positions and widths of hits in the new PCOS chambers. The program also includes an option for plotting interesting events on the Tektronix 4010, as is done in the on-line acquisition program.

A FORTRAN program was written to test the LRS model 2700 PCOS controller. An arbitrary bit pattern is sent to the module from the PDP-11/45 and is then read back as if it were chamber data in the form of clump widths and centers. This data is then displayed on the 4010 and can be compared with the original bit pattern. This program was used to debug the controller during the December test run.

An off-line analysis program was developed for Exp. 219. It includes routines which do initialization, tape handling, decoding of chamber hits, and plotting. The experimenter provides the UZER subroutine which reconstructs events and computes additional quantities to be plotted.

A program was written to search Exp. 221 data tapes in order to accumulate all scalers from many runs on a disk file. The scaler file can then be analyzed efficiently on an 11/45 or a CDC 6600.

A generalized plotting routine, GPLOT, was written for the 4010 using the RS4010 library of low-level calls. The user need generate only the coordinates of

points to be plotted and the axis labels. GPLOT automatically scales the data and plots it along with the frame, labels, and the numerical labels along the axes. The user has the option of choosing the scaling, the portion of the screen to be used, and the type of plot — points, connected points, or bars. Plots can be overlaid, so that a functional fit to a set of points can be shown, for example. The user can also change the plot limits by using the cursor.

A subroutine was written to decode tapes written on the IBM 729 with the KS90 controller. The routine is used on the 11/45s in conjunction with the tape package KLTape which originally read only Berkeley and TU10 tapes.

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XII. NUCLEAR CHEMISTRY

Nuclear Chemistry Laboratory

Counting Room Equipment

The WWVB radio receiver for the new master timer system has been received and appears to lock onto the NBS time signal and display the exact time. The interface required to convert its days, minutes, and seconds to decimal Time-of-Year for our laboratory slave clocks is being designed.

Some cabling problems were encountered in assembling the new dual-parameter γ - γ coincidence system described previously. These problems have been resolved. Also, programming has been started for the handler required to be resident in our PDP-11/40 to talk to the monitor within the PDP-11/03, which is the heart of the dual-parameter system.

Data Acquisition System (DAS)

The emphasis this quarter has been on hardware. Forty thousand words of additional memory, necessary to fill the PDP-11/40 to capacity, were received and installed. After several man-weeks of frustrating problems involving several memory controllers and memory boards, the full 124k memory became operational. The disk drives also received special attention. Two of our older drives were fitted with new fans, voltage regulators, and other parts to bring them up to the performance level of the third drive. The DEC made up an engineering change order (ECO) log book listing the ECO level of all modules in the system and the loading on the UNIBUS. It was found that the bus is exceeding its maximum-rated load and efforts are being made to alleviate this problem. Also, a heat problem in the cabinets became apparent. Additional fans were installed and the components were rearranged to promote better air flow.

Some software development was also achieved this quarter. The program to control the CAMAC scaler-timers has been completely rewritten to provide greater versatility while reducing core memory usage to a fraction of what was previously used. Other programs are being revised to improve their capabilities while reducing core requirements.

A new operating system has been generated to make efficient use of the full complement of memory now available.

Pneumatic "Rabbit" System

Development work continued on this system with particular emphasis on the branch that runs from the hot cell to the energetic neutron station at the A-6 beam stop. A small air by-pass line was installed around the slide gate valve of the hot cell terminal. This has the effect of reducing the springiness of the air column an arriving "rabbit" is stopped by and improves considerably the reliability of the arrival sequence, regardless of the weight of the "rabbit." The in-terminal time-delay capacitor was replaced with a transistorized delay which now eliminates the burning of relay contacts. It was found that by increasing to maximum the opening in the orifice plate of the slide gate valve at the energetic neutron station, "rabbits" as heavy as 500 g could be delivered to the station and retrieved. It was also found that the control console digital indicator at the end of the "snake" or stopping location of the target carrier in the energetic neutron station was very sensitive to electrical noise and would not track reliably. Special circuits were designed and installed to a) generate long (17-ms) pulses from the "snake" drive mechanism, b) transmit 48-V pulses instead of the original 5-V pulses to the counter, and c) filter the arriving pulses. While not yet perfect, the indicator is usable with the displayed reading being repeatable to $\pm 1.5\%$ of the actual distance of the "snake" end from the full "in" position (± 0.8 cm at ~ 50 cm where the neutron flux peaks).

The long "rabbit" line from the hot cell to the Nuclear Chemistry Lab. was checked out. What appeared to be a serious blockage in the line was successfully knocked out by repeated poundings with a fast-moving "rabbit." While the line is now clear, the transit time is a lengthy $1\frac{1}{4}$ min due to excessive air leakage at the hot cell terminal. The design of a new, heavy duty, air-tight terminal to replace the present troublesome terminals is nearing completion.

Work has now commenced on putting into operation the branch of the system intended for remote targeting in the Line B proton beam.

Work has progressed on the development of the WNR "rabbit" system. A 3.7-m-high test stand was designed and fabricated to set up the entire J-tube assembly. The hydraulic power supply was assembled in conjunction with the J-tube assembly to test all the rotating and vertical moving functions. Testing of this part of the system associated with the target crypt is about to commence.

Target Irradiation Facilities

Design has been completed and fabrication about half completed on the new in-air target box to replace the radiation-damaged box in the Nuclear Chemistry Cave at the end of Line B. This facility will be checked out and installed during the next quarter.

A small instrument trailer was provided north of Area B for the nuclear chemistry targeting activities on proton Line B. The TV monitor for viewing the fluorescent screen in the in-air target box, the controls for remotely inserting a target in the proton beam, and the controls for water flow to water-cooled targets (used for Exp. 150) are now located in this trailer.

Theoretical Support

The VEGAS Intranuclear Cascade Program

The breakup of the nucleus from stopped π^- is being investigated. The model used is that the stopped pion is captured on two nucleons in the nucleus, giving up its rest energy to these two nucleons. The two nucleons are then followed with the VEGAS intranuclear cascade program. The crucial initial step is to determine from which pionic orbitals the pion is most likely to be absorbed. Estimates have been made of the relative probability of absorption from different pionic orbitals.¹ This information has been used to improve the stopped pion calculation. In addition, more realistic nuclear densities are used. Up to the present, the VEGAS intranuclear cascade program has used a half-radius equal to $1.07 A^{1/3} \times 10^{-16}$ m, where A is the atomic mass, and a skin thickness of 2.4×10^{-16} m for all nuclei. In the future the option of inputting the experimental half-radius and skin thickness will be open to the user.

The spallation of both ^{181}Ta and copper from stopped π^- has been calculated with these improvements. The agreement with the experimental data² is good and is shown for ^{181}Ta in Table XI-III of this report (see p. 89). There are disagreements which tend to suggest that less energy is deposited in the nucleus than the model would suggest.

Recent calculations of spallation products for energetic $\pi^\pm$ with energies of 100, 190, and 350 MeV are compared to recent experimental data³ (see Table XI-II, p. 86 of this report). The agreement with the data is good, although the total measured cross section is ~ 3 to 9% higher than the calculated cross section for the 190- and 350-MeV cases for π^+ and ~ 8 to 16% higher for π^- . For the 100-MeV case, the experimental data is $\sim 30\%$ higher for π^+ and $\sim 50\%$ higher for π^- .

Comparison of calculated cross sections with 180- and 300-MeV $\pi^\pm$ plus ^{197}Au experimental data shows an even larger discrepancy,⁴ the data giving $\sim 20\%$ more cross section for π^+ and $\sim 44\%$ more for π^- . One possible explanation is that the average nuclear potential that the pion feels is important in the preparation of the pion in the nucleus. To date this has been neglected in the intranuclear cascade calculations, mainly because of uncertainties about the pion potential inside the nucleus. However, the time has come to put in the best available information about the pion potential that is being learned from recent elastic-scattering data on various nuclei.

A paper is in the process of being written which compares many calculations based on the isobar model of pion reactions with experimental particle spectra and spallation cross sections measured in pion-induced nuclear reactions.

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XIII. PRACTICAL APPLICATIONS OF LAMPF

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

Pion Biomedical Program

Treatment Planning

Primary emphasis during this period was placed upon improving the accuracy of the dose model in PIPLAN, the treatment planning computer program. Generally, good agreement with experiment was obtained for water phantoms and collimated beams, but when inhomogeneities were introduced, discrepancies were noted. The adjustable physical parameters in the code were varied to improve predictive capability. Since in most practical treatment setups, one or more air gaps may exist between the fixed-range attenuators and the dynamic range shifter or the bolus, the code has been extended to account for multiple scattering and geometrical propagation through layers of diverse materials. More accurate stopping-power ratios have been incorporated for calculating the dose contributions of secondary particles.

To make PIPLAN more flexible both for general use and for comparisons with experiment, installation of many new arrays and dose distributions was completed. Commands and coding were added to create graphs on printer paper and/or microfilm and to restrict printed output to items of interest. Several computer codes have been written which evaluate biological experiments according to various models which relate the physical properties of the pion beam to biological effects. These models have already been incorporated into PIPLAN to allow treatment-planning calculations to proceed with the most current biological results.

Additional activities included participation in the first treatment-planning intercomparison of pions, x rays, neutrons, protons, and heavy ions. In this study, four typical deep-seated tumors were to be treated by each type of radiation. Preliminary results were reported at the Radiological Soc. of

North America/American Assoc. of Physicists in Medicine meeting in November. Also reported were current PIPLAN calculations compared to PION1 calculations and various inhomogeneity experimental data.

Clinical results at LAMPF have prompted a study of dose distributions near interfaces of dissimilar tissues such as bone and muscle.

Biomedical Experiments

The LAMPF biomedical channel was operated for 10 experiments during the last quarter, with results submitted on the following:

●Visualization of Stopping Pion Distribution (Exp. 215) (LBL, LASL)

Visualization of the stopping pion distribution using high-energy gamma rays was recently studied. The experimental approach involved the use of a uranium slit collimator, γ -ray converter, and MWPCs to determine the trajectory of the gamma ray. Several scintillator counters were employed to reject charged particles, reduce events resulting from the large neutron background, and establish a γ -ray energy threshold. On-line computer analysis was used to determine the stopping pion depth distribution in a polyethylene target. The spatial resolution of the technique was <0.5 cm. Additional experiments are planned.

●Pion Activation of Tissue (Exp. 239) (LASL, Tel Aviv Univ.)

The purpose of this research is to study the feasibility of using the induced β^+ activity of tissue for *in vivo* pion dose localization. The experimental work is now essentially complete. Lead collimators have been used with several 78-MeV beam tunes. Thick targets, consisting of many stacked slabs, were employed. Targets of graphite, BN, H_2O (in gelatin), and tissue-equivalent liquid were irradiated four or five times for 20 min each. After each bombardment, a maximum of five slabs were counted with shielded NaI detectors. Absolute fluences were determined from known $^{12}C(\pi^-, \pi^- n)^{11}C$ cross sections.

Preliminary results for ^{11}C activity in the H_2O target were reported last quarter (LA-6678-PR, p. 93). The fraction of incident pions surviving to the stopping region is $\sim 79\%$. The probabilities of ^{11}C and ^{13}N production per pion stopped in oxygen were found to be 1.3% and 0.57%. The distinct peak in the ^{11}C activity correlates well with the position and width of the pion star dose. The total yield of ^{11}C and ^{13}N from secondary reactions has been measured in the graphite and BN targets and appears to be small relative to direct star production of these activities. These results may indicate that an *in vivo* activation method for dose localization is possible. We are also comparing the measured yields to intranuclear cascade calculations, which specifically take into account pion capture probabilities from different atomic orbitals.

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

Extensive dosimetry measurements were made on a beam used for treatment of subcutaneous and head and neck tumors; The beam has transverse dimensions of 8 cm by 10 cm, and a penetration of 15 g/cm^2 in H_2O . The dynamic range shifter was used to spread the beam to 8 cm in depth (Fig. XIII-1). The downstream portion of the peak is $\sim 70\%$ of the front edge, to compensate for the RBE at the back edge of the beam being 1.4 times greater than that at the front edge. A proton current of $76 \mu\text{A}$ on

Fig. XIII-1.

Depth-dose curve of range-shifted pion beam used for patient treatment in Cycle 11.

the Biomed target gives a peak dose rate of $\sim 3 \text{ rad/min}$ for this treatment beam.

In order to tailor the beam to the treatment volume, collimators and compensating boluses were inserted between the patient and range shifter as shown in Fig. XIII-2. An alginate bolus rested directly on the patient's skin so as to compensate for surface contours, and a polyethylene bolus directly above the alginate compensated for patient inhomogeneities and tumor depth variations so as to place the back edge of the treatment beam at the distal edge of the treatment volume. Above the bolus was a 3.5-cm-thick Cerrobend ($\rho = 9.4 \text{ g/cm}^3$) collimator to define the beam in the x-y plane. Slabs of polyethylene above the collimator were used for coarse shifts in the beam penetration. This hardware was arranged so as to minimize air gaps between the range shifter and patient, which in turn minimized multiple-scattering effects. In all cases

Fig. XIII-2.

Clinical hardware used for tailoring treatment beams to individual patient-treatment volumes.

the distal edge of the treatment volume was placed 100 cm below the effective edge of the final quadrupole in the Biomed channel. Because patient anatomy often left variable air gaps in the system, the dosimetry for each individual treatment configuration area was measured prior to treatment.

Substantial progress was made in the past cycle in the hardware developments for patient setups. For the first time, patients were set up in the patient staging area prior to treatment. This minimized beam-off time between patients to four minutes. A pair of new treatment couches were modified in order to allow support of patient and patient immobilization modules, support of an adjustable collimator holder, and the capability to take localization x rays prior to treatment to ensure that the patient is in the proper treatment position. Patient-immobilization modules were polyurethane whole-body casts, similar to those used at the Univ. of New Mexico Cancer Research and Treatment Center. A patient collimator holder was designed and fabricated which met the following requirements: 1) capable of xyz translational adjustment and two degrees of rotational adjustment so that the plane of the collimator is perpendicular to the incident beam and properly aligned with respect to the patient, 2) quickly adjustable, 3) able to support the ~15-kg collimator, and 4) entire assembly easily interfaceable with the treatment couch. A pair of localization lasers which define the xy axes at any z were installed in the treatment room, and a single laser with the same capability was installed in the staging area. These reference markers allowed patient setup in the staging area to be precisely and quickly transferred to the treatment room.

As treatments progress to multiport irradiations or to areas of the body where inhomogeneities are present, *in vivo* dosimetry becomes necessary in order to experimentally verify the treatment planning. For the first time, parallel opposed ports in the head and neck region were used on one patient, and the treatment planning was verified using silicon diode dosimeters as *in vivo* dosimeters within their standard deviation ($\approx 25\%$). The diodes (on loan from M. D. Anderson Hospital and Tumor Institute) were found to exhibit the following properties in the pion beams:

1. Diode response is correlated to dose via the same relation found to hold for fast neutron beams,¹ $D = K \ln(V_f/V_i)$, where D is the dose

in rads, K is the sensitivity, V_f is the diode forward voltage for a 25-mA current 24 h after irradiation, and V_i is the diode forward voltage for a 25-mA current before irradiation.

2. The diode sensitivity is approximately a factor of 4 less than that observed in neutron beams.
3. The sensitivity constant K varies with position in the pion beam as seen in Fig. XIII-3.

These results have prompted a more intense effort in this area with immediate plans to look further at silicon diodes and in addition to look at LiF thermoluminescent dosimeters and activation foils.

The biomed range shifter was used for the first time in late November to treat patients with large-field pion beams. A simplified operator control panel and improved hardware and software were installed for this purpose. Range-shifter sweep functions can now be calculated on the Biomed PDP-11/45 computer and transferred via paper tape to the M6800 microprocessor RAM (random-access memory). This allows functions (or depth-dose curves) to be changed rapidly, while maintaining dedicated range-shifter control via the M6800. The new control panel allows the channel operator to choose either M6800 or PDP-11/45 control of the range shifter, and also allows the simple selection of any one of several range-shifter functions. The LED displays inform the operator of the status of all components. All systems performed well with no breakdowns or malfunctions of any kind.

Fig. XIII-3.
Variation of diode sensitivity with depth for a pion beam with a narrow momentum spread.

The new range-shifter design (by D. Liska, MP-9, and J. Leavitt, MP-12) is nearing completion and fabrication should begin shortly. The new range shifter will have a longer stroke than the present model (to allow treatment of larger tumor volumes), but will be substantially smaller in total volume. This will facilitate patient setup and handling. We are also investigating the possibility of filling the range shifter with higher density fluids to further increase the effective tumor volume which can be treated without increasing the overall size of the package.

New range-shifter sweep functions are being developed for use in radiobiological and clinical experiments. Clinical data seem to indicate that, for fractionated treatment schedules, increasing the slope of the depth-dose curve (that is, the ratio of proximal dose to distal dose) might result in a more uniform biological response. As a result we are developing range-shifter sweep functions which produce more uniform pion stopping distributions (and hence more sloped depth-dose curves). As an alternative to the histogram-like sweep functions presently in use, we have developed a computer program which generates smooth parabolic functions. These new functions will present less strain on the hydraulic system and should result in more accurate tracking, as well as higher rep-rates.

Equipment has been built to measure the effects of inhomogeneities on pion dose distributions. A special phantom has been built for use with a thin-walled (30- μ m) extrapolation chamber. Perturbations in dose caused by inhomogeneities in both density and atomic composition will be measured. These data should be useful for treatment planning in regions of the body containing bone and/or air cavities.

Activation detectors are being developed for *in vivo* dosimetry. Some of these detectors will be used to measure the pion doses, and others will be used to measure only the neutron component of the dose.

•Therapy Beam Development — Micro-dosimetry (Exp. 272) (LASL)

Dose per pion and energy per ion pair (*W*-values) for pions have been obtained previously from theoretical estimates. Measurements of both quantities, along with the beam fluence, were performed at the Biomedical channel at LAMPF.

A system has been developed to measure the number of pions per unit area by use of activation techniques. Disks of plastic scintillator are placed in the beam and irradiated for several minutes. After the irradiation, an off-line measurement is made to determine the β^+ activity from ^{11}C produced in the plastic. Cross sections² for the reaction $^{12}\text{C}(\pi^-, \pi^-n)^{11}\text{C}$ were then used to determine absolute fluences. An initial check on the relative precision of this method showed it to be reproducible to $\sim \pm 3\%$. This value could be improved, if necessary.

The *W*-values were determined in the following manner: A parallel plate ionization chamber, 2.5-cm-diam, was sandwiched between two disks of plastic scintillator of the same diameter. The total charge produced in the gas volume of the chamber during irradiation was measured, and the total fluence through the gas was determined by the technique described in the previous paragraph. Data were obtained with the chamber filled with air, nitrogen, argon, methane-based tissue-equivalent gas, and propane-based tissue-equivalent gas; preliminary *W*-values for these gases for 78 ± 2 -MeV π^- are 35.8 ± 0.7 MeV, 36.2 ± 0.7 MeV, 27.5 ± 0.6 MeV, 35.1 ± 0.8 MeV, and 28.1 ± 0.4 eV per ion pair. Only the relative uncertainties are given. The absolute uncertainties include uncertainties in incident energy of the pions, stopping powers, and activation cross sections. These values also include contributions from delta rays from the walls of the ion chamber. It is not known to what extent this effect could alter the values given. We have calculated analytically the fraction of the total charge in the ion chamber produced by delta rays from the walls. Preliminary results are shown in Fig. XIII-4.

Fig. XIII-4.

The relative contribution of delta rays to the energy spectrum of 80-MeV π^- passing through a parallel-plate detector.

Since the last report, two new techniques have been developed to obtain microdosimetric spectra at high average beam intensities, and data have been taken using both methods. The high intensity of the biomedical beam (typically about 10^8 π /s/cm²-average) necessitates using the low-intensity 1-in-10 pulses for counting experiments. Even with these low-intensity pulses, pileup is still a problem. For this reason, and in order to collect data at the maximum count rate possible, the pile-up rejection system shown schematically in Fig. XIII-5 was developed. This system has a typical resolution of <200 ns, the present limitation being the response time of the detector itself.

This system, along with continued development of low-noise fast-recovery preamplifiers and LET chambers capable of having the bias voltage pulsed in coincidence with the 1-in-10 pulse, has allowed us

Fig. XIII-5.

Pile-up rejection system for microdosimetry measurement.

to take data with beams of high average intensity. To check the reliability of the new methods, data have been taken in the plateau region of various beams and in the Bragg region. The agreement with data reported in a previous progress report is generally satisfactory, although some differences have been observed below lineal energies of 1 keV/ μ m.

Monte Carlo programs have been written for generating microdosimetric spectra corresponding to the experimental data. The calculations take into account straggling distributions of path lengths in the detector and gas multiplication. We are now working to include the effect of delta rays. The program requires as input the energy spectrum for each particle type. A comparison is shown in Fig. XIII-6 of the calculated spectrum for 168-MeV/c π^- and experimental data. It is believed that we can now calculate accurately the response of the detector to monoenergetic particles. We are presently doing calculations which include the scattered pions, secondary protons, and heavier particles. These results should be available soon.

•Therapy Beam Development — Solid-State Detectors (Exp. 273) (LASL)

The studies of pion beams with thin silicon detectors has required the handling of a variety of count rates associated with different types of doses. The

Fig. XIII-6.

The dose per logarithmic interval of lineal energy vs lineal energy. The experimental data were obtained at LAMPF by J. Dicello et al.

scheme adopted was to use the 1-in-10 low-intensity pulse for the total dose produced by the incoming beam and switch to the full-intensity beam for the measurement of the LET distributions of the star products. An essential part of this technique is to use a silicon detector as a monitor that handles the counting rate of either beam. All scalers and the analyzer were gated by either beam as the occasion necessitated. Also, the size of the detectors has now been reduced to 2-mm diam so that the counting rates of the incoming pions are greatly reduced.

Figure XIII-7 is a photograph of the experimental arrangement used under the range shifter. The rubber hose carries the alcohol from the cooler to coils in the phantom and back. The cooling is used to reduce the noise in the solid-state detectors. The movable probe can be seen attached to the arm of the scanner; the fixed probe is the monitor. For ease of alignment on successive runs, the whole system was mounted on tracks.

An example of the data is shown in Fig. XIII-8. Low-LET is the dose due to passing pions, muons, and electrons; medium-LET is the dose due to protons, deuterons, and tritons; and high-LET is the dose due to alpha-particles, ^3He nuclei, and recoils.

Figure XIII-9 is a comparison of the shape of the total dose as measured by the silicon detector with the total dose measured with the primary beam monitor. For this beam, the total dose distribution was sloped in depth. The sloping in depth was an at-

Fig. XIII-7.

Experimental arrangement for characterizing pion therapy beams with thin-silicon detectors.

tempt to compensate for the increased RBE in the distal region of this distribution. This beam was used with two patients and it illustrates the complexities of pion radiotherapy. The low-LET component and the high-LET component are nonuniform distributions. The calculated stopping distribution for this beam is in good agreement with the high-LET component observed in this experiment.

Practical Applications Experiments

•Materials Analysis with Muonic X Rays (Exp. 100) (LASL, Washington State Univ.)

We are in the last stages of analysis of the data from Exp. 100. The raw muonic x-ray spectra are being fit and the peaks integrated using the Berkeley

Fig. XIII-8.
Energy distribution of the dose in a pion beam.

code SAMPO. The intensities are being corrected for counter efficiency and self-absorption in the target. The data from the dilute solutions (NaF , KCl , CuSO_4 , and AgNO_3) will be analyzed in terms of investigating detection limits as a function of concentration and time of irradiation.

Effort is now being directed toward identifying additional problems suited to the unique capabilities of the technique. Possibilities include:

- Investigation of the feasibility of verifying stoichiometric ratios in objects that have been formed by hotpressing powdered compounds such as MgAl_2O_4 and CoCrS_4 .
- Identification (characterization) of archaeological materials on the basis of major element analysis in those cases where trace element analysis does not provide clear-cut identification.
- Study of the usefulness of muonic x rays in providing chemical information about sulfur bonding in coal (the question as to whether sulfur is bonded in pyrite or in organic molecules) and about uranium oxidation states in ore (the question as to whether uranium is in the +4 or the +6 oxidation state).

Fig. XIII-9.
Comparison of the total dose as measured by a silicon detector and an ionization chamber beam monitor.

• Trapping of Positive Muons at Defects in Metals (Exp. 266) (Sandia Labs., LASL)

Experiment 266 is a study of muon spin relaxation (μ SR) in FCC metals with emphasis on determining the temperature dependence of the muon spin relaxation (or depolarization) rate. Such a program may

illuminate the process of muon diffusion and trapping in metals and thus should prove useful for characterizing of defects in materials.

A study was initiated to design an air core magnet to provide the muon-spin precessing field. High uniformity (a few parts in 10^5) for magnetic fields up to several kG is required. A computer code was written to calculate the field components in a region near the symmetry point of a Helmholtz pair with a uniform current density. This code was used to optimize the size, radii, and coil gap in order to maximize the field homogeneity. In addition, a more generalized magnet optimization program (called CSD) was obtained from L-Division at LASL. These programs will be used to design a high-field magnet system for future μ SR experiments.

For the upcoming experiment, a Helmholtz pair and power supply have been obtained from Sandia Laboratories capable of producing a field of several hundred gauss. The field uniformity of this system has been measured to be a few parts in 10^4 over a volume of $\sim 27 \text{ cm}^3$, in agreement with the results of calculations.

The cryogenic and temperature-regulation system for cooling the samples has been assembled and made to work satisfactorily. This system consists of a liquid ^3He transfer refrigerator (Heli-Tran) and a heater coil to allow temperature regulation over the range from 2 K to 300 K. To heat the samples above 300 K, a 750-W spot heater located at the focal point of a parabolic reflector is being tested. The light beam from the lamp is focused on the sample using quartz and pyrex lenses.

The data-acquisition program Q has been successfully interfaced to a Tennelec "PACE" analog-to-digital converter. The development of both the on-line and off-line data analysis programs is in progress. In addition, a computer program has been written to generate simulated μ SR data approximating that which is expected during the actual experiment. This program, along with the LASL generalized-least-squares fitting program (LSMFT), has been used to determine how the accuracy of the determination of the μ SR time is affected by the length of time allowed for the decay positron after a muon stops. The results indicate that for the relaxation times of present interest (1-20 μs), the accuracy improves rapidly as the waiting

time increases up to about two muon lifetimes (4.4 μs). Waiting longer does not significantly improve the accuracy. Further optimization studies are in progress.

●Radioisotope Production (Exp. 267) (LASL)

The radioisotope production facility is now operational, and tests with molybdenum targets in the stringers were successfully carried out during the past quarter. The remote-handling equipment functioned well and targets were inserted and retracted with proton beam on.

●Proton-Induced Radiation Damage (Exp. 269) (LASL)

Apparatus has been designed for a proton irradiation port (PIP) to be located at the former "fast rabbit" port at Target A-1. The new facility will allow thin-sample irradiation at very high-current densities. Several different samples may be assembled in one target and radiation damage studies will be carried out at very high levels of damage rate.

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

Proton detectors and the computer-controlled scanning mechanism are being designed for this experiment. Beam tunes for P^3 have been formed which will provide a 1.5-mm-wide beam spot and a 0.1% momentum bite.

A variety of new reconstruction algorithms is being made available through the implementation of the SNARK program from the State Univ. of New York at Buffalo. These algorithms are chiefly of the iterative type (ART, SIRT, etc.) which should be particularly useful in producing reconstructions from a limited number of views. An example of such a situation would be the determination of the two-dimensional phase space of a particle beam from a small number of beam-profile measurements.

●Modification of Superconducting Characteristics with Proton Irradiation (Exp. 301) (LASL)

As a prelude to Exp. 301, room temperature proton irradiations were made of three types of Nb₃Sn multifilamentary cables and one type of NbTi multifilamentary cable. The maximum integrated proton flux was $\sim 10^{16}$ protons/min. Measurements have been made at the critical temperature and current in the samples with indications that in the most heavily irradiated samples there were shifts in these quantities.

Technology Transfer

A close collaboration continues with the Univ. of New Mexico Cancer Research and Treatment Center in the applications of localized current field (LCF) techniques for localized tissue heating. A protocol has recently been approved at the Univ. of New Mexico for clinical trials of radiation and heat on carefully selected patients. The LASL will continue to supply various instruments and technical assistance to the Univ. of New Mexico in this program. An improved temperature controller has recently been completed for use at the Univ. of New Mexico Research and Cancer Treatment Center.

A complete LCF unit (controller and rf source) has been loaned to the Washington Univ. School of Medicine for use in the hyperthermia investigations which are beginning at that institution. A control unit will be loaned to Tufts Univ. for evaluation in a similar program.

During the past quarter, effort has been expended in the experiments to evaluate the use of portable LCF equipment in the treatment of "cancer-eye" (usually squamous-cell carcinoma) in cattle. Apparent remission rates have increased to $\sim 90\%$ in the most recent tests, probably as a result of improved equipment and technique. Eye immobilization methods have been simplified. As a result, several ranchers have treated the tumors after brief instructions from a veterinarian. Work continues on further miniaturization and simplification of the equipment. Experiments are done in collaboration with the New Mexico Hereford Association and the Cooperative Extension Service of the New Mexico State Univ.

The Univ. of New Mexico School of Medicine has recently approved a protocol for the investigation of a possible correlation between surface bioelectric potentials and breast carcinoma. LASL instrumentation will be transferred to the Univ. of New Mexico Cancer and Research Treatment Center for this work, probably during the next three months.

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XIV. PIGMI PROGRAM

(Summarizes work performed under the auspices of the National Cancer Institute.)

The following report is taken from the semiannual report for the PIGMI program at LASL, submitted to the NCI. Much of the work reported herein was performed by other MP-Division groups and may represent a duplication of the reports presented elsewhere in this report. However, their work is included in this report to give readers the complete background of the PIGMI program.

PIGMI Program

The PIGMI program at LASL supported by the National Cancer Institute, Division of Research Resources and Centers, of the Department of Health, Education, and Welfare has just completed the first six months of a three-year program to develop technology for the most suitable Pion Generator for Medical Irradiations (PIGMI). The program is progressing well on a number of parallel activities designed to converge during the next two years in the testing of the major innovations in proton-linac technology espoused by the PIGMI program.

Some of the activities reported here are partially supported by the ERDA Division of Physical Research in recognition of the applicability of these activities to the LAMPF program as well as the PIGMI program. In all cases the talents that have been brought to bear on these activities are talents that were selected and trained for the design and fabrication of LAMPF. We remain thoroughly convinced that the PIGMI program benefits handsomely from the close proximity and association to the LAMPF program.

The major accelerator development activities supported by or of interest to the PIGMI program at LASL in the last six months are:

1. Development of the computer program SUPERFISH, the most exciting new tool for linac, klystron, and storage ring cavity design of the last decade.
2. Continued development of the alternating phase-focused (APF) linac structure, including an algorithm for the transition be-

tween the APF structure and quadrupole-focused drift-tube linac (DTL) structure, and the selection of the PIGMI prototype parameters.

3. Development of an improved version of the disk and washer (DAW) structure, including parametric studies relevant to the optimum choice of all cavity dimensions.
4. Continued development of the rf manifold theory.
5. Mechanical design of the PIGLET cavity.
6. Procurement and assembly of a 450-MHz klystron power system, and solicitation of bids for a 1350-MHz klystron to be used with the same system.
7. Continued development of permanent-magnet quadrupole lenses.
8. Evaluation of copperplating processes for linac applications.
9. Definition of the PIGMI injection parameters and solicitation of bids for 300-kV injection power supply.
10. Completion of an APF test cavity and a microprocessor-based bead-perturbation system for APF test cavity studies.
11. Design criteria and procurement of a minicomputer system for diagnostics and control of the PIGMI prototype.

The PIGMI Prototype

The major piece of equipment to be designed, fabricated, and tested under the PIGMI program is the operating prototype of the low-energy end of the proposed design, complete with a proton beam and diagnostic gear to evaluate its performance. Steady progress is being made on the design of this prototype. The PIGMI prototype involves a 250-kV C-W power supply, a proton ion source and accelerating column, a buncher cavity and solenoid lens to prepare the beam for injection into the linac, and a prototype of the low-energy portion of the PIGMI linac structure.

The PIGMI Prototype Linac Structure

The linac portion of the PIGMI prototype has recently been defined. It consists of a single tank,

loaded with 64 drift tubes, which accelerates a proton beam from 0.25 MeV to 8.9 MeV in a total length of 2.64 m. The tank is divided into four sections as shown in Fig. XIV-1.

The first section has no quadrupole lenses among its 28 drift tubes, and is entirely dependent on the APF principle for beam confinement.

The last section is essentially a scaled-down version of a conventional quadrupole-focused DTL, and accelerates the beam from 7.1 to 8.9 MeV in a distance of 34 cm for an average acceleration rate of better than 5 MeV/m.

The middle two sections form a transition between the APF section and the DTL section. In the Quad Ramp section, permanent-magnet quadrupole lenses are introduced into every other drift tube in a +0-0 configuration with the quadrupole field gradient increasing from 0 to 6 kG/cm in a distance of 64 cm. In the Phase Ramp section, the gap phases are rapidly transformed from the +60, +60, -60, -60 sequence, used in the APF and Quad Ramp sections, to a constant stable phase angle of -20°, suitable for the DTL section. The transverse and longitudinal focusing effects for each of the four sections are shown graphically in Fig. XIV-1.

The geometrical and dynamical parameters of each of the 64 cells of the prototype are given in Table XIV-I, where PHI is the phase of the rf when the design particle arrives at the center of the gap, WS and BETA are the energy and velocity of the design particle after crossing the gap, T is the transit time factor, QS is the quadrupole gradient in kG/cm, and QL and CL are the quadrupole and cell lengths, respectively.

The performance of this prototype, as calculated by PARMILA, is shown in Figs. XIV-2 and XIV-3. The acceptance of the prototype in the XX' , YY' , and ϕ -W phase spaces are shown at the top of Fig. XIV-2. It is interesting to note that the XX' and YY' acceptances are identical, a property of the APF section. Below the acceptance graphs are the X, Y, and ϕ profiles. The "scalloping" of the X and Y profiles are "in phase" in the beginning, a property of the APF structure, and "out of phase" at the end, a property of the quadrupole focusing in the DTL structure. The damping of the phase spread is evident from the ϕ profile.

Figure XIV-3 shows the progress of a 30-mA proton beam as it travels from the buncher at the exit of the accelerating column, through a solenoid

Fig. XIV-1.
PIGMI prototype focusing effects.

lens, to the linac, where it is accelerated to 8.9 MeV. The initial phase-space distributions are plotted at the top of the figure, and the final phase spaces are shown at the bottom. One can see the focusing effect of the solenoid lens on the X and Y profiles and the bunching effect of the buncher on the ϕ profile.

The definition of the linac structure for the PIGMI prototype has now reached the point where engineering studies on methods of fabrication can begin. The goal is to complete the engineering designs and to begin fabrication by about July 1.

The PIGMI Prototype Injection System

Work has begun on several portions of the PIGMI injector. Most of the activity is involved with conceptual planning of possible designs, although some specific hardware questions are being addressed.

Beams of 50 mA have been achieved using high-gradient extraction electrodes with converging geometry. These tests indicate that the LAMPF duoplasmatron can provide the beams required for a PIGMI injector, although more detailed studies of the extraction geometry are needed.

TABLE XIV-I
PIGMI PROTOTYPE PARAMETERS

LINOUT SUBROUTINE 2

RUN= 633

NC	PHI	MS	BETA	DELTA	T	QS	QL	CL	LSUM
I		.250	.023			0.000	0.000		
1	-72.00	.36	.024	-.242	.452	0.000	1.664	1.878	1.878
2	71.75	.332	.025	.239	.461	0.000	1.225	1.926	3.804
3	71.50	.294	.025	.238	.469	0.000	.755	1.320	5.124
4	-71.25	.307	.026	-.236	.476	0.000	1.278	1.355	6.479
5	-71.00	.326	.026	-.232	.484	0.000	1.836	2.076	8.556
6	70.75	.347	.027	.230	.495	0.000	1.358	2.129	10.685
7	70.50	.362	.028	.228	.503	0.000	.845	1.469	12.154
8	-70.25	.378	.028	-.226	.510	0.000	1.418	1.509	13.662
9	-70.00	.402	.029	-.223	.519	0.000	2.030	2.299	15.961
10	69.75	.428	.030	.220	.530	0.000	1.508	2.352	18.319
11	69.50	.447	.031	.219	.540	0.000	.947	1.637	19.956
12	-69.25	.466	.032	-.217	.547	0.000	1.576	1.682	21.632
13	-69.00	.497	.033	-.214	.557	0.000	2.247	2.543	24.166
14	68.75	.529	.034	.211	.569	0.000	1.676	2.615	26.801
15	68.50	.552	.034	.210	.579	0.000	1.663	1.636	28.627
16	-68.25	.577	.035	-.208	.587	0.000	1.752	1.877	30.564
17	-68.00	.615	.036	-.204	.597	0.000	2.489	2.828	33.332
18	67.75	.655	.037	.202	.609	0.000	1.865	2.903	36.234
19	67.50	.684	.038	.200	.620	0.000	1.193	2.033	38.273
20	-67.25	.714	.039	-.198	.628	0.000	1.350	2.095	40.368
21	-67.00	.761	.040	-.195	.639	0.000	2.759	3.140	43.503
22	66.75	.811	.042	.192	.652	0.000	2.075	3.223	46.731
23	66.50	.847	.042	.191	.662	0.000	1.339	2.276	49.067
24	-66.25	.885	.043	-.189	.671	0.000	2.170	2.340	51.347
25	-66.00	.943	.045	-.186	.682	0.000	3.058	3.436	54.832
26	65.75	1.004	.046	.183	.695	0.000	2.309	3.578	58.410
27	65.50	1.049	.047	.181	.705	0.000	1.503	2.541	60.951
28	-65.25	1.096	.048	-.179	.714	0.000	2.415	2.612	63.563
29	-65.00	1.167	.050	-.176	.725	0.000	3.387	3.868	67.431
30	64.75	1.242	.051	.173	.738	0.000	2.567	3.969	71.400
31	64.50	1.297	.053	.171	.748	1.500	1.686	2.835	74.235
32	-64.25	1.354	.054	-.169	.757	0.000	2.683	2.913	77.148
33	-64.00	1.441	.055	-.166	.767	-1.073	3.747	4.287	81.435
34	63.75	1.532	.057	.163	.779	0.000	2.850	4.399	85.832
35	63.50	1.598	.058	.161	.793	3.000	1.887	3.158	88.990
36	-63.25	1.668	.060	-.159	.797	0.000	2.978	3.243	92.234
37	-63.00	1.772	.061	-.156	.807	-1.810	4.138	4.744	96.977
38	62.75	1.882	.063	.153	.818	0.000	3.158	4.864	101.841
39	62.50	1.962	.065	.151	.827	4.500	2.108	3.511	105.752
40	-62.25	2.046	.066	-.149	.834	0.000	3.297	3.603	108.955
41	-62.00	2.170	.068	-.146	.843	-2.566	4.559	5.237	114.193
42	61.75	2.300	.070	.143	.852	0.000	3.430	5.366	119.559
43	61.50	2.396	.071	.141	.859	6.000	2.349	3.893	123.451
44	-61.25	2.496	.073	-.138	.865	0.000	3.662	4.007	127.458
45	-59.82	2.650	.075	-.132	.872	-3.229	4.859	5.680	133.139
46	47.92	2.855	.078	.111	.881	0.000	3.840	5.799	138.939
47	43.39	3.031	.080	.101	.888	6.000	2.950	4.527	143.465
48	-51.54	3.188	.082	-.113	.894	0.000	4.136	4.724	148.189
49	-49.12	3.407	.085	-.106	.898	-3.814	5.178	6.209	154.398
50	29.91	3.707	.089	.067	.903	0.000	4.373	6.367	160.765
51	25.28	3.972	.092	.056	.906	6.000	3.729	5.401	166.166
52	-41.84	4.201	.094	-.085	.907	0.000	4.744	5.649	171.815
53	-39.41	4.491	.097	-.078	.910	-4.478	5.563	6.871	178.686
54	11.69	4.868	.101	.024	.910	0.000	5.006	7.046	185.732
55	7.17	5.217	.105	.014	.910	6.000	4.675	6.454	192.186
56	-32.13	5.529	.108	-.059	.910	0.000	5.437	6.741	198.927
57	-29.71	5.898	.112	-.053	.910	-5.238	5.932	7.579	206.506
58	-6.42	6.309	.115	-.012	.910	0.000	5.693	7.750	214.256
59	-10.94	6.718	.119	-.019	.910	6.000	5.758	7.634	221.890
60	-22.43	7.119	.122	-.037	.910	0.000	6.162	7.946	229.836
61	-20.00	7.545	.126	-.032	.910	-5.104	6.299	8.307	238.143
62	-20.00	7.982	.130	-.031	.910	0.000	6.476	8.517	246.660
63	-20.00	8.431	.133	-.030	.910	5.680	6.654	8.753	255.413
64	-20.00	8.906	.137	-.030	.910	0.000	7.228	9.255	264.668

TOTAL LENGTH = 264.668

Fig. XIV-2.

Performance of PIGMI prototype linac structure.

The layout of the 300-kV equipment dome has been considered, and details of rack requirements, insulator spacing, and equipment layout are being organized. The required equipment for this dome is being determined, and various procurement actions are being started. A 300-kV isolation transformer has been obtained and is being refurbished. Fiber optic cables have been obtained and have been tested on the LAMPF injectors. The general design to be used for the equipment dome is fairly well established.

Specifications have been written for a high-voltage power supply to power the equipment dome. Procurement action is under way.

Fig. XIV-3.

Performance of PIGMI prototype with buncher and solenoid.

The primary problem left to be addressed in the PIGMI injector is that of the design and selection of the acceleration column and associated ion source extraction geometry. Several possible designs are being considered including a classical-cylindrical accelerating column, a conical insulator accelerating column, and an accelerating-column system using a short accelerating tube separated from the ion source. The desire for compact designs necessitates

consideration of high-voltage insulation and electric-field grading that is closer to sparking limits than that which has been used in the present LAMPF injectors.

The PIGMI Prototype Low-Energy Transport System:

The transport system shown in Fig. XIV-4 has been laid out to accommodate a single-gap buncher and one magnetic solenoid lens with additional space for beam-diagnostic instrumentation and valves. The buncher is located immediately following the accelerating column where the beam will be focused to a circular waist by the column optics. The total length of the transport system from the buncher gap to the rf surface of the accelerator is only 80 cm.

A series of beam-dynamics runs using the PAR-MILA program were made to calculate the optimum values for buncher voltage and solenoid strength necessary to tailor a circular monoenergetic beam delivered by the column for injection into the first section of the accelerator. For the purpose of these studies, the initial section of the accelerator was assumed to be the APF structure reported at the 1976 Proton Linear Accelerator Conference.

Initial transport studies were performed using "shotgun" particle distributions, and without the coupling effects in the dynamics to explore the parameter space. The beam was then more

realistically populated in five dimensions (random in X , X' , Y , Y' , and ϕ) and the effects of coupling and space charge were included. In all cases, the transverse acceptance of the transport system exceeds that of the linac.

The solenoid is located just following the buncher, leaving room for instrumentation in the second half of the transport line. This lens, having a nominal focal length of 20 cm, could be constructed in a variety of ways. One possible configuration, using a 2-cm gap with a 16.7-kG field, has been simulated numerically. Using these lens values and a buncher voltage of 2.7 kV, 61% of a 30-mA beam, having a normalized emittance $(\beta\gamma A/\pi) = 0.14$ cm-mrad, is captured and accelerated in the linac.

High-Energy Accelerating Structure for PIGMI

The drift-tube linac structure used for the proton acceleration becomes relatively ineffective at proton energies above ~ 150 MeV. Therefore, higher-frequency accelerating structures have been developed for the high-energy part of the proton linear accelerators. The main requirements on the high-frequency structures for the design of a compact proton linear accelerator for medical applications are: 1) high efficiency for the conversion of microwave power to proton beam power, and 2) small geometrical dimensions of the accelerating structure. Both requirements have a big effect on the cost of the accelerator.

The effectiveness of the accelerating structure is determined by its shunt impedance which increases in proportion to the square root of the resonant frequency. Also, the physical size of the structure decreases with increased frequency. In the early part of the high-energy section of the linac, where the acceptance must accommodate the beam delivered by the drift-tube linac, the frequency is limited by beam-dynamics considerations. Moreover, the frequency of the high-energy structure (f_H), must be an integer multiple of the frequency of the lower-energy DTL section (f_L).

In our case, f_L was chosen to be 450 MHz and f_H will be 1350 MHz, choices which represent a good compromise between shunt impedance, geometrical size, and acceptance.

There do not exist at the present time any proton accelerating structures operating at 1350 MHz. An

Fig. XIV-4.

Ion source, accelerating column, and low-energy transport system.

extensive study was undertaken to find the most effective design for a structure to operate at this frequency. Our efforts were concentrated on the study of a biperiodic cavity structure resonating in the $\pi/2$ mode, a scheme which has certain definite advantages over other configurations.

We have made extensive use of the extremely powerful SUPERFISH code, which facilitates the study of single resonant cavities as well as chains of coupled cavities.

In addition to shunt impedance, we are particularly concerned with the operational stability of the structure, insensitivity to fabrication tolerances and tuning errors, and cost of fabrication. It is well known that stronger coupling (k) between adjacent cavities reduces the sensitivity of the entire structure to fabrication errors. It is important, however, not to design a structure with strong coupling at the expense of reduced shunt impedance and increased power consumption.

At the present time we are considering the following structures:

- LAMPF Side-Coupled Structure, coupling $k \sim 5\%$.
- Ring-Coupled Structure, coupling $k \sim 10$ to 15% .
- Disk and Washer Structure, coupling $k \sim 40$ to 60% .
- Improved version of Disk and Washer Structure, coupling k 40 to 60% .

RF Manifold Progress

A chain matrix representation of an rf-manifold-powered linear accelerator has been developed, combining the coupled-circuit model for the accelerator with a transmission-line model of the manifold. The coupled-circuit model was derived from Maxwell's equations to insure that the accelerator and manifold are described in terms of fields of the same basis. From the chain matrix representation we have obtained an implicit function describing the mode spectrum of a manifold-powered linear accelerator. A second-order perturbation expansion has been derived that enables us to calculate tuning-error sensitivities and power-flow effects as a function of relative manifold-stored energy.

The PIGLET Power Test Cavity

The selection of the operating accelerating gradient is crucial to optimizing the design of a proton linear accelerator in that the gradient is intimately related to the reliability and total cost (both installation and operating) of the linac. A judicious balance of the linac length and the rf power requirements can result in consequential savings of money. Such a balance generally implies substantially higher gradients than are currently employed in operating linacs. The gradients, however, must be sufficiently conservative so as to permit continuous operation without appreciable interruption due to sparking.

Data on sparking are sparse. The most comprehensive compendium of sparking data was collected by Kilpatrick some 20 years ago. These data document the maximum fields at which sparking might occur at different frequencies in vacuum systems employing diffusion pumps. More recent advances in vacuum technology suggest that these data are now overly conservative. The Heidelberg 60-MHz and the MURA 200-MHz studies support this view.

When high-power rf levels are applied to accelerating structures, the interactions between the intense fields, the metal boundaries, and the residual gas molecules are of concern. One of the prime goals of the PIGMI program is to investigate these interactions.

PIGLET, a 6-cell, 45-MeV, 450-MHz test cavity (shown in Fig. XIV-5), is currently being fabricated which will serve as a test vehicle for these investigations. Concurrent with this effort, a klystron driver amplifier is being assembled which will provide PIGLET with an average gradient capability of the order of 8 MV/m. The effects of geometry, plating, surface finish, high vacuum, and structure bakeout on permissible gradients will be explored.

While the primary purpose of PIGLET is gradient related, it is intended that it also exhibit as many of the PIGMI drift-tube linac features as is practical. Such features include a copperplated, stainless-steel cavity wall; a combination access slot and vacuum manifold along the top of the cavity; a stiffening beam along the cavity bottom for drift-tube support and alignment; wall and drift-tube cooling; resonance control; an rf window; and iris coupling.

Fig. XIV-5.
PIGLET power test cavity.

Since many of these features were selected because of their ease of fabrication, assembly, and maintenance, PIGLET will serve as a test of their viability.

The mechanical design of PIGLET is complete; the job is now out for bid and awaiting selection of a possible fabricator.

PIGMI Mechanical Design

A prime goal of the mechanical design effort associated with the PIGMI program is to investigate new materials and fabrication techniques in an effort to obtain increased accelerator performance and reliability at a reasonable cost.

Several 1350-MHz $\frac{1}{2}$ -cell segments have been machined from OFHC copper, aluminum, and carbon steel. These segments have been used to test copperplating and joining techniques, and also to obtain relative rf Q measurements after being

assembled into a 1-cell cavity. Stepped joints are designed to provide three important functions for an rf cavity joint: 1) an optimum electrical contact made possible by copperplated surfaces which are held tightly together by shrinkage of the weld that has a 0.050-mm gap designed to induce shrinkage, 2) a weld penetration stop to preclude welding damage to the electrical joint and copper contamination of the vacuum weld, and 3) precision transverse alignment.

Copperplating of aluminum and steel segments has been done using standard electroplating methods and also by the bright-copperplating technique. The standard electrolytic copper has the well-known problems of rough surface finish and non-uniform plating thickness. Bright-leveling copperplating is a standard commercial process that has been used in the automotive industry to achieve smooth surfaces for chromeplated parts. More recently this process is being used by accelerator builders and electronic firms. The leveling

characteristic of bright-copper reduces the surface finish quality required of the base material. Aluminum and steel segments have been bright-copperplated at LASL with the resulting smooth bright-copper finish.

Two iron drift tubes of the PIGLET size and shape have been fabricated as a base for the development of the drift-tube copperplating process. It is our intention to follow the same multistep cleaning, rinsing, plating (UBAC-R1), and coating (chromate) processes used so successfully by the Japanese in construction of their new proton linac. This development has been initiated with the electrochemistry group at LASL.

A commercial plating shop has been located which can bright-copperplate the ~1.2-m-long PIGLET tank. Two short sample pieces have been plated and are under evaluation.

A copper-wire vacuum seal has been developed which uses a disk retainer to provide precision alignment and metal-to-metal flange contact with controlled squeeze. Several seals have tested vacuum-tight on the first make-up, and one seal was leak-tight after a 533 K bakeout cycle in argon. The seal outline may be round, rectangular, or other shapes as required. Drift-tube stem seals are being developed using seals machined from solid copper. Tests are now being made to obtain torque and seal compression data on seals with different cross sections. The stem seals are designed for controlled squeeze to provide precision vertical alignment of the drift tubes.

The PIGMI RF Systems

The klystron modulator and tank for the 450-MHz amplifier is ~80% complete. A standard LAMPF klystron oil tank with a special lid was built for rf tests. The modulator deck was modified to be slightly more compact. Special filament, switchtube, and grid pulse transformers were built and mounted.

Some chassis were built for the test stand, with only one more remaining to be built. The extensive rack wiring for the 20 chassis in the control racks is only 10% complete. Cable trays need to be installed to connect signals and controls to the high-voltage power supply in the LAMPF klystron test area. A junction box will be installed with the regular

LAMPF controls and interlocks. Water requirements are being rechecked; engineering estimates are being prepared.

A layout of the klystron and the accelerator was made. The waveguide will leave the klystron at a 45° angle from the horizontal. The 45° bend has been designed and will be built soon.

The klystron and solenoid for the 1350-MHz rf system have been ordered. The same modulator and test stand will be used for both klystrons. The sockets and solenoids will be interchanged. The klystron and solenoid for the 450-MHz klystron are on hand and ready for operation.

A low-power, WR-1800 load was built and tested at 450 MHz. A water load for high-peak power has been built in a WR-2100 waveguide and initial rf tests at low power have been made. A design objective is to have the water load at a 45° angle. The rf tests will soon be completed, and the load will be ready for the first tests of the klystron.

Two alumina rf windows for PIGLET were received and tested. The thicker window (1.91-cm) had a VSWR of 6.5:1 at 450 MHz when mounted in a 5-cm-thick mounting plate. The windows together are 3.18-cm thick and have a VSWR of 1.07:1. A 3.3-cm window should give a perfect match, and such a window has been ordered.

A three-stage rf driver for the 450-MHz klystron has been built and tested. The final stage can deliver over 1 kW, and the entire chain should operate over the 400- to 450-MHz band. The chain is ~90% complete.

Two WR-2100 waveguide-to-coaxial-line transducers were designed and built. The first couples the 25-cm-diam coaxial line from the klystron to the waveguide, and the second couples the 8-cm coaxial line to waveguide. The latter coupler has been used in all the small-signal rf tests to date.

The APF Test Cavity

A zero-power model of the alternating phase-focused section of the accelerator is being constructed. The tank (Fig. XIV-6) is a full-scale cross section (400-mm) model to be used for experimental measurements of the rf fields by the bead-perturbation technique. This program will proceed in conjunction with analytical studies.

Fig. XIV-6.
APF test cavity.

The model was designed to provide as much versatility as possible in order to accommodate changes that may be required for future perturbation measurements. A tank length of 800 mm was fabricated with the capability of being reduced in length, or extended to 880 mm. Any number of drift tubes can be installed and at any axial station within the APF tank. A removable cover was incorporated to permit changes of the axial station of the drift tubes and optical alignment using tooling bars without disturbing the bead-perturbation setup.

A detachable panel supports the hysteresis synchronous motor, encoder, light-limit switches, and connectors. This panel permits easy removal of the entire bead-perturbation system without dismantling the tank assembly.

The bead-perturbation-measurement system is ~90% complete. The basic microprocessor-based instrument is housed in a single chassis which, for convenience, is mounted in a mobile rack together with a Tektronix storage oscilloscope and a digital calendar clock.

An interface card has been designed and built which measures the period of the intermediate frequency from the bead-perturbation experiment with great speed and precision. This card allows the period of each cycle to be measured by a 10-MHz-crystal-controlled clock. The card interrupts the

microprocessor on each negative-going zero crossing, causing it to read the period count of the just-finished cycle. These data are stored in RAM or transferred to a larger computer for analysis.

Plotting hardware and software have been developed which provide for graphic display of the bead-perturbation data. Tweek knob and joystick capabilities have been developed which will facilitate the generation and control of a cursor for interactive graphics.

A controller, with both manual and microprocessor control capabilities, has been designed and built for the beadpull motor. Electrical braking and optical limit switches have also been incorporated in the controller design.

Software support for the items mentioned above has been going on in parallel with the hardware development. A teletype-system monitor has been written to facilitate development of a diagnostic-systems software.

Permanent-Magnet Quadrupoles

The limited size of the proposed drift-tube linac imposes several requirements on the quadrupole focusing magnets. Most of the drift-tube linacs presently in service operate at half the frequency of the PIGMI linac and are consequently about twice the diameter. The size of the traditional linac can accommodate electrically excited quadrupole magnets. Accelerator designers have investigated permanent magnets in the past but, because of the requirement for high gradients in the low-energy end of the machine and the desire for variable-field capability, have chosen conventional electromagnets.

Incorporation of the APF portion of the linac reduces the magnetic field-gradient requirements to values that can be achieved by the use of permanent magnets. Also, permanent-magnet technology has advanced recently with the introduction of new materials with higher energy products and increased field characteristics. Linear accelerator design capabilities have progressed to the point that the required quadrupole gradients can be determined with sufficient accuracy that fixed-field magnets can be used.

Permanent-magnet quadrupole models have been constructed to gain experience in the field of

permanent-magnet technology which is considerably different from that of electromagnets. These models were not constructed as a final design but to provide inexpensive hardware to experimentally investigate the field capabilities, permeance coefficients, and harmonic content.

Magnet models with different pole radii-to-bore radii ratios were fabricated to accept permanent-magnet poles in the shape of circular disks (Figs. XIV-7 and XIV-8), magnetized across the diameter. Alnico and ferrite magnet materials are both being investigated.

Axial and transverse field surveys are being measured with Hall-type gaussmeters (Fig. XIV-9), and harmonic-content measurements, to determine field quality, are made with rotating coil instrumentation. Permeance coefficients of the various models are deduced from fluxmeter measurements to establish optimum geometries for various permanent-magnet materials.

All of the models to date have used permanent-magnet material charged in the "open circuit" condition by the vendor, which does not represent the optimum field that can be realized if the completed magnet is charged after assembly.

Fig. XIV-7.

Circular-pole permanent-quadrupole-magnet model.

Table XIV-II shows characteristics of some of the models studied to date.

Drift-Tube Linac Studies

The conventional drift-tube-linac portion of a PIGMI accelerator would extend from 8 to 150 MeV, and consist of three tanks, each 40 cm in diameter and ~12 m long. Each of these cavities would be driven from a common rf manifold at 450 MHz and would have accelerating gradients of 6 MV/m. A

Fig. XIV-8.

Circular-pole permanent-quadrupole-magnet models.

Fig. XIV-9.

Rotating coil instrumentation for magnetic-field measurements.

TABLE XIV-II

PERMANENT-QUADRUPOLE-MAGNET
CHARACTERISTICS

	Ceramic Pole Material			
	R_p/R_B			
	1.00	1.15	1.30	1.45
Bore radius (cm)	0.964	0.838	0.741	0.665
Gradient (kG/cm)	1.95	2.45	2.95	3.51
$\int B' \cdot dl$ (kG)	3.78	4.44	5.12	6.05
Magnet l (cm)	1.50	1.50	1.50	1.50
Effective l (cm)	1.94	1.81	1.73	1.72

	Alnico Pole Material			
	R_p/R_B			
	1.00	1.15	1.30	1.45
Bore radius (cm)	0.964	0.838	0.741	0.665
Gradient (kG/cm)	1.02	1.27	1.53	1.83
$\int G' \cdot dl$ (kG)	2.21	2.74	3.10	3.57
Magnet l (cm)	1.50	1.50	1.50	1.50
Effective l (cm)	2.16	2.16	2.03	1.95

stable phase of -20° would provide adequate longitudinal acceptance for the beam, having been well bunched by the APF section. The focusing law would be a continuation of the $+0-0$ period established in the APF/DTL transition using permanent-magnet quadrupoles.

Cavity calculations using the SUPERFISH program have been performed for a representative set of DTL cells in order to evaluate their geometrical and electrical properties. The drift tube in each of these cells was 7 cm in diameter with a 1.5-cm bore and a 10° face angle on each end. Values of the gap-to-cell length ratio, transit-time factor, and shunt impedance resulting from these runs are presented in Table XIV-III.

SUPERFISH

A new rf cavity code SUPERFISH has been developed that calculates the axisymmetric rf fields (and various secondary quantities) and the as-

sociated resonance frequencies in axisymmetric cavities of otherwise arbitrary shape.

This code can solve many problems which could not be handled easily by previously existing codes and in some cases could not be handled at all. The first of these is the ability to solve completely arbitrary boundary shapes as long as they have cylindrical symmetry. It has no difficulty in solving severe geometries, i.e., those which have a radial-to-longitudinal ratio of 30:1. Another feature is the ability to have a variable-mesh density, which allows the solution of larger problems than would be possible with a fixed-mesh density. And another rare feature of this code is the ability to solve for the resonant frequencies and field distributions of higher modes than the fundamental. This feature is currently being exploited for accelerator, buncher, storage-ring, and klystron applications.

The SUPERFISH code has been tested for many numerical effects such as mesh size and geometric configuration. It has been determined how these factors influence the calculation of the resonant frequencies and secondary quantities such as transit time factors and stored energy. These effects have been studied in the fundamental mode as well as in higher modes.

On the CDC 7600 under the Livermore Time-Sharing System, it takes $T \approx 0.75 \cdot 10^{-6} N^2 \epsilon$ (s) for one such solution [N represents the total number of mesh points and ϵ the short (mesh) dimension of the problem divided by the long (mesh) dimension]. This time is so short because the coefficient matrix

TABLE XIV-III

DRIFT-TUBE-LINAC PARAMETERS

$\frac{W}{\text{MeV}}$	β	G/L	T	$\frac{Z}{\text{M}\Omega/\text{m}}$
10	0.145	0.160	0.879	107.6
20	0.203	0.217	0.878	105.8
40	0.283	0.292	0.83	101.3
60	0.342	0.344	0.7	99.2
80	0.389	0.381	0.724	95.9
100	0.428	0.411	0.677	94.0
120	0.463	0.436	0.634	92.4
140	0.493	0.456	0.601	89.9

of the system of equations can be partitioned into a block tridiagonal form.

PIGMI Diagnostics and Control

A modest computer-based diagnostics and control system has been defined to facilitate the evaluation and control of the PIGMI prototype and associated hardware.

Specifications for the computer portion of this system were prepared, and procurement is in progress. An order has been placed for the following

equipment with delivery expected by the end of February:

- 1) A Data General (NOVA three-dimensional computer with 48k of core).
- 2) One 10-MByte Disk,
- 3) One Dual Floppy Disk.
- 4) One 30-cps hardcopy terminal,
- 5) One Versatec printer plotter, and
- 6) Two TI-745 portable terminals.

The software delivered with the system includes a RDOS (a real-time disk operating system with multitasking and foreground/background capability) and a FORTRAN IV with runtime libraries and a commercial subroutine package.

XV. MANAGEMENT

Another major milestone was attained when the HRS achieved 100-keV resolution on November 1, 1976.

The chronology of major achievements as presented by Louis Rosen, LAMPF Director, to the annual users meeting, are given below:

- Groundbreaking ceremonies —
February 15, 1968.
- Major construction funds released —
October 12, 1968.
- 5-MeV beam achieved —
June 10, 1970.
- 100-MeV beam achieved —
June 21, 1971.
- 211-MeV beam achieved —
August 27, 1971.
- 800-MeV beam achieved —
June 9, 1972.
- Dedication ceremonies (dedicated to U.S. Senator Clinton P. Anderson) —
September 29, 1972.
- Simultaneous delivery of H^+ and H^- beams —
May 4, 1973.
- First experiment (Exp. 56) received beam (Area B) —
August 24, 1973.
- Beam to Area A (first mesons identified) —
August 26, 1973.
- Beam to Area A-East —
February 6, 1974.
- Usable 100- μA beam to switchyard —
September 5, 1974.
- First radiotherapy treatment trial —
October 21, 1974.
- Start of Great Shutdown (79 experiments run, 13 completed) —
December 24, 1974.
- Acceptable simultaneous 100- μA H^+ beam and 3- μA H^- beam to switchyard —
September 14, 1975.
- First pions through EPICS channel —
March 18, 1976.
- Production beam in Area A and Area A-East (End of Great Shutdown) —
April 5, 1976.
- 100- μA production beam —
August 15, 1976.

- 200- μA beam to Beam Stop —
October 23, 1976.
- HRS achieved 100-keV resolution —
November 1, 1976.

Budget and Personnel Levels

Operating costs for this period were ~5% higher than forecast. Fiscal year 1977 operating funds are still limited to \$18 415 000, pending action by the Congress. Approximately 15% of the capital equipment allocation has been spent as committed. The average number of full-time-equivalent employees chargeable to the medium-energy physics program is 334, slightly less than forecast.

Safety

LAMPF Safety Program

The great diversity and complexity of LAMPF, and the multitude of hazards its operation entails, make necessary a very sophisticated and multifaceted safety program, involving considerable redundancy. The main elements of our management approach to health and safety concerns are:

- Policy-making and policy-review apparatus.
- Mechanism for implementing established general policies by the LASL Health Division and supplemental policies established by LAMPF.
- Assessment of compliance with, and effectiveness of, the safety program.

The basic unit in any safety program is the individual employee. He or she must understand the rationale for the safety organization and regulations, and must be willing to comply. This understanding and compliance is facilitated by ensuring that safety policymakers and supervisors maintain the respect and confidence of each employee. We therefore involve many of our employees, on a rotating basis, with formal safety responsibilities for group activities and/or for geographical areas. With every activity is associated a technical supervisor who has overall responsibility for the safety of that activity. In addition, there may be, if the hazards warrant, one or more designated safety officers for the various components of the activity.

These personnel are responsible for the overall well-being of people and equipment associated with the activity which they supervise or monitor.

In addition, every area of building or real estate is under the jurisdiction and is the responsibility of an administrative unit. That unit may be a group, in which case the group leader is the responsible individual, or it may be a committee, e.g., the Buildings and Grounds Committee, in which the chairman has "line" responsibility.

The LAMPF users represent a problem somewhat different than normally encountered at LASL. They arrive at LAMPF to implement or prepare for specific experiments and are in residence a relatively short time. Each experiment to be mounted must undergo an engineering review, part of which is concerned with personnel and equipment safety. Unless the LAMPF Health and Safety Office (HSO) approves a given experiment, it will not go on the floor. By this means we ensure that the basic design is sound from the safety standpoint. In addition, an experiment engineer is assigned to each experiment and he monitors all aspects of the mounting, execution, and dismantling of every experiment. Safety is one of his concerns. Finally, every LAMPF user is required to read a summary of our safety policies and procedures and every User Group is required to identify one member who is formally responsible for the safety of the activities of that group and serves as an interface between the LAMPF HSO and that group.

Radiation hazards are probably our chief safety concern. Among the problems posed is the individual transport of radioactive materials or debris into "clean" areas. A final line of defense against that hazard is in the form of automatic monitors placed at key points of egress. A recent innovation is the emplacement under the only exit from the LAMPF site of a highly sensitive radiation detector which will signal contamination of vehicles or cargo as they approach the site exit.

To measure compliance with safety regulations and to identify desirable changes in procedures or equipment, we have periodic surveillance by LAMPF safety officers, by LAMPF safety committees, by high-level supervisors, and by H-Division personnel.

As a result of the above program, but primarily because our staff cares, our safety record over the

past ten years has been very good. At one point we worked 10^6 consecutive people-hours without a lost-time injury. A similar record was established last year, if one includes LAMPF users.

In summary, a great deal of money and effort are devoted to avoidance of injury to personnel and of damage to plant and equipment. Approximately one employee of every five, working at the LAMPF site, has some formal health and safety responsibilities, aside from those vested in each LASL employee.

Radiological Safety

Individual and total man-rem exposures remained at acceptable levels. During October-December, 135 LAMPF-associated personnel received 24.5 man-rem; the maximum individual exposure was 1 rem. Craft personnel were not included in this figure because they could have received exposures at areas other than LAMPF.

Detailed preparations were made for an experiment to be conducted in the LEP channel to measure the γ -ray energy spectrum from pion capture in tritium (T_2) and other light elements. This experiment, No. 50, requires special safety considerations because of the large quantity of liquid T_2 ($\sim 80\,000$ Ci) and H_2 used as targets. To minimize possible hazards:

- An enclosure equipped with a forced exhaust system was constructed for the entire tritium and hydrogen gas-handling apparatus. The exhaust duct is vented above the roof of Area A and contains tritium detectors to provide early leak indication. Tritium detectors were placed at selected occupied locations in the experimental areas.

- Detailed written procedures were developed that specify the operation of the gas-handling systems, operational restrictions and regulations, personnel access and control, and physical surveillance. Emergency procedures cover situations involving potential or actual release of tritium.

- Personnel directly involved in the operation of the tritium apparatus were trained in the tritium gas-handling systems, operation of emergency generators, alarm and emergency procedures, and the use of Scott air packs and tritium monitors.

Thirty-six operational plans for work involving radiation were reviewed and approved.

Meetings

The following safety committees met this quarter: LAMPF Safety Committee, Group Safety Officers Committee, Experimental Areas Safety Committee, and LAMPF Hydrogen Safety Committee.

Inspections

Seven site inspections were conducted by the LAMPF Health and Safety Office (HSO). Deficiencies were reported to the appropriate groups for corrective action.

Review of Experiments

Safety reviews were held for 15 experiments, in addition to Exp. 50 described above. No unusual safety problems were identified.

Safety review forms are sent routinely to experiment spokesmen for completion.

First-Aid Training

Thirty-five personnel completed a Standard Multimedia First-Aid Course conducted by the LAMPF Safety Officer.

Accidents

Fifteen accidents resulting in injuries were reported this quarter. Thirteen of these were minor; the other two injuries resulted in five lost work days.

After-Hours Surveillance

To ensure personnel adherence to safety rules and procedures, additional surveillance was provided during shutdown periods at nights and weekends.

LAMPF Visitors Center

The LASL administration has returned to MP Division the authority to obtain leases for housing

units for priority assignment by the LAMPF housing office. This action restores the flexibility in scheduling required during production runs of the accelerator.

During this report period, approximately 200 itinerant visitors were received at LAMPF, with representatives from 8 foreign institutions. There were 149 arrivals recorded of LAMPF users, with 162 departures. Research guests at LAMPF during this report period are listed in Appendix A.

There are 11 graduate students participating with approval of their thesis advisors, in the work-study program in effect at LAMPF.

Organized tours of the LAMPF site were conducted for the following:

- Representatives of Hanford Engineering Development Labs.

- Nurses from St. Vincent's (Santa Fe, NM) Hospital.

- LASL families (4).

- New Mexico Teachers Meeting.

- Representatives of Western Area Governors and Colleges.

- Physics students from Highlands Univ.

- N.A. Technical Institute.

- ERDA Senior Management Review Comm.

- Physics students from Univ. of Southern Colorado.

- Physics students from Univ. of New Mexico Northern Branch Coll.

- ERDA Task Group.

- Associated Universities, Inc.

- Up With People group.

- Attendees of meeting of Numerical Analysis Special Interest Group.

- Dodge City (Kansas) Community Coll.

LAMPF Program Advisory Committees

During its January meeting the LAMPF Program Advisory Committee reviewed eighteen new proposals and heard reports on the nuclear chemistry program and six experiments already in progress.

The membership of the PAC for 1977 is made up of the following:

- S. L. Adler Inst. for Advanced Study

- F. H. Boehm California Inst. of Tech.

- J. G. Cramer Univ. of Washington

R. A. EisensteinCarnegie-Mellon Univ.
 G. T. GarveyANL
 Lee Grodzins .. Massachusetts Inst. of Tech.
 B. C. Harvey LBL
 J. R. Huizenga ... Nucl. Structure Res. Lab.
 A. D. KrischUniv. of Michigan
 I. L. MorganBalcones Inst. Res. & Dev.
 D. E. NagleLASL
 Louis RosenLASL
 M. J. Saltmarsh OPNL
 E. P. SteinbergANL
 H. M. Steiner LBL
 M. M. Sternheim ... Univ. of Massachusetts
 E. W. Vogt Univ. of Brit. Columbia
 R. E. WelshColl. of Wm. and Mary
 Joseph Wenener BNL

LASL Aides (non-voting)

D.R.F. Cochran, Secretary

L. E. Agnew	A. A. Browman
George Bell	D. C. Hagerman
J. N. Bradbury	T. M. Putnam

Observers:

S. P. Koczan	LASL
George Rogosa	 ERDA
Howell Pugh	 NSF
Marcel Bardon	 NSF

The next meeting of the PAC will be held during the last week of July 1977. The deadline for the submission of new material is June 3, 1977.

The Solid State Physics and Materials Science Subcommittee will meet during the last week of May 1977. This committee is comprised of:

T. L. Estle	Rice Univ.
A. N. Goland	BNL
P. K. Haff	Sloane Physics Lab.
B. L. Holian	LASL
J. Manley	LASL
M. J. Saltmarsh	 ORNL
T. A. Tombrello	CIT

The Biomedical Program Advisory Committee will hold a meeting at LASL on May 15, 1977. The membership of this committee is as follows:

F. H. Attix	Univ. of Wisconsin
J. N. Bradbury	LASL
R. F. Kallman	Stanford Univ. Medical Center
M. M. Kligerman	UNM Cancer Center/LASL
L. H. Lanzl	Univ. of Chicago
D. F. Petersen	LASL
P. W. Todd	Pennsylvania State Univ.

LAMPF Users Group, Inc.

The Tenth LAMPF Users Meeting was held at LASL on November 8-9, 1976. The annual report was given by David A. Lind (Univ. of Colorado), Chairman of the LUGI Board of Directors. Members and officers of the Board of Directors were elected for 1977. The election results were presented by Vernon W. Hughes (Yale Univ.), Chairman of the Nominating Committee. The elected officers and members for 1977, and their terms of office, are as follows:

Chairman: Harvey B. Willard (Case Western Reserve Univ.); two-year term (second year to be served as Past-Chairman).

Chairman-Elect: John C. Allred (Univ. of Houston), three-year term (second year to be served as Chairman, third year to be served as Past-Chairman).

Past-Chairman: David A. Lind, one-year term.

Secretary-Treasurer (appointed office):
 Donald R.F. Cochran (LASL).

Members: Barry M. Freedom (Univ. of South Carolina), Paul W. Todd (Pennsylvania State Univ.), to serve second year of two-year term; and Ralph C. Minehart (Univ. of Virginia) and Glen A. Rebka, Jr. (Univ. of Wyoming), elected to two-year terms.

The Board of Directors and the TAP met twice during this report period, on November 10, 1976, and January 10-11, 1977. Summaries of the minutes of these meetings were prepared by Hillard H. Howard (LASL), User Liaison Officer, and distributed in the February Users Newsletter.

The Board of Directors, at their November meeting, appointed the following to two-year terms on the TAP, beginning in 1977:

Edward Gillette, Colorado State Univ. — Biomedical Facilities
Allen N. Goland, BNL — Solid-State Physics and Materials Science
Michael McNaughton, Case Western Reserve Univ. — Polarized Beam
Ralph C. Minehart, Univ. of Virginia — P ³
J. J. Peterson, Univ. of Colorado — EPICS
Klaus Ziocck, Univ. of Virginia — LEP

George C. Igo, Univ. of California at Los Angeles — HRS (was appointed to a one-year term to replace Edward R. Flynn)
Continuing members of the TAP for 1977 are:
Albert A. Caretto, Carnegie-Mellon Univ. — Nuclear Chemistry

George Glass, Texas A&M Univ. — NPL
Bill W. Mayes, Univ. of Houston — Experimental Facilities
Peter Nemethy, Yale Univ. -- Neutrino Facilities
Richard J. Powers, California Institute of Technology -- Muon Experiments

APPENDIX A

RESEARCH GUESTS AT LAMPF DURING PERIOD NOVEMBER 1, 1976 - JANUARY 31, 1977

John C. Allred	Univ. of Houston	Steven A. Dytman	Carnegie-Mellon Univ.
James Amann	Carnegie-Mellon Univ.	Ronald D. Edge	Univ. of South Carolina
Helmut W. Baer ...	Case Western Reserve Univ.	Patrick O. Egan	Yale Univ.
Thomas J. Baird	Rensselaer Poly. Inst.	Robert A. Eisenstein	Carnegie-Mellon Univ.
Peter D. Barnes	Carnegie-Mellon Univ.	Richard D. Felder	Rice Univ.
Stephen M. Bart	Univ. of Houston	Donald R. Fenstermacher ..	UNM Cancer Center
Thomas S. Bauer	UC, Los Angeles	John C. Fong	UC, Los Angeles
F. E. Bertrand	Oak Ridge National Lab.	Dan R. Fortney	Purdue Univ.
John L. Beveridge	TRIUMF	Sherman Frankel	Univ. of Pennsylvania
Philip R. Bevington	Case Western Reserve Univ.	William Frati	Univ. of Pennsylvania
Jim A. Bistirlich ...	Lawrence Berkeley Lab.	Hans Frauenfelder	Univ. of Illinois
S. Biswas	Purdue Univ.	Gerhard Fricke	Univ. of Mainz
C. W. Bjork	Univ. of Wyoming	Jozica Gabitzsch	Rice Univ.
Gary S. Blanpied	Univ. of Texas	Wilhelm B. Gauster	Sandia Lab.
Marvin Blecher	Virginia Poly. Inst.	D. S. Gemmell	Argonne National Lab.
Felix H. Boehm	California Inst. of Tech.	Shalev Gilad	Tel-Aviv Univ.
Joseph E. Bolger	Univ. of Texas	George Glass	Texas A&M Univ.
Jonathan S. Boswell	Univ. of Virginia	Paul F. Glodis	UC, Los Angeles
Richard L. Boudrie	Univ. of Colorado	Robert Gluckstern	Univ. of Maryland
Kenneth Boyer	Univ. of Texas	Kazuo Gotow	Virginia Poly. Inst.
W. J. Braithwaite	Univ. of Texas	Charles A. Goulding	Florida A&M Univ.
Hubert Brandle	UC, Los Angeles	Pierre Grand	Brookhaven National Lab.
John C. Browne	Lawrence Livermore Lab.	Mark B. Greenfield	Florida A&M Univ.
H. C. Bryant	Univ. of New Mexico	Chilton B. Gregory	Univ. of New Mexico
James A. Buchanan	Rice Univ.	Edward E. Gross	Oak Ridge National Lab.
Joseph J. Burgerjon	TRIUMF	P. C. Gugelot	Univ. of Virginia
G. R. Burleson	New Mexico State Univ.	Alan A. Hahn	California Inst. of Tech.
Elizabeth Cameron	UNM Cancer Center	Eldon Haines	Jet Propulsion Lab.
Roger D. Carlini	Univ. of New Mexico	Klaus Halbach	Lawrence Berkeley Lab.
D. E. Casperson	Yale Univ.	Robert L. Hall	Univ. of Houston
David T. Chiang	Univ. of Washington	Isaac Halpern	Univ. of Washington
John M. Clement	Rice Univ.	Clifford K. Hargrove	National Res. Council
Bruce E. Collins	Univ. of Houston	Ryugo S. Hayano	Univ. of Tokyo
Joseph N. Craig	CGR Medical Corp.	Ann H. Hayes	UNM Cancer Center
Kenneth M. Crowe	Lawrence Berkeley Lab.	Richard Helmer	Idaho National Eng. Lab.
Frank H. Cverna ...	Case Western Reserve Univ.	Herbert E. Henrikson ...	California Inst. of Tech.
Colgate W. Darden	Univ. of South Carolina	Virgil L. Highland	Temple Univ.
Judith M. Dembo	UNM Cancer Center	John C. Hill	Iowa State Univ.
Arthur B. Denison	Univ. of Wyoming	Nathaniel W. Hill	Oak Ridge National Lab.
Michael J. Devereux ...	New Mexico State Univ.	Norton M. Hintz	Univ. of Minnesota
Byron Dieterle	Univ. of New Mexico	Martha V. Hoehn	Florida State Univ.
Joey B. Donahue	Univ. of New Mexico	William J. Hoffert	Indiana Univ.
Mohan Doss	Carnegie-Mellon Univ.	John H. Hoftiezer	Rice Univ.
William H. Dragoset	Rice Univ.	Kenneth R. Hogstrom	UNM Cancer Center

Robert E. Holland Argonne National Lab.
 Charles L. Hollas Univ. of Texas
 A. A. Hruschka UC, Irvine
 Vernon W. Hughes Yale Univ.
 Ed V. Hungerford Univ. of Houston
 George J. Igo UC, Los Angeles
 Jun Imazato Univ. of Tokyo
 Harvey Israel Private Consultant
 Steven G. Iverson Northwestern Univ.
 Harold E. Jackson Argonne National Lab.
 Mahavir Jain Texas A&M Univ.
 Mark J. Jakobson Univ. of Montana
 David A. Jenkins Virginia Poly. Inst.
 R. H. Jeppesen Univ. of Montana
 K. F. Johnson Temple Univ.
 William Johnson Univ. of Rochester
 David M. Judd Rice Univ.
 Herbert G. Judd UC, Irvine
 Jan Källne Univ. of Uppsala
 Charles A. Kelsey UNM Cancer Center
 Thomas R. King Univ. of Wyoming
 Hartmut F. Klonk Purdue Univ.
 Lynn Knutson Univ. of Wisconsin
 I. G. Kostoulas Michigan State Univ.
 Thomas Kozlowski Brookhaven National Lab.
 Kenneth S. Krane Oregon State Univ.
 Joseph Z. Kukulka Carleton Univ.
 Ray Kunselman Univ. of Wyoming
 Gary Kyle Univ. of Minnesota
 Richard G. Lane UNM Cancer Center
 Phillip M. Lang Northwestern Univ.
 Alan G. Law Univ. of Regina
 Chris P. Leavitt Univ. of New Mexico
 James D. Lesikar II Rice Univ.
 Edward G. Lieberman Lawrence Berkeley Lab.
 Rodger Liljestrand Univ. of Texas
 Stanley Livingston Private Consultant
 Joseph W. Lo Univ. of Houston
 May M. Lo Univ. of Houston
 Earle L. Lomon Mass. Inst. of Tech.
 Steven C. Luckstead Washington State Univ.
 Carl A. Ludemann Oak Ridge National Lab.
 D. J. Malbrough Univ. of South Carolina
 Fesseha Mariam Yale Univ.
 Thomas Marks, Jr. Univ. of South Carolina
 Nancy Matz UC, Los Angeles
 Bill W. Mayes Univ. of Houston
 James S. McCarthy Univ. of Virginia
 W. K. McFarlane Temple Univ.
 Dorothy H. McGrath UNM Cancer Center

Michael McNaughton Case Western Reserve Univ.
 Fred L. Milder Virginia Poly. Inst.
 James P. Miller Lawrence Berkeley Lab.
 Ralph C. Minehart Univ. of Virginia
 Murray Moinester Tel-Aviv Univ.
 C. Fred Moore Univ. of Texas
 Donald W. Mueller Private Consultant
 Gordon S. Mutchler Rice Univ.
 Robert A. Naumann Princeton Univ.
 B. M. K. Nefkens UC, Los Angeles
 Peter Nemethy Yale Univ.
 Charles Newsom Univ. of Texas
 L. C. Northcliffe Texas A&M Univ.
 Andrew W. Obst Northwestern Univ.
 Michael A. Oothoudt Univ. of Minnesota
 Douglas A. Ortendahl Lawrence Berkeley Lab.
 Alden T. Oyer Univ. of Wyoming
 Gianni Pauletta UC, Los Angeles
 Grace I. Perez New College
 Robert F. Petry Univ. of Oklahoma
 Werner J. Pietsch Argonne National Lab.
 Lawrence S. Pinsky Univ. of Houston
 Joanne L. Pizzuto UNM Cancer Center
 Hans S. Plendl Florida State Univ.
 William W. Plumlee UC, Los Angeles
 Arthur M. Poskanzer Lawrence Berkeley Lab.
 Richard J. Powers California Inst. of Tech.
 Barry M. Preedom Univ. of South Carolina
 A. J. Ratkowski Argonne National Lab.
 Glen A. Rebka Univ. of Wyoming
 Robert J. Ridge UC, Los Angeles
 Peter J. Riley Univ. of Texas
 Peter L. Roberson Virginia Poly. Inst.
 Isaac I. Rosen Univ. of New Mexico
 Ted D. Rupp Univ. of New Mexico
 Marvin Sachs UNM Cancer Center
 Oscar R. Sander UC, Los Angeles
 Mark A. Schardt Arizona State Univ.
 John P. Schiffer Argonne National Lab.
 Wolf-Udo Schroeder Univ. of Rochester
 Ryoichi Seki California State Univ.
 Carol A. Selheimer UNM Cancer Center
 Kamal K. Seth Northwestern Univ.
 Hasan Sharifian Univ. of New Mexico
 Tilak C. Sharma Oregon State Univ.
 Joseph D. Sherman Carnegie-Mellon Univ.
 D. G. Shirk Iowa State Univ.
 Frank T. Shively Lawrence Berkeley Lab.
 Ingo Sick Univ. of Basel
 Alfred R. Smith UNM Cancer Center

Gregory Smith Univ. of Colorado
 Lester E. Smith Univ. of Texas
 John W. Somers Univ. of New Mexico
 Larry B. Sorensen Univ. of Illinois
 Jan Soukup UC, Los Angeles
 James R. Spechi Argonne National Lab.
 Rolf M. Steffen Purdue Univ.
 Marcus D. Stevens UNM Cancer Center
 Gerd Strassner Univ. of Zürich
 L. Wayne Swenson Oregon State Univ.
 Robert L. Tanner Private Consultant
 Willard Thomas Univ. of New Mexico
 James D. Thomasson Univ. of Houston
 Hossein Tootoonchi Univ. of New Mexico
 J. K. Valentine Temple Univ.
 Philip Varghese Univ. of Oregon
 Stephen L. Verbeck ... New Mexico State Univ.
 Jurgen Vetter Universitat Heidelberg
 Jean-Luc Vuilleumier ... California Inst. of Tech.

Charles N. Waddell Univ. of Southern California
 E. A. Wadlinger Univ. of Virginia
 John B. Watler Univ. of Wyoming
 Keh-Chung Wang California Inst. of Tech.
 K. H. Wang Baylor Univ.
 Thomas P. Wangler Argonne National Lab.
 Linda J. Warnes UNM Cancer Center
 W. R. Wharton Carnegie-Mellon Univ.
 Charles A. Whitten UC, Los Angeles
 Harvey B. Willard .. Case Western Reserve Univ.
 Suzanne Willis Yale Univ.
 David Wolfe Univ. of New Mexico
 H. G. Worstell Private Consultant
 James Worthington Argonne National Lab.
 T. Yamazaki Univ. of Tokyo
 Vincent Yuan Univ. of Illinois
 Benjamin Zeidman Argonne National Lab.
 Gisbert zu Putlitz Universitat Heidelberg