02-1823

MASTER

LA-6109-PR
Progress Report

UC-28
Issued: October 1975

Medium-Energy Physics Program

February 1—April 30, 1975

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87545

UNITED STATES
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
CONTRACT W-7405-ENG. 36

The four most recent reports in this series, unclassified, are LA-5708-PR, LA-5770-PR, LA-5845-PR, and LA-5959-PR.

In the interest of prompt distribution, this report was not edited by the Technical Information staff.

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22151
Price: Printed Copy $5.45 Microfiche $2.25

CONTENTS

GLOSSARY OF TERMS USED IN THIS REPORT

ADC – Analog Digital Converter

ASCII – American Standard Code for Information Interchange

CCF – LASL Central Computer Facility

CCR – Computer Control Room (mother computer)

CPU – Central Processing Unit

CRT – Cathode Ray Tube

C-W – Cockcroft-Walton

DACT – Data-Acquisition and Control Terminal

DVM – Digital Volt Meter

EFB – Effective Field Boundary

ETL – Equipment Test Laboratory

fh – Filament Hours

FWSS – Fast-Wire-Scanner System

hfs – Hyperfine Structure

hvh – High-Voltage Hours

ICR – Injector Control Room

IDS – Information Display System

IEC – International Electrotechnical Commission

IFA – Interface Amplifier

I/O – Input/Output

ISIC – Insertable-Strip Ion Chambers

IVR – Induction Volt Regulator

LAMPF – Clinton P. Anderson Meson Physics Facility

LCF – Localized Current Fields

LED – Light-Emitting Diode

LEEP – LAMPF Electronics and Equipment Pool

LET – Linear-Energy Transfer

MBD – Microprogrammed Branch Driver

m.i. – Mineral Insulated

MIG – Metal Inert Gas

MSSC – Multistrip Scintillation Chamber

MWPC – Miltiwire Proportional Chamber

NIM – Nuclear Instrumentation Module

NMR – Nuclear Magnetic Resonance

PHA – Pulse-Height Analyzer

PLI – Procedural Language Interface

RICE – Remote Information and Control Equipment

RIU – RICE Interface Unit

SCC – Serial Crate Controller

SCR – Silicon Control Rectifier

SSD – Serial System Driver

TDC – Line-to-Digital Converter

TDI – Temperature Difference Integrator

TIG – Tungsten Inert Gas

TOF – Time of Flight

Experimental Area

Primary beam lines in experimental area:

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

Experimental beams:

- Beam Area A:
  - BSA – Beam Stop A
  - EPICS – Energetic Pion Channel and Spectrometers
  - LEP – Low-Energy Pion Channel
  - Neutrino A
  - P^3 – High-Energy Pion Channel
  - RADIP – Radiation Damage and Isotope Production

SMC – Stopped Muon Channel

TA-1 – Target A-1

TA-2 – Target A-2

TTA – Thin Target Area

Beam Area B (Room BR):

AB – Neutrons

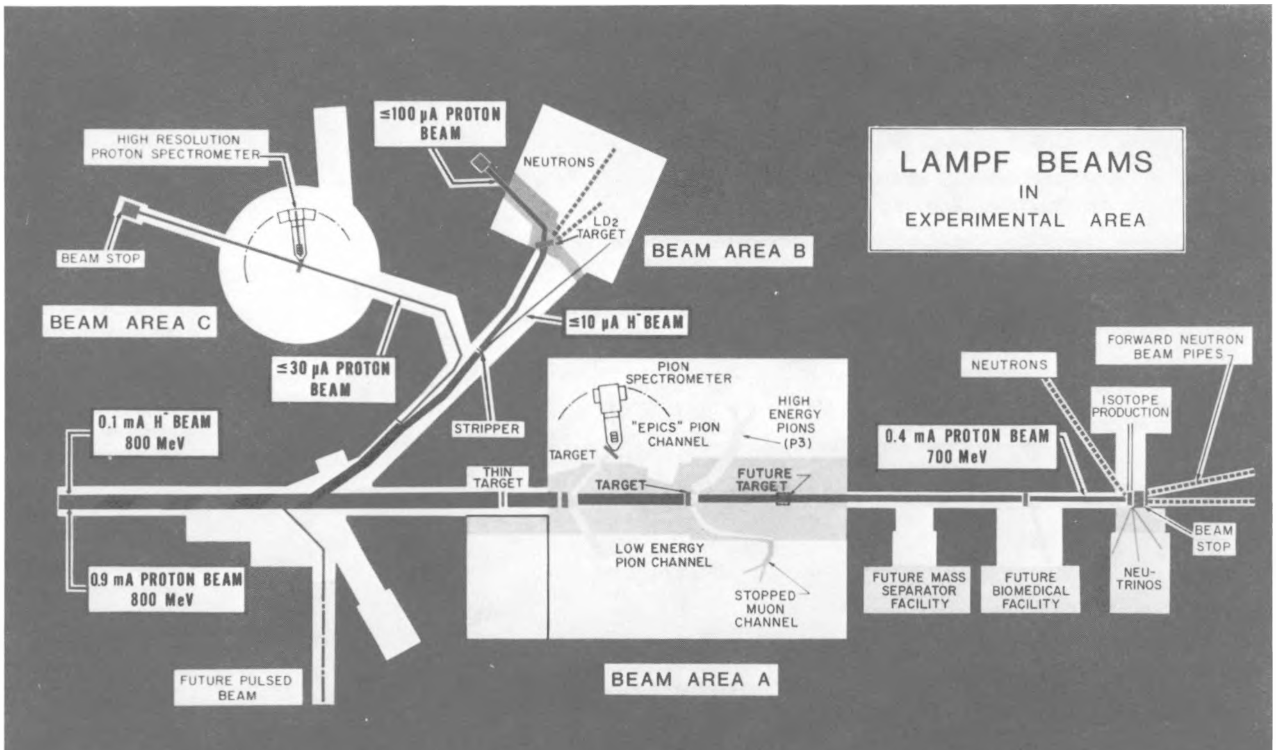
AB – Nuclear Chemistry

EPB – External Proton Beam

Beam Area C:

CCH – Area C Control and Counting House

HRS – High-Resolution Proton Spectrometer



Channel	Energy (MeV)	Beam
LOW ENERGY PION	0-300	$3 \times 10^9 \pi^+$/SEC. OR $8 \times 10^8 \pi^-$/SEC.
HIGH ENERGY PION (P^3)	100-600	$10^{10} \pi^+$/SEC. OR $10^9 \pi^-$/SEC.
EPICS PION BEAM	50-300	$4 \times 10^8 \pi^+$/SEC. OR $10^8 \pi^-$/SEC.
STOPPED MUON	0-165	$5 \times 10^7 \mu^+$/SEC. OR $10^7 \mu^-$/SEC.

Channel	Energy (MeV)	Beam
NEUTRONS (AREA B)	795	2×10^7 n/cm^2-SEC
NEUTRONS (BEAM STOP)	1-20	10^9 n/cm^2 - SEC. (INST.)
BIOMEDICAL	80-100	$2 \times 10^8 \pi^-$/SEC.
NEUTRINOS	20-50	$5 \times 10^7 \nu$/cm^2 - SEC.

QUARTERLY REPORT ON THE MEDIUM-ENERGY PHYSICS PROGRAM

FOR THE PERIOD ENDING APRIL 30, 1975

I. SUMMARY

Engineering Support

A major part of the group's effort was spent on the dismantling, cleaning, reassembly, and aligning of the 201-MHz linac. All of the new bellows were received, annealed, leak checked, and installed on the drift-tube stems. The 201-MHz tanks are within a few weeks of being fully operational.

Two klystrons, one from each vendor, were rebuilt in this quarter. On has passed the electrical acceptance tests, and the other has not been tested. Sixty-four 500 ℓ/s and ten 2400 ℓ/s ion pumps were also rebuilt during the quarter.

Magnet testing for the WNR line is complete, and the slow kicker has been tested and is ready for installation. The floor plates, magnet support structures, and other equipment have been installed in the switchyard and waterfall areas of this line.

Work on the Biomedical beam line is continuing: helium chambers, windows, beam-halo shields, and dust covers for this line are being fabricated. Installation will commence as manpower becomes available.

Accelerator Support

The major effort this quarter has been the continued upgrading and refurbishing of the accelerator for improved reliability and increased duty factor prior to turn-on next fiscal year.

During this period the accelerator support group effort has been concentrated almost entirely on improvement of these systems under our control. Examples are installation of oil-cooled crowbar resistors for the 201-MHz rf systems, addition of isolators to the reference drive-line systems to prevent directional coupler failure, new closed-loop control for 201-MHz system high-voltage regulation, and intertank phase monitoring to allow observation of phase stability in the phase control systems.

A large amount of manpower was devoted to development and improvement of the beam-diagnostics equipment. The beam scrapers, high-power emittance jaws, absorber/collector jaws, and fixed-slit-emittance jaws are examples. Standardization and spare-parts control were also improved during this period.

The magnet power-supply systems have undergone extensive modification and improvement this quarter. Rework to improve the reliability and performance of these systems is well under way, but probably will not be completed by the time the experimental program resumes. The less critical items will be deferred to a later date when the accelerator is shut down for other scheduled maintenance.

Accelerator Systems Development

Considerably higher levels of understanding were achieved this quarter on a number of accelerator beam-dynamics problems, including cause and effect of field distributions in the first tank of the linac, the effect of quadrupole field multipole components, the 805-MHz structure length error problem, and a new investigation into alternating-phase-focused accelerators.

Field tuning of the 201.25-MHz linac tanks was initiated, with very good data from the bead-pull equipment, electronics and computer. Alignment of the drift tubes is progressing well. The bridge-coupler in module 13 was replaced to compensate for length errors and is nearly retuned.

Extensive work on data-base development was completed on applications for experimental program scheduling, the Visitors Center, computer systems maintenance, and on assimilation of new tools for other work.

Diagnostic equipment development continued.

Numerous modifications, alterations and improvements were made to the injector and beam transport systems to make operation easier and more reliable at high-duty factor. A change in the H^- ion-source anode aperture construction resulted in an unexpected increase in current; up to 2.25 mA has been achieved in preliminary tests.

Electronic Instrumentation and Computer Systems

Several modifications were made to the H^+ and H^- injector-control systems to improve their performance for the next operating cycle.

The process of gathering requirements for a new master timer and of developing an initial design for the hardware was started.

The extended shutdown provided an opportunity to install in the resident operating system of the control computer a number of changes which are expected to make significant improvements in its speed and reliability, and which added new features required for future operation.

The new hardware instructions developed for the control processor of the control computer were installed and tested except for one set which will be installed next quarter.

A prototype system was developed to provide a write-through cursor controlled by a joystick on the Tektronix 611 storage-type display scopes. The system will be evaluated as an aid to operations next quarter.

Work continued on the information-exchange bus which will become the basis for developing the third operator console.

Extensive design work was done on a system of graphical displays diagramming the accelerator for operators. This system of blueprint graphics will be data-base driven for ease of updating.

Steady progress was made on the switchyard Fast Wire Scanner System which involves a satellite computer.

Design activities began on several different and redundant hardware/software systems to protect beam-line equipment in Area A against beam-induced damage and burnout.

Numerous and significant changes were made to the control instrumentation along the primary and secondary beam lines. Most of these changes involved the scheduling, installation, and check-out of wiring.

Orders were placed for the equipment needed to upgrade the Terminal computer into a multi-user PDP-11/45 system.

Considerable effort was invested in the development and check-out of the general data-acquisition program for LAMPF users, otherwise known as the Q-Project.

The first test of a two-crate serial CAMAC system was successfully completed using a new CAMAC Serial Driver.

The sharing of LAMPF technology with industry continued through the efforts of several staff members.

Accelerator Operations

The accelerator was shut down for upgrading during the entire quarter. Operators were assigned to training and support activities.

A major development effort was undertaken to improve the beam-current monitor system. A new current monitor-calibration system is under construction. It will provide separate calibration pulses to the linac, Line A, and Lines B-C-X with computer control of amplitudes and time dimensions.

The old North Port beam line was dismantled and the equipment assigned to spares. In the 805-MHz accelerator, all ion pumps drawing over 1 mA were removed, reconditioned, and reinstalled. All vacuum-isolation valves were removed and modified. Comprehensive testing of the RICE analog-data systems was started. The pulsed-signal (video) distribution system was modified to bypass the remote matrixing switches in the sector buildings in favor of a clearly labeled manual-patch system. A run-permit panel was built and installed in the injector control room showing the status of both H^+ and H^- beam transport lines. Warning lights were installed on experimental area magnets to meet safety requirements. The controls for the switchyard and experimental area water systems were modified to provide time delays and front-panel jumpers for all interlocks. Soft vacuum interlocks were installed on the drift-tube linac. Closed-circuit-television equipment was acquired, checked, modified, and maintained. The existing coaxial cable system was surveyed and documented. Spare units for the activation protection system were assembled and checked out. Personnel safety systems for Line B, Room B, EPB, and the Line B nuclear chemistry cave were completely redone to make them consistent with operating modes. The switchyard personnel safety system was modified to accommodate changes incident to the WNR line installation.

Procedures were developed for checking all fast-protect and run-permissive interlocks. Personnel safety interlock check procedures were updated.

Beam tuning procedures are under development in collaboration with the accelerator development group. Efforts are being made to develop quantitative criteria for beam diagnostic measurements in order to reduce subjectivity in the beam-tuning process.

Experimental Areas

A computer terminal that will enable continuous remote monitoring of major service systems and experiment setups has been ordered for installation in the Experimental Area Manager's Office. The staff shop in Area A has been upgraded and is now available for use by LASL personnel and user research teams.

Existing water systems are undergoing modifications to increase capacity, improve reliability, and provide for more efficient management. Three new systems are being fabricated.

Performance tests have been made of cryogenic refrigerators, and development studies of LH_2 target-flash materials are under way.

Extensive in-depth studies of switchyard beam-optics design criteria have been carried out. These studies have led to substantial revisions of the switchyard layout. The quadrupole focusing magnets have been changed, several new beam strippers and scrapers will be installed, and two new beam stops will be added. The new arrangement should provide for a clean transmittal of the linac-output beams to the experimental areas, provide for beam-diagnostic requirements, and also enable the stringent Line C phase-space requirements to be met.

Harps for the main beam line have been redesigned to use ceramic printed-circuit boards and to accommodate collection fields for the secondary-emitted electrons.

Optics calculations and design studies for high-intensity operation of Line A have led to a large number of hardware improvements which are now being implemented. These include 13 collimators, 10 additional harps, 6 additional toroids, redesign of harp construction and electronics, relocation of one harp and one quadrupole triplet, addition of beam-halo shields, 3 beam-on-target monitors, and some additional spill monitors. A new harp located between A-1 and A-2 should provide for accurate on-line measurement of the A-1 spot size. The entire harp system has been studied in detail. A number of corrections which should reduce noise problems are being made.

The initial Line A beam burnout-protection system will consist of a computer-based beam-transmission monitor, magnet-current monitoring, collimator water-temperature and flow interlocks, vacuum gauges, temperature trip-outs in air-cooled collimators, and a number of spill monitors and area radiation monitors. Additional devices such as secondary-emission guard rings, beam-on-target monitors, and more toroids will be installed now; they will be available for future very-high-intensity operation. They cannot be placed in the protection system until electronics and information-processing equipment is developed. Calculations are under way to estimate the worst case of time-to-failure for missteered beam striking a collimator. These and other calculations are helping to define the level of protection needed as a function of beam current. A system of redundant monitoring of magnet currents will be tested in a trial installation.

A scheme for remote monitoring of long-term position shifts of major components along Line A has been devised and is partially designed.

Work on preparing the P^3, SMC, and LEP secondary-beam lines for high-intensity operation has continued. This includes upgrading and radiation-hardening of adjustable collimators, control systems, vacuum hardware, power cabling, and lifting fixtures. Preliminary optics design calculations for a new beam area in the last leg of the SMC are in progress. Work on a number of minor improvements in Beam Area B is under way.

Magnet-measurement efforts have been devoted largely to WNR beam components. The LX-BM-01 magnet has been modified, and several new steering magnets are being built.

The prototype cryostat for the polarized proton target is undergoing cryogenic tests after repairs. The ^4He pumping system, microwave power supply, and a set of pole caps for the Varian magnet are all on order.

Fabrication of the redesigned components for RADIP is now well along. In addition, revisions to the shielding are being made which should decrease dose rates at operator locations.

The Merrimac box-lifting mechanism has been repaired and a manual-control system, using television viewing, is being implemented to permit easier maneuvering.

A new remote-handling system called Monitor is ready for operational development. Monitor consists of a remotely controlled articulating hydraulic crane with an electric manipulator attached to its boom end. The assembly is mounted as a trailer which can either be towed into position or lifted in by a crane. Using television, all monitor movements may be controlled from a distance of 30 m or more. Most remote-handling operations in Area A will be effected in conjunction with the building crane, which can be operated with extended-pendant control and television viewing. Eventually, the system should be equipped with a servo master/slave manipulator.

Shielding design, fabrication, and installation were major activities during this report period. Overall general patterns were completed, and shield envelopes were defined. Most of the major shielding materials for the Great Shutdown are now on hand.

The PERT system, which includes the bulk of the tasks needed to complete the high-intensity modification program in the experimental areas, shows that the work is not being completed at a rate commensurate with an August 18th turn-on of beam in Area A. Extremely close coordination and resource allocations will be required to prevent a delay longer than one month beyond the scheduled date.

Large-Spectrometer Systems

Energetic Pion Channel and Spectrometer (EPICS)

The major accomplishment of this period was the completion of the shimming and mapping of 1P-BM-01 and 1P-BM-04. Analysis of the maps from all four magnets is not yet complete; however, preliminary results indicate that the shimming reduced the line width from $\sim 4 \times 10^{-4}$ to 1.5×10^{-4} rms at 15 kG where the design resolution is 0.9×10^{-4} rms. The remaining line width can be corrected with the FM (multipole magnets), and two of the three necessary FM magnets have been delivered by the Univ. of Colorado group. Since we have now shown that the FM magnets will have enough strength to make any necessary optical corrections, we have eliminated all futher work on the H_t correction windings for the EPICS channel and spectrometer. With the completion of the mapping and shimming, it is now possible to proceed to install the EPICS channel in the shielding. At this moment, we are approximately one week behind the schedule announced at the last Users Meeting. We now expect to have the channel installed and ready for alpha-particle testing approximately the 15th of July of this year.

Research

Although the LAMPF accelerator was off during this quarter, the many LASL and visitor physicists associated with LAMPF experiments have been busy analyzing data taken in the previous year and preparing new experiments for the coming fall. A number of experiments have reached the stage of public exposure: there are 13 contributed talks, 1 invited talk, and 5 published papers represented in the experiments described in this report.

A greatly extended range in the detection of residual stable nuclei following pion interactions resulted from the Exp. 62/121 collaboration. They used GeLi detectors to measure gamma rays following interactions of 100-MeV π^+, 220-MeV $\pi^\pm$, and 200-MeV protons. From ^{58,60}Ni targets, they saw alpha-removal nuclei (including four-alpha removal) strongly. For ^{58}Ni, the mean number of nucleons removed was six to seven for pions independent of energy and charge. They suggest that comparison of the inelastic excitation for $\pi^\pm$ might be a (unique) way of extracting neutron B(E2) values.

Analysis of data for small-angle (6°-24°) $\pi^+ - {}^{40}Ca$ elastic scattering has been done (Exp. 80) at 174 MeV and 204 MeV. Enhancement of the cross section because of constructive nuclear-coulomb interference is seen; the measured values agree well with a model by H. Bethe.

Attempts to detect parity violation in the strong interaction (Exp. 137), through asymmetries in the scattering of longitudinally polarized protons, were continued. Measurements of p−p scattering at 15 MeV at the LASL tandem were consistent with an upper limit of 3×10^{-7}. Data on p−Be scattering at 8 GeV at the ZGS accelerator at ANL being analyzed, with preliminary results giving a statistical accuracy of 10^{-6}.

Cross sections and energy spectra for p, d, t, ^3He and ^4He emission induced by 235-MeV π^+ and 800-MeV protons on magnesium, nickel, and silver were reported (Exp. 153). The particle-emission spectra had exponential fall-offs characterized by N_0 $\exp(-bp_n^2)$, where p_n is the momentum per nucleon. The parameters N_0 and b vary rapidly with outgoing particle mass A_0 but only slowly with target mass A_T.

Micromapping of the thorium and uranium concentrations on the surfaces of lunar rocks has been started (Exp. 161) by inducing fission with fast neutrons from the A-6 beam stop. Fission tracts are observed in a mica sheet placed in contact with the polished rock surface. Analysis of the thorium/uranium ratios for a number of samples is proceeding.

During a feasibility study for low-energy pion-nucleus elastic and inelastic scattering (Exp. 180), a measurement of $\pi^+ - {}^{12}C$ scattering at 50 MeV was taken. The angular distribution from 30° to 120° was obtained. Comparison with simple optical potentials shows that these are in substantial disagreement with the data when the free π-nucleon parameters are used.

Several groups have reported studying neutron fluxes in preparation for future experiments. A multicomponent neutron shield of boron, gypsum, lead, and steel was tested (Exp. 26) for effectiveness in shielding against neutrons produced by 800-MeV protons stopping in uranium. The results indicate that the shielding planned for the WNR target should be adequate. A movable steel shielding plug, 1 m × 1 m × 0.75 m located at the A-6 beam stop, enabled tests of neutron backgrounds for three neutrino experiments. A 5500-kg water Cerenkov counter (Exp. 31), two 2700-liter tanks of $Ca(NO_3)_2$ and $C_2C\ell_4$ (Exp. 53), and a sandwich of plastic scintillator and optical spark chambers (Exp. 148) were used to measure both accelerator neutron and cosmic-ray backgrounds in the Neutrino Facility. By measuring neutron fluxes with two positions of the movable plug, it was determined that a final shielding configuration of 6-7 m of steel is needed. Tests will continue this fall. Fast neutrons from the A-6 beam stop have been used to measure cross sections for (n,2pn), (n,α), (N,2), and (n,3pn) reactions by radio-chemical means (Exp. 111). The values obtained are large enough to indicate that new neutron-rich nuclides should be generated over the entire periodic table by the (n,2pn) reaction and over the region $Z < 60$ by the (n,3pn) reaction.

A simpler version of the π^0-spectrometer (Exp. 181) has been proposed to study the charge-exchange reaction $\pi^- p \rightarrow \pi^0 n$ at energies of 30-160 MeV. This experiment is designed to have ±2% precision and thus will compliment the elastic-scattering measurements now being done (Exp. 96), and will enable tests of charge independence at the few percent level. Monte Carlo calculations have been made to simulate the resolution and line-shape of the spectrometer for various detector geometries.

Two types of detectors have been developed for beam Line A diagnostics as part o the Great Shutdown program. Quadrant secondary-emission monitors are currently being constructed in order to provide a fast-protect system for mis-steering of the main proton beam. A prototype ion chamber has been built which will indicate whether the proton beam is striking a pion-production target.

Theoretical efforts on the interactions of pions in nuclear matter are continuing. These have begun with pion scattering at the 3,3 resonance in regions of low-nuclear density (corresponding to the nuclear surface), and at non-resonance energies in regions of high nuclear density (the nuclear interior) where correlations and multiple reflections seem to be important.

Theoretical models for the depolarization of muons in liquid helium are being studied. The mechanism being considered is that of electron recombination by the initial mesic helium ion to form a neutral $\alpha\mu e$ atom, and subsequent sharing of the muon polarization with the electron.

Atomic theory is also being invoked to study the atomic capture of negative mesons. A statistical generalization of the Fermi-Teller model is being tried, with Monte Carlo calculations of the ionization cross section, capture cross section, and atomic ℓ-state resulting from the cascade.

Practical Applications of LAMPF

Much effort has been applied to Great-Shutdown tasks. A number of hardare and software additions and improvements were made at the control facility for the biomedical channel. Permanent helium tanks and two slit systems for the channel have been designed and partially fabricated. The analysis of the tuning results obtained in the first section of the channel has been completed. Analysis of the microdosimetry and dosimetry data taken during the final beam cycles is continuing. Projects under way include new waterproofing systems for all dosimeters, redesign of the 40-cm primary-beam monitor, computer interfacing of the 3-D scanner, and the design of new inexpensive electrometers.

Analysis of some of the muonic x-ray data from Exp. 100 was completed with good agreement between experiment results and prediction. Thermal treatment of spontaneous animal tumors is continuing with localized current fields. Three animals have recently been treated with a less invasive technique than that used previously. Apparatus for the whole-body heating of animals has been constructed and given to H-Y to test thermal tumor therapy. The possibility of detecting tumors by measuring bioelectric potentials on the skin is being experimentally evaluated.

Publications

M. D. Cooper and R. A. Eisenstein, "FITPI: Modifications to the Optical Model Program PIRK for Parameter Searches and Total Cross Sections," Los Alamos Scientific Laboratory report LA-5929-MS (April 1975).

F. K. Wohn, W. L. Talbert, R. S. Weinbeck, M. D. Glascock, and J. K. Halbig, "International-Conversion Coefficient Determination of Odd Parity for the 108.8-keV First-Excited State of ^{91}Rb," Phys. Rev. C **II**, No. 4 (April 1975).

G. A. Miller and J. E. Spencer, "Pion Charge-Exchange Reactions with Nuclei," Phys. Letters, **53B**, 329 (December 1974).

Papers Prepared for Publication: Papers Submitted at Conferences

G. A. Miller and J. E. Spencer, "A Survey of Pion charge-Exchange Reactions," submitted to Nucl. Phys.

M. E. Bunker, B. S. Nielsen, J. W. Starner, B. J. Dropesky, and W. R. Daniels, "The ^{158}Er → Value," submitted for presentation at the APS Mtg., Washington, D.C., April 18-May 1, 1975.

L. R. Veeser, G. J. Russell, E. D. Arthur, P. A. Seeger, W. F. Sommer, D. M. Drake, R. G. Fluharty, and R. F. Bentley, "Spectrum and Shielding Measurements and Calculations of Neutrons Produced by 800-MeV Protons," presented at the Conf. of Nuclear Cross Sections and Tech., Washington, D.C., March 1975. (To be published in proceedings.)

M. Johnson, "Theory of Meson Exchange Potentials for Nuclear Physics," submitted to Ann. Phys.

R. L. Hutson, "Calculations of Two-Dimensional Electrical Field and Potential Distributions Around Electrodes in Conducting Media," submitted to Medical Physics.

H. B. Knowles, G. E. Tripard, and F. H. Ruddy, "Plastic Track Detectors as Negative Pion Macro and Micro Dosimeters," submitted for presentation at the 17th Ann. Mtg. of Amer. Assoc. of Physicists in Medicine, San Antonio, TX, August 3-7, 1975. (To be published in proceedings.)

H. I. Amols, J. F. Dicello, T. F. Lane, G. W. Pfeufer, J. A. Helland, and H. B. Knowles, "Microdosimetry of Negative Pions at LAMPF," presented at the Amer. Assoc. of Physicists in Medicine, Chicago, IL, December 1-6, 1974. (To be published in Radiology.)

H. I. Amols, J. F. Dicello, M. E. Schillaci, M. A. Paciotti, T. F. Lane, J. N. Bradbury, D. L. Roeder, and J. A. Helland, "Absorbed Dose and Radiation Quality for Background Radiation from a Negative Pion," to be presented at the 17th Ann. Mtg. of the Amer. Assoc. of Physicists in Medicine, San Antonio, TX, August 3-7, 1975.

M. M. Kligerman, J. F. Dicello, H. T. Davis, R. G. Thomas, C. J. Sternhagen, L. Gomez, and D. F. Petersen, "Initial Comparative Response of Experimental Tumors to Peak Pions and X Rays," presented at the joint meeting of the Amer. Assoc. of Physicists in Medicine and the Radiological Society of North America, Chicago, IL, December 1-6, 1974. (To be published in proceedings.)

J. F. Dicello, H. I. Amols, T. F. Lane, A. S. Lundy, J. D. Doss, H. B. Knowles, and J. E. Barnes, "Dosimetry for Pion Beams at LAMPF," to be presented at the 23rd Ann. Mtg. of the Radiation Research Society, Miami Beach, FL, May 11-12, 1975. (To be published in Radiation Research.)

M. M. Kligerman, C. J. Sternhagen, F. Dobrowolski, H. T. Davis, J. E. Barnes, T. F. Lane, J. N. Bradbury, and D. F. Petersen, "Initial Comparative Response of Metastatic Superficial Nodules and Surrounding and Underlying Normal Tissue to Peak Pions and X Rays," to be presented at the Amer. Radium Soc. Mtg., May 4-9, 1975.

H. I. Amols, J. F. Dicello, and T. F. Lane, "Microdosimetry of Negative Pions," to be presented at the 5th Symposium on Microdosimetry, Verbania Pallanza, Italy, September 22-26, 1975.

J. D. Bowman, C. M. Hoffman, C. Hwang, R. E. Mischke, D. E. Nagle, J. M. Potter, D. M. Alde, P. G. Debrunner, H. Frauenfelder, L. B. Sorensen, H. L. Anderson, and R. Talaga, "Limit on Parity Violation in P-Nucleus Scattering at 6 GeV/C," submitted to Phys. Rev. Letters.

J. S. Frank, R. H. Heffner, K. A. Klare, R. E. Mischke, D. E. Nagle, and D. C. Moir, "The Elastic Scattering of Low-Energy Pions on Protons," submitted for presentation at the VI Intern. Conf. on High-Energy Physics and Nuclear Structure, Santa Fe, NM, June 9-14, 1975. (Proceedings to be published.)

H. A. Bethe and M. Johnson, "Nuclear Matter Theory for Pion Scattering from Nuclei," ibid.

M. Leon, "Nuclear Resonances in Hadronic Atoms," ibid.

J. D. Knight, C. J. Orth, M. E. Schillaci, R. A. Naumann, H. Daniel, K. Springer, and H. B. Knowles, "Recent Experimental Results of the Mesic Chemistry Program at LAMPF," ibid.

C. A. Bordner, P. A. M. Gram, W. Hassenzahl, H. H. Howard, T. R. King, A. T. Oyer, G. A. Rebka, and F. Shively, "A Measurement of the Cross Section for the Reaction $\pi^- + p \rightarrow \pi^+ + n$ at 350 and 300 MeV," ibid.

C. A. Bordner, P. A. M. Gram, W. Hassenzahl, H. H. Howard, F. T. Shively, T. R. King, A. T. Oyer, and G. A. Rebka, "The Elastic Scattering of Positive Pions by Carbon at 147 MeV," ibid.

G. Glass, M. L. Evans, M. Jain, L. C. Northcliffe, C. G. Cassapakis, Production at 0° from the Reaction $pp \rightarrow np\pi^+$ at the Medium Energies," ibid.

G. Ringer and J. Negele, "Deformed Hartree-Fock Description of the Fe, Ni, and Zn Isotopes," ibid.

J. E. Spencer and H. A. Thiessen, "Coincidence Experiments at Intermediate Energies," ibid.

G. Rinker and L. Wilets, "High-Order Vacuum Polarization in Exotic Atoms," ibid.

M. Leon and R. Seki, "Atomic Capture of Negative Mesons; I. The Fermi-Teller Model," submitted to Ann. Phys. (N. Y.).

M. Leon and J. H. Miller. "Atomic Capture of Negative Mesons; II. The Fuzzy Fermi-Teller Model," submitted to Ann. Phys. (N. Y.); also submitted for presentation at the VI Intern. Conf. on High-Energy Physics and Nuclear Structure, Santa Fe, NM, June 9-14, 1975.

S. Shlaer, "The Role of Computers in an Experimental Radiation Therapy Facility," submitted for presentation at Canadian Information Processing Soc. 1975 National Conf., Regina, Saskatchewan, Canada, June 24-26, 1975.

L. S. Gomez, D. M. Smith, and J. F. Dicello, "Effects of Negative Pions on Testes Weight Loss and Spermatogenic Stem-Cell Renewal in Mice," submitted for presentation at Work-in-Progress session of the 23rd Ann. Mtg. of the Radiation Research Soc., Miami Beach, FL, May 11-15, 1975. (To be published in proceedings.) Also submitted to Radiation Research.

M. T. Wilson, L. L. Thorn, and D. L. Grisham, "The First-Generation LAMPF Target and Insertable Beam Monitoring Instrumentation Mechanisms," submitted for presentation at the 23rd Conf. on Remote Systems Tech., San Francisco, CA, November 16-21, 1975.

C. L. Morris, "The Sensitivity of π^+ and π^- Inelastic Scattering to Differences in the Neutron and Proton Amplitudes," submitted to Phys. Rev. C.

D. R. Machen, J. M. Potter, and R. F. Thomas, "A Serial Driver Module for the Camac Serial Highway System," submitted for presentation at the 1975 Nucl. Sci. Symposium, San Francisco, CA, November 19-21, 1975.

D. R.Machen, J. M. Potter, F. J. Naivar, E. P. Elkins, and D. D. Simmonds, "Camac-Based Computer-Computer Communications Via Microprocessor Data Links," ibid.

J. F. Dicello, R. D. Colvett, W. Gross, and U. Kraljevic, "Beta Emission from Encapsulated Sources of Californium-252," submitted to Radiation Research.

J. D. Bowman, "Parity Nonconservation in P-P and P-Nucleus Scattering," presented at the Symposium on Intern. Studies in Nuclei, Mainz, February 17-20, 1975. (To be published in proceedings.) Also submitted for presentation at the Gordon Conf., Colby, NH, June 21, 1975. (To be published in proceedings.)

LAMPF Experimental Program Reports and Publications

(Parasite experiment) C. J. Orth, W. R. Daniels, and B. J. Dropesky, "Identification of ^{236}Th," submitted to Phys. Rev. C.

(Exp. 2) M. D. Cooper, D. C. Hagerman, R. P. Redwine, H. O. Meyer, M. J. Jakobson, R. H. Jeppeson, I. Halpern, L. D. Knutson, R. E. Marrs, G. R. Bowleson, K. F. Johnson, and J. R. Calarco, "$\pi^\pm$ - ^{4}He Total Cross Sections from 50-100 MeV," prepared for the Conf. of the Amer. Phys. Soc. (Washington, D.C., April 28-May 1, 1975); submitted to Bull. Am. Phys. Soc.

(Exp. 7) J. P. Davidson, E. B. Shera, L. K. Wagner, and R. M. Steffen, "Muonic X-Rays from the Transition Nuclei ^{194,195,196}Pt," prepared for the Conf. of the Amer. Phys. Soc. (Washington, D.C., April 28-May 1, 1975); submitted to the Bull. Am. Phys. Soc.

(Exp. 37) T. W. Crane, D. E. Casperson, V. W. Hughes, P. A. Souder, R. D. Stambaugh, P. A. Thompson, H. F. Kaspar, H. W. Reist, H. Orth, G. zu Putlitz, and A. B. Denison, "Precision Measurements of $1S_{1/2}$ Muonium Hyperfine Structure Interval $\Delta\nu$: I. Experimental Method," prepared for the Conf. of the Amer. Phys. Soc. (Washington, D.C., April 28-May 1, 1975); submitted to the Bull. Am. Phys. Soc. and Phys. Rev.

(Exp. 37) T. W. Crane, D. E. Casperson, V. W. Hughes, P. A. Souder, R. D. Stambaugh, P. A. Thompson, H. F. Kaspar, H. W. Reist, H. Orth, G. zu Putlitz, and A. B. Denison, "Precision Measurement of $1S_{1/2}$ Muonium Hyperfine Structure Interval $\Delta\nu$: II. Results," ibid.

(Exp. 50) H. W. Baer, J. A. Bisterlich, S. Cooper, K. M. Crowe, J. P. Perroud, R. H. Sherman, F. T. Shively, and P. Trüoel, "Photon Spectrum in Pion Capture on Tritium," submitted for presentation at the VI Intern. Conf. on High-Energy Physics and Nuclear Structure, Santa Fe, NM, June 9-14, 1975. (Proceedings to be published.)

(Exp. 56) C. W. Bjork, P. J. Riley, B. E. Bonner, J. E. Simmons, K. D. Williamson, Jr., D. W. Werren, H. C. Bryant, C. G. Cassapakis, S. Cohen, B. D. Dieterle, C. P. Leavitt, D. M. Wolfe, M. L. Evans, G. Glass, J. C. Hiebert, M. Jain, and L. C. Northcliffe, "Neutron Spectra from Proton Bombardment of Deuterium at 647 and 800 MeV," prepared for the Intern. Conf. on Few Body Problems in Nuclear and Particle Physics, Laval Univ., (Quebec, August 27-31, 1974).

(Exp. 56) B. E. Bonner, J. E. Simmons, K. D. Williamson, Jr., D. W. Werren, H. C. Bryant, C. G. Cassapakis, S. Cohen, B. D. Dieterle, D. M. Wolfe, M. L. Evans, G. Glass, J. C. Hiebert, M. Jain, L. C. Northclife, C. W. Bjork, and P. J. Riley, "Measurement of the 0° Neutron Spectrum from the Reaction $p + p \rightarrow n + p + \pi^+$ at T_p = 764 MeV," ibid.

(Exps. 67 & 119) B. J. Dropesky, G. W. Butler, C. J. Orth, R. A. Williams, G. Friedlander, M. A. Yates, and S. Kaufman, "Excitation Functions for the $^{12}C(\pi\pm,\pi N)^{11}C$ Region of the (3,3) Resonance," submitted to Phys. Rev. Letters.

(Exps. 67 & 119) N. P. Jacob, S. S. Markowitz, R. R. Wilbar, and M. M. Sternheim, "Neutron Knockout by Pion$^\pm$ on ^{14}N, ^{16}O, and ^{19}F," Bull. Am. Phys. Soc. **20**, 663 (1975).

(Exp. 81) J. Hudomalj-Gabitzsch, J. Witten, N. Gabitzsch, G. Mutchler, J. Clement, T. Williams, G. Phillips, E. Hungerford, L. Y. Lee, B. Hayes, M. Warneke, and J. Allred, "Pion Production by 800-MeV Protons in the Reaction $^1H\,(p,\pi^+,p)N$," Bull. Am. Phys. Soc. **20**, 554 (1975).

(Exp. 81) T. M. Williams, T. R. Witten, M. Furic, D. Mann, J. Gabitzsch, G. Mutchler, J. Clement, R. Felder, G. C. Phillips, B. Mayes, E. Hungerford, L. Lee, M. Warneke, and J. Allred, "Quasi-Free Scattering in p=d Break-up Reactions at 800 and 600 MeV," Bull. Am. Phys. Soc. **20** 554 (1975).

(Exp. 84) Clark Goodman, "Neutron Energy Flux and Dosage in the LAMPF π^- Biomedical Channel," Los Alamos Scientific Laboratory report LA-5746-MS (October 1974).

(Exps. 86 & 79) A. M. Zebelman, A. M. Poskanzer, J. D. Bowman, R. G. Sextro, and V. E. Viola, Jr., "Fragments from Uranium Irradiated by 2.1 GeV/Nucleon Deuterons and Alpha Particles," Lawrence Berkeley Laboratory report LBL-3427; submitted to Phys. Rev. C.

(Exp. 100) R. L. Hutson, "*In vivo* Tissue Analysis Using Mu-Mesic X Rays," Los Alamos Scientific Laboratory report LA-5867-MS (February 1975).

(Exp. 105) R. G. Helmer, R. C. Greenwood, R. J. Gehrke, and C. W. Reich, "Gamma-Ray Studies of the Decay of ^{128}Ba and ^{128}Cs," Bull. Am. Phys. Soc. **19**, 1029 (1974).

(Exp. 105) M. E. Bunker, J. W. Starner, B. J. Dropesky, W. R. Daniels, and B. S. Neilson, "The $^{158}Er \rightarrow {}^{158}Ho$ Decay Scheme and Q_B Value," Bull. Am. Phys. Soc. **20**, 625 (1975).

(Exp. 111) J. C. Hill, K. H. Wang, and R. F. Petry, "Production of Neutron-Rich Nuclides Using High-Energy Neutrons at LAMPF," Bull. Am. Phys. Soc. **19**, 1027 (1974).

(Exp. 111) R. F. Petry, K. H. Wang, and J. C. Hill, "Study of the ^{200}Pt - ^{200}Au Decay Chain at LAMPF," Bull. Am. Phys. Soc. **19**, 1019 (1974).

(Exp. 119) M. M. Sternheim and R. R. Silbar, "Effects of Nucleon Charge Exchange on the $(\pi,\pi n)$ Puzzle," submitted to Phys. Rev. Letters.

(Exp. 125) L. C. Northcliffe, M. L. Evans, G. Glass, J. C. Hiebert, M. Jain, H. C. Bryant, C. G. Cassapakis, S. Cohen, B. D. Dieterle, D. M. Wolfe, B. E. Bonner, J. E. Simmons, D. W. Werren, C. W. Bjork, and P. J. Riley, "Precision Measurement of n-p Charge Exchange Cross Section at 640 MeV," prepared for the Intern. Conf. on Few Body Problems in Nuclear and Particle Physics, Laval Univ., (Quebec, August 27-31, 1974).

(Exp. 142) W. K. Hensley, J. R. Huizenga, D. G. Perry, J. C. Browne, and C. Kalbach, "Muon Lifetime Measurements in the Actinide Elements," prepared for the Conf. of the Amer. Phys. Soc. (Washington, D.C., April 28-May 1, 1975); submitted to the Bull. Am. Phys. Soc.

(Exp. 147) D. G. Perry, D. W. Barr, J. S. Gilmore, D. J. Dudziak, M. L. Simmons, G. J. Russell, P. A. Seeger, M. J. Fluss, R. Heinrich, and V. A. Ryan, "Neutrons from a High Energy Proton Beam Stop," Proc. First Topical Mtg. on Technology of Controlled Nucl. Fusion (San Diego, CA, April 16-18, 1974), Vol. I, p. 333.

(Exp. 153) J. F. Amann, P. D. Barnes, M. Doss, S. A. Dytman, R. A. Eisenstein, J. Penkrot, and A. Thompson, "Studies of Charged Particle Emission in Reactions Induced by 220 and 50-MeV Plus-Pions," submitted to Bull. Am. Phys. Soc. and Phys. Rev.

(Exp. 161) E. L. Haines, I. D. Hutcheon, and J. R. Weiss, "Fission Track Record of Apennine Front Kreep Basalts," submitted to Lunar Science VI (1975).

(Exp. 163) E. B. Shera, G. A. Rinker, Jr., M. J. Bennett, R. B. Perkins, E. T. Ritter, H. D. Wohlfahrt, G. Fricke, L. K. Wagner, R. K. Sheline, R.M. Steffen, and J. W. Negele, "Muonic Isotope Shifts in the Even Fe Nuclei," submitted to Phys. Rev. Letters.

(Exp. 166) R. J. Powers, F. Boehm, P. Vogel, A. Zehnder, T. King, A. R. Kunselman, P. Roberson, P. Martin, G. H. Miller, R. E. Welsh, and D. A. Jenkins, "A Precise Determination of E2 and E4 Moments in ^{165}Ho from Muonic X Rays," Calif. Inst. of Technology report CALT-63-218 (January 1975); Phys. Rev. Letters **34** No. 8, 492 (February 24, 1975).

(Exp. 180) R. A. Eisenstein, J. Amann, P. D. Barnes, M. Doss, S. A. Dytman, J. A. Penkrot, and A. C. Thompson, "Elastic Scattering of 50-MeV π^- and ^{12}C," prepared for the Conf. of the Amer. Phys. Soc. (Washington, D.C., April 28-May 1, 1975); submitted to the Bull. Am. Phys. Soc.

(Exp. 206) R. O. Mueller, V. W. Hughes, H. Rosenthal, and C. S. Wu, "Collision Quenching of the Metastable 2S State of Muonic Hydrogen and the Muonic Helium Ion," submitted to Phys. Rev. A.

II. ENGINEERING SUPPORT

LAMPF Accelerator

Accelerator Support

A major portion of the 201-MHz linac renovation was accomplished in this quarter. All the prime bellows were received from the vendor, furnace annealed, and installed on the drift-tube stems. The tank section weld joints were all leak checked and repaired as required. The interior surface of the tanks was then cleaned, and the drift-tubes were installed. All four tanks were repositioned to coincide with the drift-tube alignment reference line.

The drift tubes in Tanks 2, 3, and 4 have been installed and realigned to a tolerance of ± 0.13 mm and referenced to the new LAMPF coordinate system. The water and vacuum manifolds for these tanks are also complete.

The drift-tube quadrupole-magnet manifolds and jumpers were installed on Tank 4, the water system flushed, and the magnets tested for proper operation. Manifolds and jumpers are being installed on Tanks 2 and 3. All post couplers, drive loops, and monitor loops have been cleaned and reinstalled in Tanks 3 and 4. The angular positions and gaps of the posts have been set, and a bead pull is under way in Tank 4. All the tank head assemblies and the intertank spacer were removed, and most have been disassembled and cleaned. The Tank 4 heads were reassembled for the bead pull and then modified for further tests.

The spring-finger flanges on the Tank 1 drift tubes have been modified to accommodate a 2.61-mm-thick Viton 0-ring, which will replace a troublesome wire seal.

A set of cold traps and refrigerators has been ordered for the 201-MHz soft vacuum system. The refrigerators have been delivered.

The solenoid valves on the 211-MeV beam stop were replaced with a single valve that was mounted on the beam channel wall away from the maximum radiation area. The maximum allowable beam current the 211-MeV beam stop can accommodate was determined to be 100 μA.

The EAI residual gas analyzer has been repaired and returned to LAMPF.

A total of 15 magnets was installed and realigned using the new LAMPF coordinate system in the injector area. The H^+ and H^- columns were also realigned and these lines are now complete with the exception of the quad doublet nearest Tank 1.

Major rework of the transition region, between the 201-MHz and 805-MHz sections of the linac, has been finalized, and drawings are being prepared to relocate quadrupole doublets, beam boxes, valves, and diagnostic devices. This effort will start when work on the drift-tube linac permits.

The 50-mm isolation valves on the accelerator beam line and in the injector area have been modified to accept aluminum wire seals instead of the aluminum foil seals.

The two replacement bridge couplers for modules 12 and 13 were completed. The bridge coupler for module 13 has been installed, and the final tuning activities are under way. The four quad doublets in this module have been removed, and will be reinstalled and aligned when the module tuning is completed.

Several position monitors for the 805-MHz linac have been modified by the addition of rf coupling loops for ΔT experiments.

A total of 73 furnace heats was run this quarter. Most of these heats were in support of the accelerator-improvement activities, such as the two new 805-MHz bridge tanks, collimator parts for the accelerator injector, rf drive-loop posts, and the replacement bellows for the 201-MHz drift-tube stems.

The remaining furnace heats were in support of the ion-pump and klystron-tube rebuild operations at ETL, and the development braze heats requested by other MP-Division personnel.

One of the two H_2 gas dryers used in the furnace room has been returned to the manufacturer (U.S. Dynamics) for rebuilding; however, the remaining dryer is adequate for supporting the present brazing schedule.

805-MHz RF System

The klystrons were run ~ 2000 hvh and 4000 fh in this quarter because of the extended shutdown. Most of these hours were to test rebuilt klystrons. The two klystrons which were rebuilt in the last quarter have been operated for 424 fh on the accelerator. This pair of klystrons has accumulated 2348 fh and is performing well.

Klystron Repair Facility

One VA-862-A klystron, S/N 214, and one L-5120 klystron, S/N 2026, were rebuilt this quarter. Klystron S/N 214 has been tested at full power for over 100 hvh and a total of 778 fh at the ETL. Klystron S/N 2026 has not yet been installed, but its perveance and vacuum are quite good. The high-voltage section of this klystron was modified during the rebuild to reduce the voltage gradients and the crowbar rate which had been high prior to the klystron's failure.

A pinch-off assembly with metal flanges for the L-5120 klystron was designed, fabricated, and used on a klystron. The bolt-on, pinch-off assembly eliminates a troublesome hand brazing operation and facilitates future rebuilds of the klystron. A set of inspection fixtures has been fabricated to measure and gauge the inside axial dimensions of the klystron gun assembly.

The entire klystron-rebuilding area is being rearranged to include a heliarc welding area, a cleaning area, a fume hood, an assembly room, and an overall improvement in parts flow. The space for the new equipment is being obtained by removing the klystron spares from the ETL building. A klystron storage and transport box is now being fabricated for this purpose.

Kovar and stainless steel welding rings to be used in the rebuilding of the klystron high-voltage sections have been ordered. Spare high-voltage and rf-window assemblies have also been ordered.

Ion Pump Rebuilding

Rebuilding of the 805-MHz ion pumps (500 ℓ/s) has continued as scheduled with the completion of 64 units during this quarter. One hundred and four of these pumps have now been rebuilt and baked out under vacuum. Two of these pumps were selected at random, and pumping speeds were determined in the pressure range of 5×10^{-5} torr to 10^{-9} torr. One test pump had all standard, large-cell anodes, while the other had 50% LAMPF-modified, small-cell dual anodes. Both pumps had a peak pumping speed of 560 ℓ/s in the pressure range of 10^{-6} torr and 5×10^{-8} torr. No differences in pumping speed or pressure-current relationship could be detected.

Ten of the twelve large 201-MHz ion pumps (2400 ℓ/s) have now been rebuilt and baked out under vacuum. Cleaning of the pump bodies was very difficult because of the numerous pockets, corners, and crevices. High-pressure steam and acid etching were both tried with little success. Neither of these methods would remove the gummy-type deposits. The best method, now part of the standard overhaul procedure, is to fire the stainless-steel pump bodies in dry H_2 at 920°C, which reduces the residual deposits to a fine, loose powder that can be removed with a vacuum cleaner—followed by an ethanol rinse.

Magnet Testing and Metrology Lab

Two of the LAMPF pool quadrupole magnets have been prepared and preinstallation tested. These magnets will become part of the revised version of the switchyard.

Coils for the experimental bending magnet scheduled for use in the LEP line have been designed, detailed, and the order placed with a vendor for fabrication.

A Wang program has been generated to provide a printout of the basic characteristics, status, and location of the LAMPF pool magnets. The program is nearing completion and will permit rapid update and distribution as new magnets are incorporated or changes occur.

Six bending and nine quadrupole magnets for the injector area were processed through the tooling dock.

Routine inspection and calibration and/or adjustment of optical instruments, such as jig transits, theodolites, alignment scopes, and precision sight levels, were completed on the collimator test stand at the ETL.

Experimental Lines

Weapon Neutron Research Facility (WNR)—Line D

Tooling dock inspection and installation of alignment blocks for all Line D WNR magnets required for the switchyard and waterfall area are complete.

All of the WNR main beam-line magnets have been prepared and tested prior to installation with exception of the revised version of LD-BM-00. Production winding and potting of the steering magnets is in progress, and two of the twenty coil assemblies are complete.

Figures II-1, II-2, and II-3 show the initial installation of the floor plates and magnet support structures for the switchyard and waterfall areas. The

Fig. II-1.
Line "D" waterfall area before magnet installation.

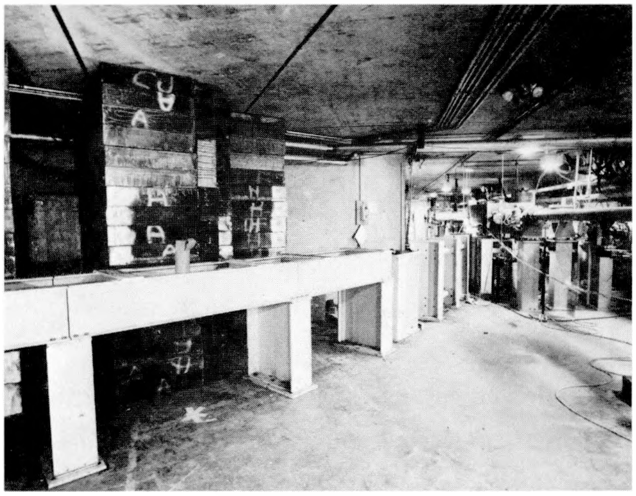


Fig. II-2.
Support structure installation—Line "D" SWYD area.

completed supports with magnets for the switchyard area are shown in Figs. II-4, II-5, II-6, and II-7. The current status of equipment installation in the waterfall area is shown in Fig. II-8.

The floor-plate layout for the kicker magnet, LD-BM-00 beam plug, and LD-QD-01-02 magnets have been completed, and supports are ready for installation as soon as Line A modifications are finished.

Assembly of 15 beam wire-scanner linear actuators was completed, and they are now being wired and checked out prior to installation.

A temporary beam stop was assembled and is ready for installation. This stop will be installed in place of the first Line D quadrupole-triplet magnet and will be used for line tuning.

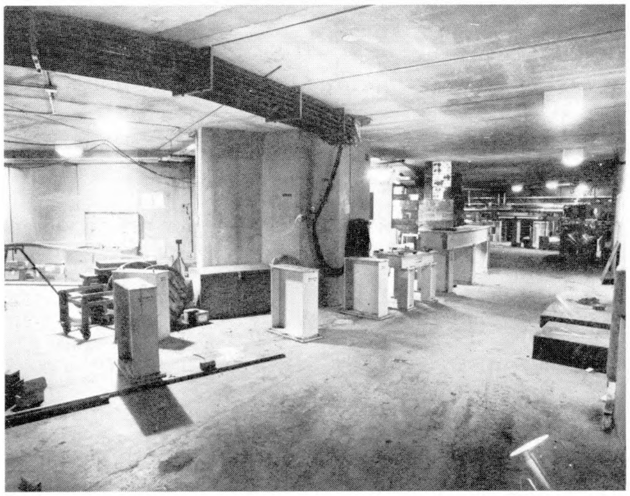


Fig. II-3.
Support structure installation—Line "D" SWYD area.

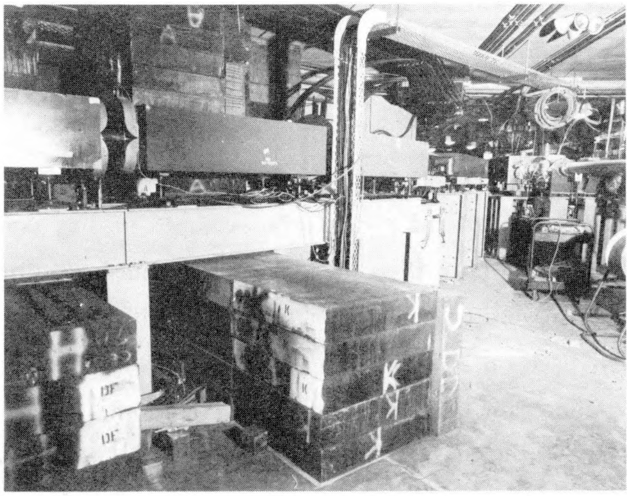


Fig. II-5.
Line "D" SWYD area with magnets installed.

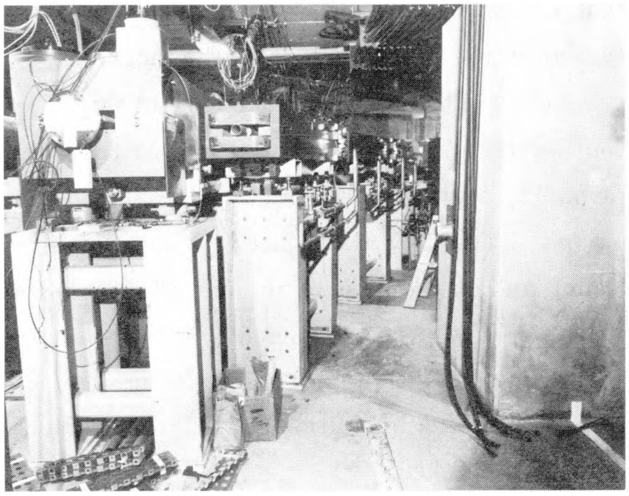


Fig. II-4.
Line "D" SWYD area with magnets installed.

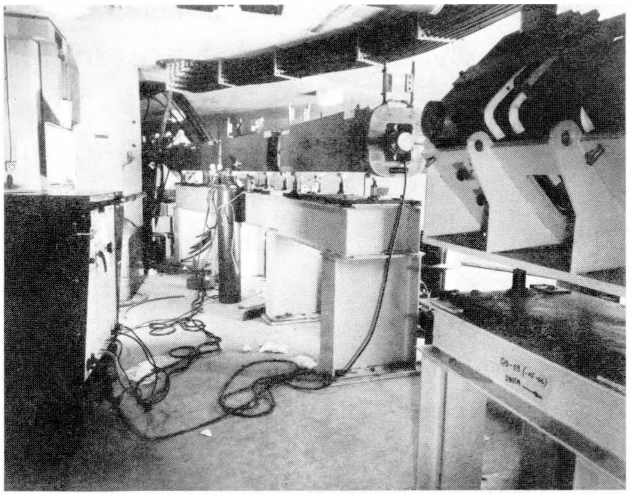


Fig. II-6.
Line "D" SWYD area with magnets installed.

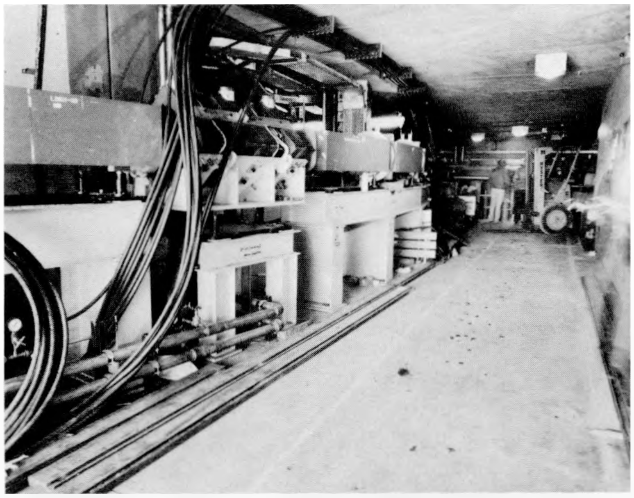


Fig. II-7.
Line "D" SWYD area with magnets installed.

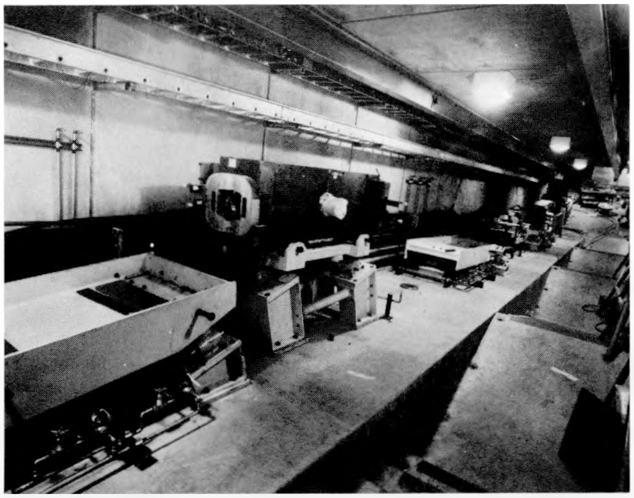


Fig. II-8.
Line "D" waterfall area with bending magnets installed.

During the past quarter development has continued on both the slow kicker for initial beam-line tuning and on the fast kicker which will ultimately be used on WNR.

The slow kicker has been completed and is ready for installation in the switchyard. It is capable of running at rates ranging from 0.5- to 12-Hz at any current from 0- to 400-A. The magnetic field regulation system holds the field to within 0.1% of the desired value for up to 1 ms of beam duration.

Assembly of the fast kicker has progressed well, and the testing program on the fast-deflection system will be stepped up now that the slow kicker is completed. During the last quarter of FY-75 and the first quarter of FY-76, the detailed testing of the fast kicker at 25-kV, 6000-A should begin.

Biomedical Beam Line

The quadrupole triplet and first two bending magnets were removed from the beam line in order to incorporate helium chambers, windows, beam-halo shields, and dust covers. Components are being fabricated, and installation work will commence when manpower is available as higher priority work is accomplished.

Slit 2 was modified to permit installation of a wire chamber upstream of RT-BM-03.

A helium chamber with one remotely removable window has been designed and fabricated for the initial triplet in this line.

Magnetic shields for the cooling-water flow switches were designed and fabricated for the last six magnets in the beam line. Preliminary tests indicate that these will solve the malfunctioning problems caused by the fringe fields from the magnets.

Installation has been completed for the third-level cantilevered shielding support over the treatment room. The support plates for close-packed shielding around RT-QM-07 have been installed. Initial layout and installation of the slit SL-02 support structure have been completed. Final installation and welding of the support will be done after RT-BM-01-02 is back in position and critical clearances have been checked.

All parts are on hand for the cover for the last magnet in the ceiling of the treatment room. Hanging, fit-up, and installation will commence when manpower is available. After assembly checking, the unit will be dismantled for painting.

Energetic Pion Channel and Spectrometer (EPICS)

The drawings for the EPICS separator shield plug and the track system are complete. These two items have been fabricated and delivered but not installed. Associated shielding around this plug and the A-1 target mechanism shield plug was removed, modified as required, and replaced. Design of the actuating mechanism for plug removal is partially complete.

A recheck of target point A-1 with respect to Line A, LEP Line, and EPICS reference line was made in preparation for EPICS channel installation and alignment.

Other Beam-Line Support

A check of magnet SMC-BM-01 in the Stopped Muon Channel was made, and an error in the location of tooling holes was discovered. This was corrected and the magnet realigned.

Survey type work was performed in Area A East to assist in the installation of large steel plates and other equipment placements.

Three turbomolecular pump packages for the switchyard and Area A have been ordered, and a high-pressure, ion-gauge controller for Line B has been received.

An alignment setup was made on one of the large HRS magnets prior to and during assembly. This assured correct alignment of the magnet sections, which is a critical factor. A special prism designed and built for this setup was used.

Instrumentation

Ten toroids were wound for use in the experimental areas. Figure II-9 is a photograph of the largest of these. This toroid will be used in Area A and will have an aperture of over 30 cm when completed. Six vacuum boxes for the switchyard and Line B current monitors have been received, but not assembled. A new method of packing these toroids with polyamide varnish and fiberglass tape has been used to provide a more radiation-resistant current monitor. Merrimac-serviceable current monitors were designed for Area A. Two prototype preamplifiers were built and tested. These have four remotely controlled gain settings for sensitivities of 20, 100, 500, and 2000 nA of beam current per volt of output. Twenty-four voltage-to-frequency converters were built in a production run, and a sample tried in Area A.

The problem of sag due to thermal expansion in the harp wires is being investigated. Very fine nickel ribbon (7.6-μm $\times$ 0.2-mm) has been used in these tests. The sag is being measured for ribbons with and

Fig. II-9.
Partially assembled toroid for the 30-cm current monitors in Area A.

without springs, and ribbons strung with different tension. The present ribbons are expected to sag approximately a centimeter when the central 5-cm section of the 33-cm ribbon is heated to 800°C by the beam in Area A. An intense program to reduce this sag to ~ 0.25 mm is under way.

Electron Prototype Accelerator

Very little was accomplished this quarter in the rebuilding of the EPA because of the concentrated effort to complete LAMPF accelerator rework activities during the present extended shutdown period. Some materials and components were ordered.

Experimental Support

A remotely controlled hoisting mechanism for an existing cryogenic target is being designed for Exp. 2. The design concept for the mechanism is now firm, and it will mount to the stand previously used to support and locate other experimental devices used in this experiment.

The engineering design was completed for the 6800-kg "Bicentennial Magnet" being rebuilt at LAMPF for Exp. 29/64. Purchase requests have been placed for some of the long-lead-time components such as screw-jacks and large roller bearings. However, the detail drafting of the stand structure has been delayed to allow higher priority drafting to proceed during the shutdown period. (The engineering concept of this design is shown on Dwg. SK-MP-8-162 and by a scale model that was built of the magnet and its stand.)

The circulation and jump systems for Exp. 31 are being built. A request has been filed with Zia for the installation of the anticounter supports for this experiment.

A temporary support stand and tilting mechanism were designed and fabricated for the large aperture Cerenkov chamber previously built at LAMPF for Exp. 130. This stand will permit this chamber (weighing 295 kg) to be used in other experimental areas prior to its planned use on the EPICS line structure.

A target chamber, for containing liquid glycerine, was designed and fabricated for Exp. 137 (Figs. II-10 and II-11.) This chamber was used initially by LAMPF personnel at the Argonne ZGS accelerator.

Two detector assemblies have been assembled for Exp. 179. A typical assembly is shown in Figs. II-12 and II-13. New pole pieces for the magnet and an acrylic detector holder have also been fabricated for this experiment.

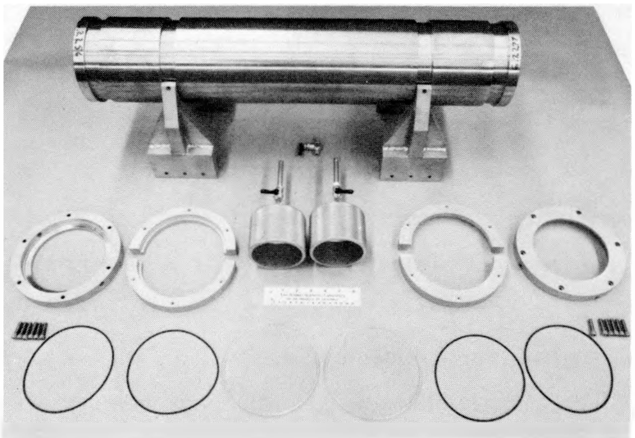


Fig. II-10.
Parts for chamber piece.

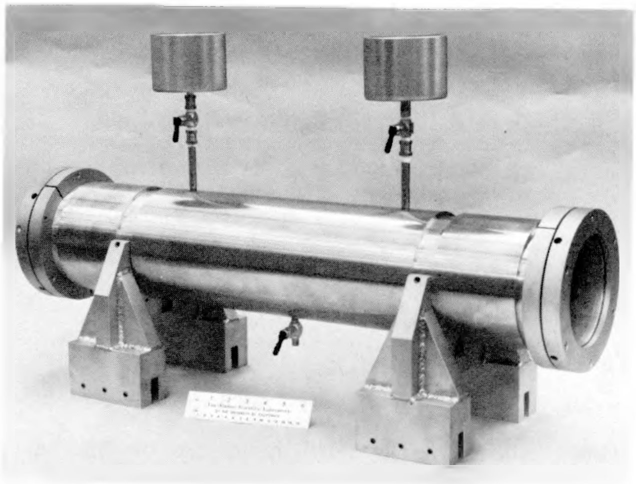


Fig. II-11.
Assembled chamber.

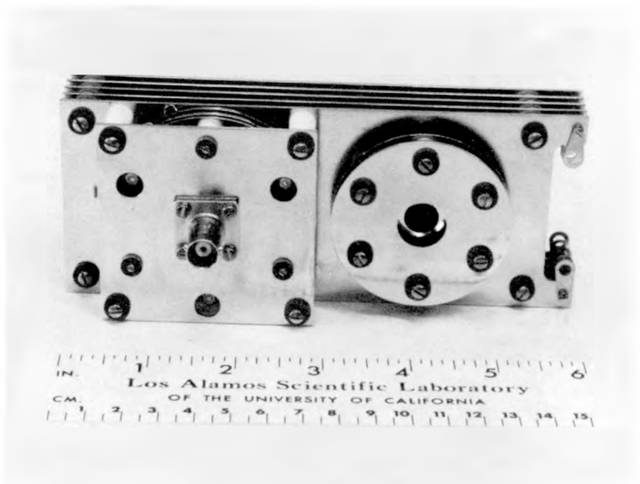


Fig. II-12.
Detector assembly, Exp. 179.

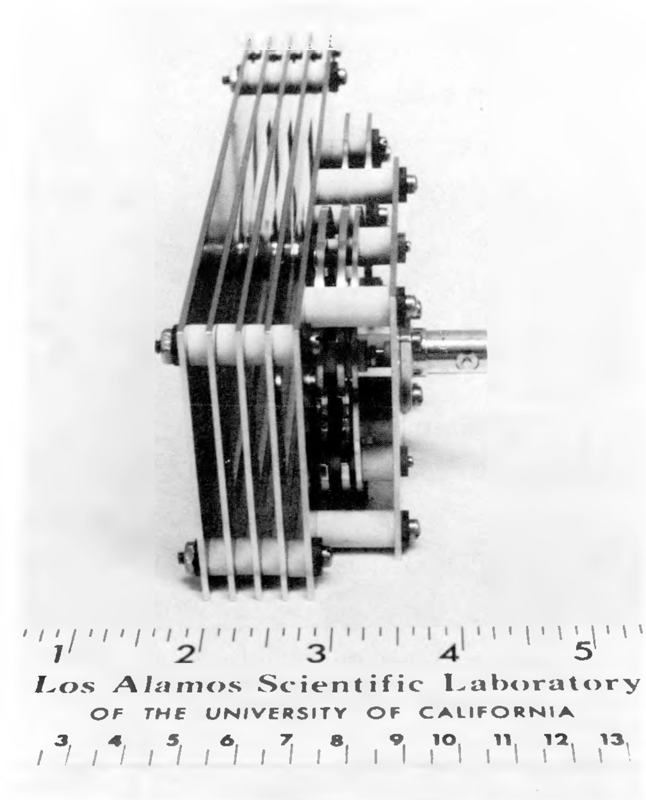


Fig. II-13.
Detector assembly, Exp. 179.

III. ACCELERATOR SUPPORT

201-MHz RF System

The quarter was entirely devoted to system preventive maintenance and retrofits. The crowbar resistor cooling was changed from air to an oil bath with water cooling. Preliminary runs indicated a lack of cooling on the oil bath, and heat exchangers and pumps were ordered. One heat exchanger was received and installed, and the pumps are on hand.

A heat run at 12% duty factor into a 50-Ω load was conducted on module 4 for 70 h. The only failure during the run was the bias supply for the tubes in the PA Modulator. After the run, inspections of the cavities showed no damage to the finger stock. One transmission-line bullet had burned on one finger, and there was burning at the bullet joint on the output window. The RCA 7835 X3-R1 failed during the first effort at the heat run. This tube failed with 10 000 h of filament time and shortly after reaching 10% duty factor. The succeeding tube ran at 12% duty factor in the heat run with no problems.

All the smaller rf cavities in the 201.25-MHz system and one of the 7835 cavities were disassembled, cleaned, and refurbished during the quarter. A second 7835 cavity is in the process of being cleaned and refurbished, and the third cavity will be done after the heat runs are completed.

Several rf tubes were installed and conditioned during the quarter. The 4664 continues to exhibit gas problems at turn-on when it has been off for only short periods (6 h or more). Experiments with processing the tubes by running small amounts of dc current through the elements have shown promise in cutting the processing time significantly when the tube is put in rf service. It is hoped that this will provide an economical method of keeping a semi-processed 4664 on hand for a spare in the event of a tube failure.

Terminations were designed for the Belden 8871 cable, and a test run on the cable and terminations is being made in module 1. If the test cable shows significant improvement in life over the RG17, the rest of the stands will be retrofitted with the Belden cable.

The HV insulators on the 4664 and 4616 cavities were replaced with new insulators of the same design. The loading on all the 4616 cavities was fixed. The 4616 in module 4 showed very little drift during the heat run, as well as appearing to operate at a better loading point.

A new closed-loop control for the high voltage, using semiconductors, was designed and tested during the quarter. Printed circuit cards are now being fabricated, and this modification should be complete by the end of the shutdown.

805-MHz rf System

A large number of modifications to improve the reliability of the 805-MHz rf systems, or to reduce the time of repairing systems or units, were accomplished during this quarter, or will be completed before accelerator turn-on.

A partial listing of modifications and major maintenance completed follows:

1. Extensive modifications were made to quad magnet power supplies to improve performance and reduce troubleshooting time, including quick-change printed-circuit cards, better cooling, and dust protection.
2. The hv-cable failure-indicator system was completed.
3. The bucket-rotator spare was klystron-tested.

4. The induction voltage regulator was removed from Sector G, tested, and found good. It will be reinstalled in Sector G when the new insulator arrives, hopefully before July.
5. All cables and connections in all induction-voltage-regulator, transition-region, and vacuum-breaker cabinets were checked.
6. Riser pipes were installed on hv-pad cables to keep water out of the conduit.
7. The hv cable from the transition region to the capacitor room in Sector B was replaced.
8. In the capacitor room of the transition region in Sector C, the hv cable was dug up and checked for water. None was found, but a bleed hole was installed.
9. Spare units were tested and several repaired.
10. The hv rectifier boards were repaired.
11. Fifteen quad magnet dollies were constructed (quads weigh 140.43 kg).
12. Floor joints and capacitor room-to-floor joints were sealed.
13. The arc-detector system was modified to prevent unwanted override.
14. The hv dividers were modified to be oil cooled.
15. Crowbar current transformers were grounded.
16. Modulator tanks were inspected for water in the oil.
17. A spares inventory was completed, and additional spares were ordered.
18. High voltage in all sectors was calibrated.
19. All sector racks and capacitor rooms were thoroughly cleaned.
20. Spare bins and modules for MP-1 units that control water, vacuum, and resonance were ordered and some were received.
21. Several of MP-8's vacuum-pump power supplies used at ETL were modified.

Modifications and maintenance partially completed and due to be completed by the turn-on date:

1. Vacuum-pump power-supply modification to prevent fires is 75% complete.
2. The hv cable-testing is 90% complete.
3. The capacitor room fail-safe cooling-system plans have been drawn, and the system will be installed in Sector H for evaluation until the next major shutdown.
4. The bucket-rotator tank-resonance system has been moved from Sector A to Sector B. It needs final calibration with rf into the bucket rotator.
5. The hv ground-fault system to turn off the vacuum breaker is installed and is being calibrated.
6. The tank-to-tank phase-monitor-system equipment installation is completed in Tanks 5 through 12.

Much routine maintenance was accomplished. Periodic inspections and calibration of several systems were initiated and will be completed before turn-on. The technician training classes are continuing and are scheduled to be completed June 18. All sections reviewed and added to their equipment data-base information. These data were submitted to MP-9 for inclusion in System 2000. The Belden 8871 hv cable being tested at ETL has 3431 hvh and 2040 h drawing current.

Low-Level RF System

The Great Shutdown has necessitated that almost all low-level rf effort be applied to maintenance and upgrading of the system. Such projects as the 201-MHz test stand, solid-state interface amplifier development, and the 201-MHz 8501 amplifier have been temporarily put aside.

The source room amplifiers have been refurbished, cavities cleaned, and all tubes which have run over 10 000 h replaced. Modifications of the interlock systems were made, both to increase reliability, and to facilitate the addition of motor-driven switches at the input to the 805- and 201-MHz drive lines.

These new coaxial switches have replaced the old coax patch panel which was formerly used to patch one amplifier chain to the drive line and the other to a dummy load. This will make the changeover of amplifier chains a much faster and more pleasant task.

Upgrading of the 201-MHz timing signals in the experimental areas is continuing. Eventually timing signals will be permanently located at all counting houses and in many of the trailers.

During routine maintenance of the drive line, it was discovered that more than 85% of the directional couplers had badly burned resistors in the coupling loops. Because of these resistor failures, the couplers had lost all direction, and had in effect become either capacitive probes or inductive loops, depending on whether the resistors had failed to open or shorted. An extensive investigation, which included discussions with the coupler vendor, indicated that the most probable cause of failure was operating the couplers without a load on the output port.

All couplers were removed from the drive line, the resistors replaced, and the units checked and calibrated. When reinstalling the couplers, isolations were installed at the output port so that the units will always be loaded, even when the coax to the units is removed.

Phase and Amplitude Control System

Considerable effort was spent in bringing all 805-MHz phase subsystems back to top operational condition. Nine phase subsystems were determined to be marginal, either because of low or changing diode output, excessive hysteresis, or sticking operation. These faults were corrected, and the units were successfully subjected to original receiving inspection criteria. The 201-MHz subsystems have not undergone diode checks, but these units will be modified with solid-state diodes prior to turn-on.

Modifications have been made on Bunchers I and II to solve several problems. These modifications include improved "Local-Computer" switching, buncher on-off indication to computer, and a true "no-field" condition when Buncher II is delayed. New phase and amplitude-printed circuit boards have been developed and built. These will replace the hand-wired prototypes currently in use, and provide additional hardware for the new buncher presently being installed. All phase and amplitude equipment necessary for the new buncher is available with the exception of the fast-phase shifter. Although parts are being ordered for three additional units, it may become necessary to use our only 201-MHz spare for a short period of time.

An interlock system has been installed in all phase-control cards so that if a phase-control card is removed from an rf module, a "Run Permit No-Go" will occur. Previously, a phase-card could be removed, accidentally or otherwise, without any apparent effect except to the beam itself.

In the past, we have noted interrelated effects between the phase- and amplitude-control loops and other devices such as wire scanners, water-temperature controllers, and other units using the common +24-V dc power supply. These effects are being eliminated by providing each fast-phase shifter with its own isolated supply. This task is now in progress and should be completed by May 9.

One additional project is currently under construction. The "Reference Line Temperature Controller Interlock" is a device which will monitor the temperature of the reference line. This is done in the following manner: if one reference-line temperature controller in any one sector building fails, or exceeds its normal temperature range, the computer is flagged with a warning. If two or more temperature controllers in any sector building exceed normal requirements, a "Run Permit No-Go" will be initiated which will turn off the beam. The design phase of this project is complete, but fabrication is only 20% finished.

Because of extensive time spent on the tank phase system, the phase and amplitude group is behind its original Great Shutdown schedule.

The design of the packages for the redundant phase-monitoring is complete. Some temperature cycling and drift studies were performed on the packages, and the most stable components of those tested were selected. Installation of the packages for rf Tanks 5 through 12 is complete. Three of the tanks have been run, and power levels to the packages set. Short-term evaluations on the three 805-MHz packages were run after installation. Drifts and noise appeared to be well within original specifications. Further studies of the packages are planned as soon as all the 805 tanks in Sector B can be run. MP-9 has begun generation of software for accumulation of data by the main control computer as well as computer-based calibration of the packages.

The 201-MHz packages are complete with the exception of one component that has not been received from the manufacturer. No effort at installation of the 201-MHz packages has been attempted because of the continued work on the Alvarez tanks. It is planned to install packages for all three bunchers as well as the four Alvarez tanks.

A special package was generated to attempt the phase measurement between modules 4 and 5. An rf hybrid was used to sum the two rf signals with crystal detection at the hybrid output. This is the same technique now used for phase control between the two frequencies. The source room setup uses resistive tees to sum the two frequencies, and it is hoped that the difference in hardware plus the difference in location of the two detectors will identify any drifts that may be taking place.

Power Supplies

The modification program described in the January 31, 1975 progress report is continuing on all Ling-built and Acme-built power supplies.

The control and metering chassis for WNR, EPICS, and Biomed Lines are now being modified with the new circuitry for reversing switch control.

The dc cable installation in shaft A1 and A3 for the WNR line is now complete. The dc cabling between power supply and magnet is now complete up to the waterfall section of the WNR line. Installation of the control and metering chassis and regulator bin for the 18 WNR power supplies has been started.

The new power supply for Exp. 37 has arrived and will be installed in June. One of the two power supplies it replaces (an Acme 464kW, 1850A) will be moved to Exp. 99.

The iron-core water-cooled choke needed for the Ling 1050kW, 2000A power supply on EPICS has been ordered.

The order for three new power supplies to replace three very unreliable power supplies on the Stopped Muon Line has been released. Delivery will be in June 1975.

Work is continuing on the new magnet by-pass shunt systems for WNR, EPICS, and LEP.

All power-supply regulator bins are being removed and sent to the fabrication vendor for wiring modification to eliminate all interaction between the on/off state of the oven in the regulator and the regulator itself.

The main-line power supply in the transition region has been rewired internally. The control for this power supply is now compatible with the standard LAMPF control philosophy. This completed the needed rework on all the transition region's bending magnet power supplies.

The transition region bending magnet by-pass shunt systems have been modified so all the individual shunt plates on any one magnet are controlled by just one closed-loop control signal which measures the total current drawn by all the plates.

A zero-start limit switch has been installed on the motor-driven helipot (which controls the output) of the Transrex power supply used for Line C HRS. This limit will be used in the new on/off, up/down control system to be installed in this unit by MP-1.

Specifications on one of the two 115kW, 1000A power supplies ordered as spares (Item 4 on LN4-41435) have been changed so it will be able to drive the Varian electromagnet. Delivery of both units is scheduled for June 1975.

Preliminary studies on the 2000A rated reversing switch indicate it is not capable of reliable operation at this current level. A design modification on this switch is now under way. (Refer to MP-11-7, 2000A Reversing Switch Studies.)

Beam Diagnostics

The activities of the beam diagnostics section during the last quarter have been essentially in three areas: 1) preventive maintenance of existing beam diagnostics equipment, 2) organization of maintenance activities and procurement of spare equipment, and 3) design and development of new beam-diagnostics systems.

The task of performing preventive maintenance on the beam-diagnostics equipment was continued during this quarter. The maintenance of the 805 wire-scanner system was completed. All 805 wire-scanner actuators were removed from the beam line, cleaned, lubricated, checked for wear, measured, checked for plate alignment errors, checked electrically, given an operational check with a 13.6-kg load, and were reinstalled.

Approximately 100 linear-actuator driver modules were modified, repaired, and checked out during this period. We have 25 more driver modules at this time which require modifications and check-out. The required preventive maintenance of the frequency tuner system will be performed when the tuners are installed during the next quarter. Preventive maintenance of the 50 actuators which will be used in various other systems (scrapers, emittance, etc.) was initiated during this quarter.

The procurement of spare parts was continued. The fabrication of spare equipment at MRL in Albuquerque is progressing satisfactorily. Approximately 75% of the requested equipment has been received from MRL. Progress on the writing of maintenance procedures, system descriptions, etc., was very limited this quarter by the lack of sufficient manpower.

A large amount of time during this quarter was devoted to the design and development of new beam-diagnostics devices and systems. The designs were essentially completed during this quarter for the following devices: 1) beam scrapers, 2) high-power emittance jaws, 3) absorber/collector jaws, 4) EM-11 fixed-slit-emittance jaws, 5) the 201-viewing screens, 6) EM-7 fixed-slit-emittance jaws. The fabrication of these devices was initiated. The design of the control systems for the devices listed above was completed during this quarter. Three types of control bins were designed and drawings were made. The fabrication of 12 of these bins was initiated and is ~ 25% complete. A control system (wiring and control bin) for the 121-MeV absorber/collector was designed, fabricated, and installed. The design of the major portion of the wiring system for the devices listed above is ~ 90% complete. Cables are being fabricated at MRL. Approximately 20% of the cables are complete. Installation of these cables and the cables required to move the emittance switch from the beam line to the equipment aisle will be initiated during the coming quarter. The design of a new harp board (ceramic) was completed during this quarter. The boards are being fabricated by an outside vendor and will not be received before the end of the Great Shutdown. Seventeen of the old-type boards have been fabricated and will be used until they can be replaced by the new boards.

The drilling of the beam boxes, actuators, and plates for alignment pins was 90% completed during this quarter. The wiring of the 25 new actuators was initiated and is 50% complete. The process of replacing the motors on all emittance actuators is ~ 70% complete. The control chassis changes resulting from this motor change will be made to the five emittance chassis next quarter.

Vacuum Systems

201 Vacuum

The vacuum support for the 201 linac has been continuous since the tank reassembly started in late March. The vacuum crew is assisting with the reinstallation of the drift tubes, post couplers, tuning slugs, monitoring loops, and drive lines.

Transition Region

The only attention the transition-region vacuum has received by the vacuum section since the Great Shutdown was the installation of a rebuilt ion pump.

Vacuum

The returning of the 805 tanks to vacuum (10^{-7} torr) after rebuilding of valves, pumps, and current monitors is proceeding on schedule. All of the modules through F have been thoroughly leak-checked and are on the pumps running below 1 mA with the exception of 5, 6, 9, 11, 12, 13, and 17. Of these, 5 and 6 are waiting for actuators; 11, 12, and 13 are being tuned after installation of new bridge couplers; and 9 and 17 are running slightly over 1 mA for unknown reasons. Except for an occasional missed wire seal on the reinstalled rebuilt equipment, most of the leaks found have been corroded manifold hats and porous window spacers. The vacuum crew has had to replace or repair one or two of each in each sector.

Switchyard and Area A

A 0.00127-cm Havar window, 7.62 cm in diameter, has been built and tested for installation into a Granville-Phillips valve for the switchyard. This window has been flexed from atmospheric pressure to a few microns and leak-checked 120 times and still doesn't leak. The purpose of this window is to isolate the switchyard from Area A during periods of high pressure (above 3 μ) in Area A. No other vacuum support has been required during this period.

Area B

The hydrogen vent system in Line B was removed and reinstalled upstream to a less congested section of the line.

Line EP

No support was required this period.

Area C

Area C support for this period consisted of a couple of field welds and some leak-checking of the large magnets.

Mechanical Support

Oil tanks for the 201-MHz crowbar resistor cooling have been installed. Cooling water has been extended from the equipment room in Sector A to the capacitor rooms and oil tanks. Circulating pumps and heat exchangers are to be installed within the next three weeks to circulate and insure adequate oil cooling.

Rework of the 201-MHz drive loops for Tanks 2, 3, and 4 is nearing completion. The loop for Tank 4 has been finished and installed. The loop for Tank 3 finished but not installed. The loop for Tank 2 is finished except for one final solder joint.

Installation of the WNR cooling system is complete except for final hookup of flexible hose at each magnet and plumbing installation at LD-BM-00 and LD-QD-01. This amounts to about 50 h of work and will be finished when final magnet installation is complete.

Redesign of the MP-9/MP-11 beam-diagnostics sensing and measuring equipment is complete. Drawings are in the shop, and fabrication of devices is progressing well. A new air compressor and dryer have been installed for the rf reference line. The old unit has been rebuilt as a spare.

IV. ACCELERATOR SYSTEMS DEVELOPMENT

Accelerator Beam Performance

201-MHz Linac Field Distribution—First Tank

The Tank 1 bead-pull field-distribution measurements done at the end of the last quarter were analyzed. The integrated field across the gaps in this tank should fall on a straight, tilted line. Except for the first and last cells, the field distribution was generally on a tilted line, but with local variations from it.

The first and last cells are higher and lower, respectively, than desired. It was verified analytically that this is caused by the method of producing the tilted field distribution through perturbation of the end cells. Such a "bump" in the first cell causes a significant energy-phase oscillation when particles are injected at the design energy of 750 keV. If the injection energy is lowered to 745 keV and the rest of the cells are at the design field, the oscillation in Tank 1 can be eliminated.

However, errors greater than about 1% in the central-cell fields also cause unacceptable longitudinal oscillations. Such errors were present in the fields as measured, and were influenced by the position of the slug tuners.

The "bump" at the last cell causes a mismatch into the second tank when phasing is carried out, assuming the ideal field distributions. Phasing to a modified criterion can reduce this effect.

Other anomalies were found between the field integral values obtained by different methods. A program of studies using particle dynamics codes and equivalent circuit models was formulated to find a consistent design compromise. The Tank 1 field distribution will be set as before by end-cell perturbation. Using the actual field distribution achieved, an injection energy and Tank 2 phasing will be derived which minimizes the phase oscillation.

201-MHz Post-Coupled Tank Field Distribution

Hardware was assembled for bead-pull field distribution measurements on the 201-MHz linac tanks as they were reassembled and aligned. The computer system previously used for the 805-MHz linac bead-pulls was applied; some additions were made to the programs to allow raw-data dumps and on-line averaging. With the use of improved microwave components, the system produces results of exceptional precision and stability.

Raw data analysis by more powerful off-line programs is being carried out to check details of the on-line results.

Field adjustment on Tank 4 was completed.

Effect of Quadrupole Field Multipole Components in the 201-MHz Linac

One of the primary limitations on increased beam current in the linac is the radiation caused by low-density halos or tails on the beam. A major manifestation of such tails has been wide, asymmetrical extensions of the beam profile, often containing several percent of the total beam current. It is unlikely that effects of such magnitude are caused by space charge because they are present at low current. A study was initiated into the effect of quadrupole magnet imperfections.

Any nonlinearities in the field of quadrupoles are known to have adverse effects on beam quality. The drift-tube quadrupoles are very linear but have measurable multipole fields up to the 14th harmonic, some being stronger than 1% of the quadrupole field at half of the bore radius.

A code has been developed which includes the effects of multipole fields on the dynamics of particles in the drift-tube linac. The code can include the multipole amplitudes which were measured for representative quads as well as drift tube misalignments.

The first results of these dynamic runs indicate the following:

1. Axial beams in an aligned linac are unaffected by multipoles.
2. Beams injected axially into a misaligned linac without multipole aberrations develop transverse oscillations but do not develop tails.
3. Beams injected off axis into an aligned linac with multipole aberrations have transverse oscillations and can develop small tails.
4. Beams injected off axis into a misaligned linac with multipole aberrations can develop large tails.
5. The transverse admittance of a perfect linac is reduced by misalignments and is further reduced by multipole effects.

The realignment of the 201-MHz linac should alleviate this problem. However, the horizontal oscillation of the beam, long observed and believed to be caused by mechanical vibrations, is of sufficient magnitude for tail formation. This problem will also be investigated next quarter.

These studies will be extended to the 750-keV transport, and through the 805-MHz linac where the steering windings on quadrupole doublets are known to cause strong sextapole moments.

Low-Energy Linac Structures—Alternating Phase Focusing

An alternating phase-focused linac structure has been discovered which shows promise for acceleration of protons and heavier particles at energies below the practical limit of the magnetically-focused drift-tube linac structure. The stable areas in both the transverse phase space and the longitudinal phase space are quite comparable to those of the existing structures in LAMPF. The advantages offered by the new structure are that they can probably be built of higher frequencies making them smaller and more efficient, and they can be extended down in energies to considerably lower injection energies.

201-MHz Linac Alignment

Alignment measurements made in the last quarter and early in this quarter were analyzed and a plan developed for Injector 201-linac realignment during the shutdown. Depending again on the integrating capabilities of the human eye, the alignment was performed using standard optical alignment scopes. The most difficult problem was to determine, beyond reasonable doubt, where the intertank alignment stands should be placed to assure an in-line line-of-sight connecting the 201 and 805 linacs. Once the alignment stands were in place, they were checked periodically against the floor and wall stickers which constitute the LAMPF coordinate system. It was decided to realign the tank structures to these lines. The tanks were moved by coordinated jacking at the support points, and responded essentially as rigid bodies. The internal drift tubes were replaced starting at Tank 4 and aligned to a precision of ±0.1 mm or better. At least two sets of measurements were made on the assembly, one following complete installation. To date, Tanks 4, 3, and 2 have been completed. The results for the two planes are shown in Figs. IV-1 and IV-2. For convenience, the original alignment, determined first in terms of tank heads early in 1974 and later verified with the filling in of the internal drift-tube positions, is shown along with the realigned finished product. It can be seen in both figures that alignment of Tank 4 was in general better than that in Tanks 2 and 3. The reasons for

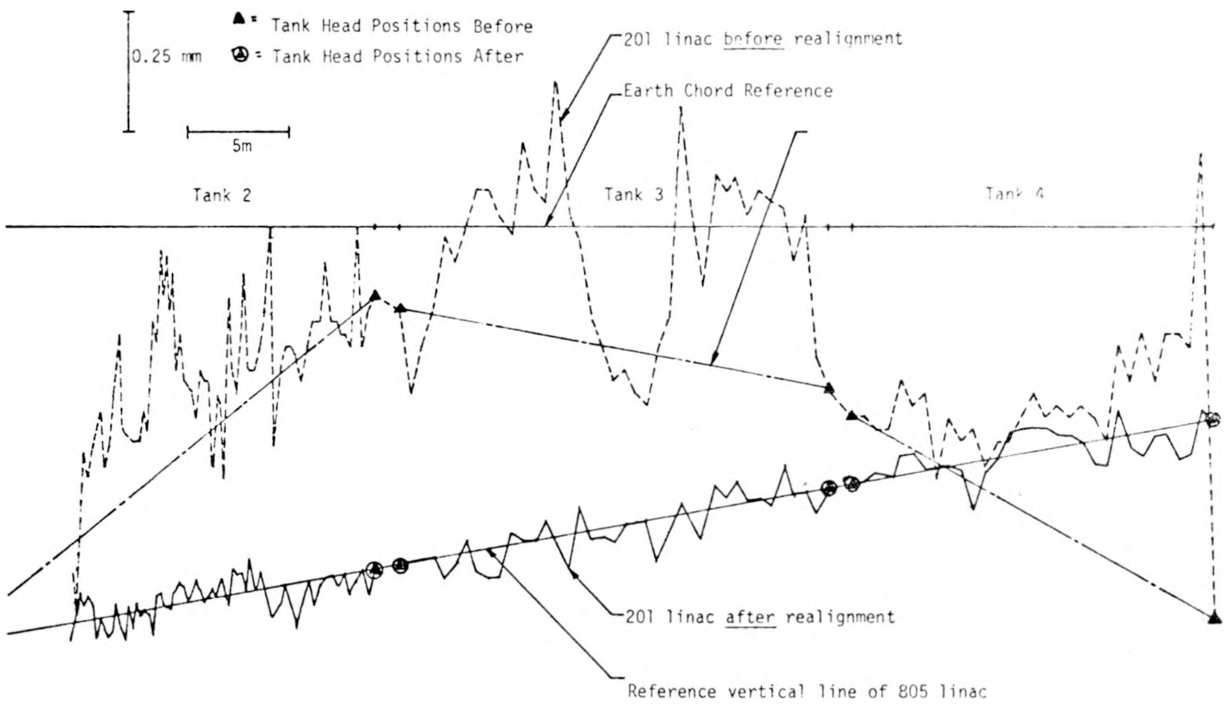


Fig. IV-1.
Comparison of 201-Linac Before and After Realignment - Vertical Plane.

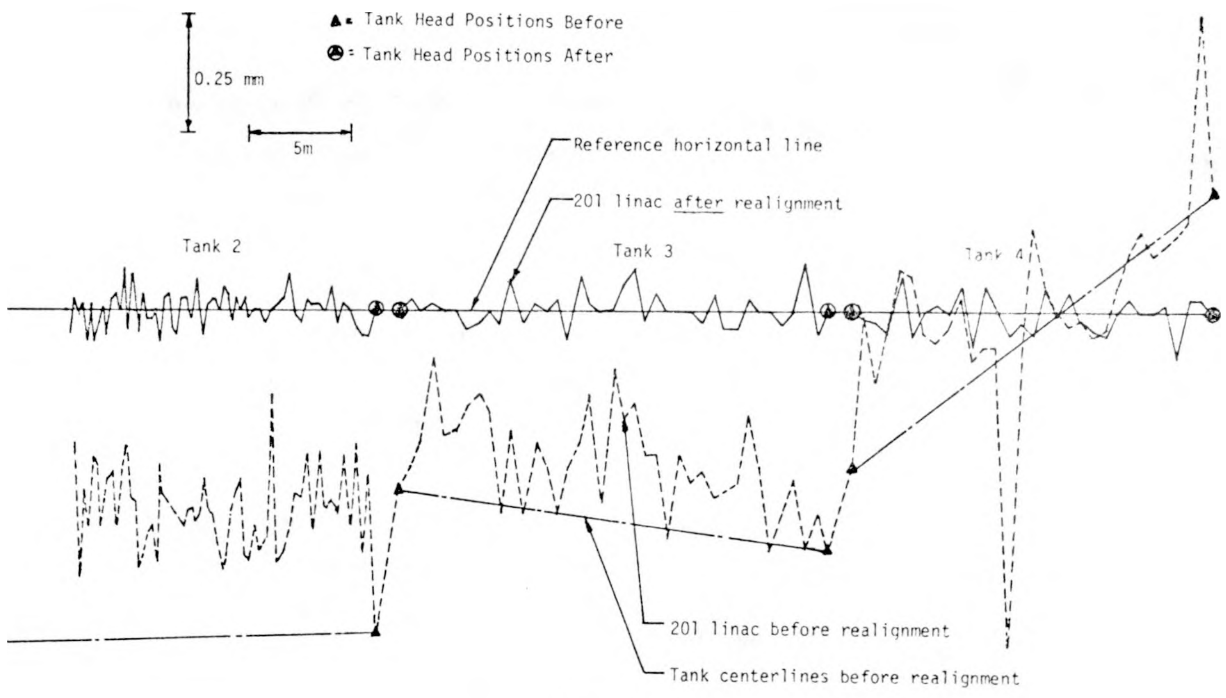


Fig. IV-2.
Comparison of 201-Linac Before and After Realignment - Horizontal Plane.

this are not known but might be due partly to overheated stems caused by ruptured bellows or rf window implosions.

The LAMPF coordinate system was extended to the injector area, and major portions of the H^+ and H^- systems were realigned.

Also completed in this quarter were the design and fabrication of a special-purpose alignment tool which will be used to measure the vertical and horizontal displacements and the roll angle of all the beam boxes in the 805 linac.

Transverse Emittance Matching

A new matching procedure has been proposed for matching the beams at the entrance to the 805-MHz linac and at the module 12-13 region, where a discontinuity in the structure occurs. The procedure is an iterative two-stage process. The first stage is a measurement of the emittance and an estimate of the degree of the mismatch. Wire scanners are used for this measurement. The second stage is an off-line calculation to find quad values that improve the match. Operator interaction with the matching calculation is provided. Most of the software has been written and is in the process of being checked out.

805-MHz Linac Length Corrections

A solution to the problems caused by the length errors in the 805-MHz linac was proposed. Numberical studies indicate that a major improvement in the performance of the linac can be gained by shortening the bridge coupler in module 13 by 9 mm. This modification has been implemented. The numerical studies also show that the acceptance can be increased by an additional 10% by changing the lengths of nine more bridge couplers in modules 5 through 12. Most of these changes are less than 2 mm. Consequently, it was proposed that methods of making small changes in bridge coupler lengths should be assessed.

The new bridge coupler to correct the drift length between tanks of module 13 has been installed and tuned. The tuning operation included setting the frequency of two accelerating cavities, two coupling cavities, and the bridge cavity. Bridge cavity tuning also included installing and adjusting posts such as to minimize power-flow phase shifts, and enlarging the input iris to achieve the desired coupling. Extra posts and end tuners fabricated when the accelerator was built were used after being cleaned and machined as necessary. It was not necessary to change the number of bridge-cavity posts, but the new bridge cavity uses 5.08-cm-diam posts in place of the 2.54-cm-diam posts used in the old bridge cavity. Bead-pull measurements are in progress to set the rotation of the notched post such as to make the field amplitude averages for the tanks agree.

Accelerator Systems Development

Operations Support Development

Operations/Maintenance Data Base. Detailed inventory of accelerator equipment was completed and documentation of the rack inventories finished. Inventory of the experimental area equipment is progressing. Meetings have been held with appropriate personnel to discuss formats and kinds of daily and monthly reports needed.

Experimental Schedule Data Base. Transfer of this data base to System 2000 was essentially completed this quarter, along with a system of input and retrieval programs. The data base was heavily used for the PAC meeting in April.

Visitors Center Data Base. The job of creating a data base for the new Visitors Center was assigned, and substantial progress was made. System design was completed, the data base initiated, and programs for adding and altering were written and debugged. An initial retrieval program has been written.

PDP-11 Maintenance Data Base. A data base for maintenance and component records on computer systems at LAMPF was completed and heavily used during the quarter. Programs were written to read existing data cards of several kinds into the data base, and procedures were outlined for production runs. Assistance was given in writing strings for direct retrieval from the TTY terminal. Transfer of the data base to another maintenance manager was successfully accomplished.

Other. Documentation for the MP-DO property control data bases was improved, and assistance given as needed for special-purpose retrievals. Familiarization with the Master Control data base system and the LTSS operating system was completed. The Master Control system has very powerful capabilities for text manipulation, and should prove useful for bibliographic and possibly medium-energy physics data purposes.

Diagnostic Equipment Development

Investigation of problems in the current-monitor system was completed this quarter, with tests conducted on the optimum turns ratio, coil position on the core, bi-filar windings, and operational amplifier characteristics.

Radio-frequency-interference and operational-amplifier problems in the beam-position-monitor electronics were solved, but temperature sensitivity of the diode detectors remains a major problem. Work on a long-range solution was suspended because of other shutdown activities.

Maintenance work on the Δt system was completed. New minimum-phase-shift amplifiers and a better temperature controller were received, and a switch-position encoder was designed and tested.

A beam-loss-ratio detector for the injector beam transport system was prototyped. This amplifier will monitor the beam currents at two points in the beam transport line and shut off the beam if the ratio changes more than a predetermined amount.

The feedforward system for automatic control of the 805-MHz linac fields was modified and additional equipment built.

In collaboration with the accelerator support group, a new generation of higher power, more standardized hardware was designed for emittance and phase-scan measurements and scrapers. Four-jaw scrapers capable of handling 10 μA average current on each jaw were designed for installation at the 40-, 70-, and 100-MeV points. Viewing screens were designed for 40 and 70 MeV.

Injector Programs

Ion Sources

H^+ Ion Source. An extensive effort was initiated to understand and eliminate the sensitivity of the H^+ ion-source control systems to trip at the time of high-voltage faults in the H^+ injector. The major cause of these trips has been traced to the computer control system; provision has been made to run dome ion source systems in a local control mode in order to eliminate these trips when the injector is run with high-duty-factor beams. Testing is still under way to trace the source of the problems. It was found that substantial improvement resulted from modification of the dome RICE power supplies.

Work is also in progress to simplify and minimize the interlock safeguards now employed in the H^+ ion source systems.

The new, fast-protect modules for the H^+ injector have been completed and are ready for testing. Fast-protect interrupts will be provided for beam impingement on the accelerating tube electrodes and for high-voltage faults on the equipment dome. These interrupts are expected to minimize the severity of sparking faults.

A mechanical leak gas flow system was tried in the H^+ ion source but was removed for further development when hysteresis effects in the valve drive unit resulted in nonuniform control of the hydrogen flow.

Tests have been carried out on the H^+ ion-source test stand to determine whether a deeper expansion cup could be used with the existing H^+ duoplasmatron. These tests were motivated by the desire to incorporate a variable-aperture Pierce anode electrode assembly on the present duoplasmatron. The tests indicated that an unacceptably large arc current was required to achieve the design beam current with the relatively thick Pierce anode assembly initially proposed. Design work has been started to obtain a variable-aperture Pierce anode assembly without having to make any change in the expansion cup depth. The use of such a device is desirable since it would more readily permit the reduction of the extracted beam current while maintaining a constant current density in the accelerating column. At present, the entire source must be removed and modified in order to effect this change.

H^- Ion Source. Two long-standing operational problems of the H^- injector have been a tendency of the beam current to oscillate at a few Hertz at maximum output of the source and a tendency for the maximum output of the source to decrease over a period of months from 1 mA to as low as 0.6 mA. The first problem proved to be an interaction of the SCR power supply for the extractor with the H^- dome motor-generator set. The relatively high impedance of the MG set was sufficient to cause the SCR power supply to oscillate under full load conditions. A simple filtering in the SCR timing circuits was enough to solve the problem. The lowered beam current was traced to melting of the anode aperture in the H^- duoplasmatron. Since this has been a chronic problem, several experimental apertures were made adding copper to the iron in the aperture. A simple copper-iron laminate with 1-mm copper nearly completely eliminated the melting and returned the current to about 1.1 mA. An aperture with a 3.2-mm copper plug in the center was then made to try to preclude any melting of the anode aperture. Unexpectedly, the H^- current improved to 1.6 mA, and the required arc current (the source of aperture heating) decreased by about 50%.

Testing is still in progress on the apertures, with 2.25 mA having been reached at 3% DF with a canal voltage of 22 kV. It thus seems likely that a substantial increase in beam current will be available from the H^- injector. No emittance measurements have yet been made since the beam line containing this equipment is still being modified. Future tests will include prolonged running at 6% DF and emittance measurements.

A number of other experimental changes in H^- were tried, including a 7-hole multiaperture electrode set constructed some time ago. The results were in agreement with those found on the test stand over two years ago. A current of 2.5 mA was reached at low duty factor, but the output current was noisy, and very high arc current and gas flow were required. With the present ion source and power supplies, it seems unlikely that the multiaperture source would prove satisfactory.

Polarized Ion Source. The construction of the 850-kV C-W high-voltage power supply is essentially complete, and acceptance tests will be conducted early in May at the vendor's plant.

The construction of the shielded enclosure for the C-W generator is progressing. The completion date is now expected by the middle of July; the additional month of construction time is primarily the result of implementing additional facility services that will be installed after the shielded enclosure is completed.

Design work on the argon cell has started. The argon cryopump was tested and functioned as expected. Further tests will be carried out next quarter using this pump on the P-9 polarized ion source.

The column matching lens and gate valve assembly have been completed and assembled.

A small scale mockup of the new C-W has been built to measure the performance. The operating voltage is 750 V or 1/1000 the full size value. This 10-kHz 7-stage rectifier is powered by a small amplifier and transformer much like the real C-W.

Cockcroft-Walton High-Voltage Generators and Accelerating Columns

Cockcroft-Walton Generator Improvements. The H^+ Cockcroft-Walton (C-W) generator was put back into operation after the replacement of the entire control system with one employing standard LAMPF modules. The control logic is basically the same with some minor changes in timers. The new system has functioned as expected and appears to have corrected the intermittent fault problems that have been present since the overvoltage power incident several years ago. The new system also provides more complete status indications to make future troubleshooting simpler to carry out.

During high voltage conditioning runs on the new accelerating tube, one of the rectifiers in the H^+ C-W rectifier stack was found to be arcing internally and was replaced. The rectifier was still functional but was operating at 71.1°C, which is well above allowed operating temperature. The end bellows on the rectifier had collapsed, lowering the oil level at the top of the rectifier and thus permitting arcing to occur. The cause of this failure is currently being investigated with the vendor. Several other rectifiers in the H^+ stack were operating above their normal range and will be replaced with new units in June. All rectifiers in the H^- C-W stack were checked and found to be operating at normal temperature. The extensive past history of sparking problems in the H^+ injector is believed to be the cause of these failures.

Both MG sets have been overhauled in preparation for programmatic running. Lifetime on oil seals and rotating bearings continues to be good.

A development effort has started to try to synchronize the 5-kHz drive voltage in the C-W generator to the 60-Hz line frequency. The necessary synchronizing circuits have been developed, but drifts in the C-W oscillator are currently too big to be handled by this system. Work is in progress to improve the frequency stability of the oscillator.

The H^+ and H^- compensated voltage dividers were calibrated using a spare section which has been sent to NBS for a calibration from 0-200 kV. Each divider consists of five sections. Under test, all but one section was shorted out so that full voltage of the C-W appeared across one section. The spare section was then used to measure the C-W voltage, and the normal C-W voltage read-out then determined the resistance of the section under test. Except for one section, the resistances were within about 0.02% of the values previously determined at LASL. If a one-digit typographical error for the one section is assumed, it is within 0.02% also. The overall difference in any case would only be 0.08%, this section being in the H^+ injector. The overall value for

H^- is within 0.01%. The voltage linearity of each section was 0.01% or better from 0-200 kV, equivalent to 0-1000 kV normal operating voltages. Thus the C-W voltage calibration is believed to be accurate to a few hundredths of a percent. The spare section is being built up into a portable 200-kV divider for future measurements.

H^+ Accelerating Column. The H^+ accelerating column was reassembled and put back on the beam line four weeks after removal. This column contains a new accelerating tube and new titanium electrodes of much larger beam aperture (4.0-cm-diam.).

The electrodes were aligned on a jig post mounted concentrically in a plug which fit snugly into the same opening used by the ion source. The aperture alignment is concentric within an estimated ±0.05 mm. The electrodes were secured by grooved pins which fit into the titanium rings bonded between the ceramics of the accelerating tube. This method of support does not perturb the electric field like the protruding button support system used on the previous H^+ accelerating tube. Examination of that tube showed severe tracking along the ceramic because of discharges from the buttons. Other features of this design are the large pump-out holes in the electrodes and the use of electrodes at every titanium ring position to reduce the potential drop between electrodes to 54 kV.

Voltage conditioning was quite rapid, requiring only 1-1/4 h to reach normal operating voltage at 750 kV and 3 h to reach 860 kV. For low-duty-factor beams, the column high-voltage conditioning is complete, and the injector is now operational. For 6% duty-factor beams, the column operates satisfactorily, but further high-voltage conditioning with high-duty-factor beams is still required to achieve performance comparable to the H^- injector.

Injector Vacuum Systems. The beam transport lines for both injectors were reassembled after new alignment tooling was put on the transport magnets. All injector ion sources and beam transport elements were realigned to the new linac axis except for the final portion of the beam line whose installation and alignment must await completion of the work on Tank 1. Many modifications and improvements in beam line hardware have been carried out during this reassembly. Perhaps the most important modification in terms of improving stability and reproducibility in injector operation has been the incorporation of a series of beam apertures in the transport lines which define the desired beam axis and limit the possible beam excursions from this axis. These apertures also provide suitable cooled surfaces which are capable of absorbing any beam spill in the event of magnet failures or mis-steering errors in the operation of the injectors. Work has begun on a beam transmission protect system which will ensure a minimum beam-spill level. Once this system is completed, the injector beam lines should be fully operational for 1 mA beams.

Collaborative Programs

Biomed Pion Range Shifter

The range shifter and jib-boom subassemblies are now complete. A test lab has been established at the Biomedical Facility for testing of the system. The hydraulic power supply is being assembled. This 10-hp unit will have adequate reserve to supply the demands of the range shifter at full stroke as well as other target-related jobs if required.

Energetic Pion Channel and Spectrometer

Early in this quarter, the high-voltage delivery system for the beam separator was tested to voltages of 350 kV. Subsequent to this, the entire electrode system was brought to 240 kV in vacuum before breakdown occurred. The rated operating potential for the unit at full 9-cm gap is 320 kV. Breakdown difficulties experienced thus far appear to be in the oil-filled cable termination. Investigation revealed that arcs through the oil produced contamination on the main insulator. The presence of metal chips and possibly dirty oil, as well as a few unfinished metallic surfaces, probably aggravated the problem. The termination is being modified to allow use of concentric acrylic cylinders to break up the oil path and to allow certain obvious finishing of the electrodes.

The pressurized SF_6 portion of the delivery system appears to have withstood full voltage with no problems. The connecting conductor between the high-voltage linac and the electrodes carries a 33-MΩ resistor which failed as a result of overvoltage caused by repeated sparks. This resistor has been replaced by a cluster of seven 200-MΩ resistors in parallel with much higher voltage ratings.

The voltage divider, long considered the weakest link in the system, experienced no difficulties at 240 kV although one ceramic was fractured in removing the unit to check it. An improved design with stronger metal-to-ceramic bonds and spark gap protection is being fabricated as a spare.

Most spare parts for the separator have been ordered. The command and control requirements to operate the system were worked out and 1 system. The method of removing the separator from the channel has been finalized and is being fabricated. This involves removal of a 182-metric-ton shield plug from in front of the separator as shown in Fig. IV-3. The removal of the separator itself should be

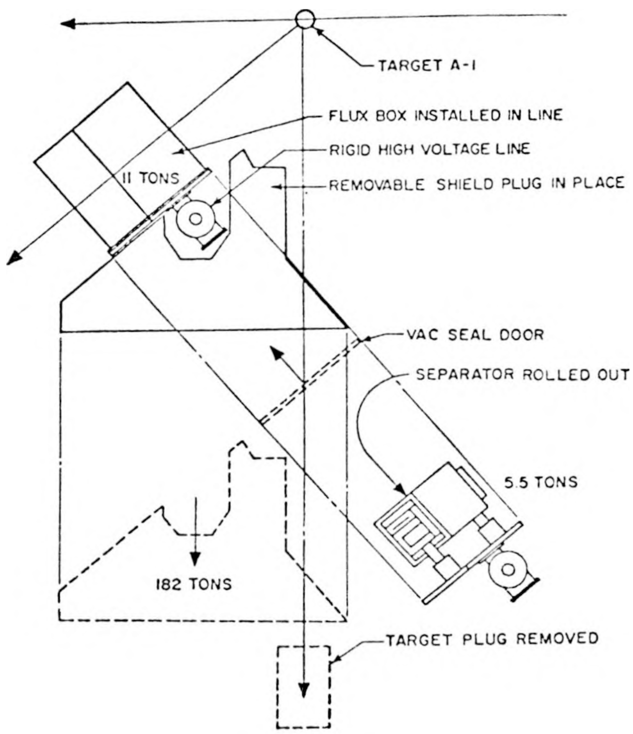


Fig. IV-3.
Beam Separator Shielding and Removal.

relatively easy now that the improved design for the flux box has been completed. This new design incorporates an 0-ring groove which should greatly reduce the number of bolts required to hold the door to the box. The new box has arrived in Los Alamos and will be installed in the EPICS line soon.

The original parameter range for the beam separator is shown in Fig. IV-4. This was computed for ion-proton separation. Recently, new possibilities have arisen. These involve use of the separator at even lower energies, 20 to 50 MeV, to sweep out electrons or positrons. Voltages required in this lower energy range are again high.

One compelling feature of the separator that has still to be tried is the bias electrode which lies behind the bar-electrode cathode. During conditioning, large x-ray production occurred in the unit. It is ex-

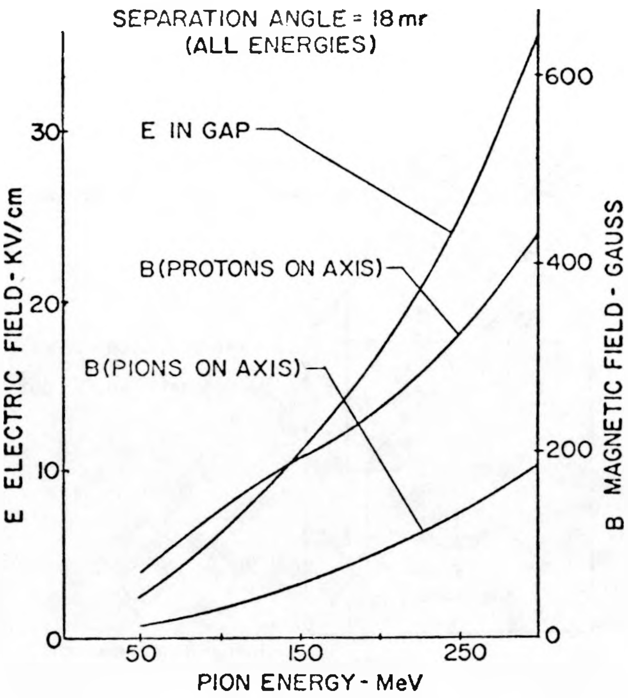


Fig. IV-4.
EPICS Beam Separator Parameter Range.

pected that several kilovolt biasing potentials applied to this electrode may reduce this problem substantially. This has not been tried due to a missing feedthrough and connecting cable which is being installed at present. Bleeding in small quantities of N_2 to maintain pressure in the flux box at 10^{-4} torr was successful in that it reduced sparking rate and open-loop voltage fluctuations.

V. 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.

Accelerator Instrumentation and Control Systems

Injector Control Systems

The injector control systems include controls for the H^+ and H^- ion sources, both Cockcroft-Walton (C-W) accelerators, and the beam transport equipment leading from both sources to the first tank of the drift-tube linac.

Several modifications were made to the H^+ injector control system to improve it for the next operating cycle. A new binary command module was installed and tested. This module incorporates the binary command and mode select functions in a single module. This approach will prevent arc downs caused by transient voltages from turning off the equipment. A replacement was designed for the palladium leak that controls H_2 flow. The replacement, a mechanical valve driven by a pulse motor, is being tested. A new NIM-bin power supply was installed in the H^+ dome to operate the Pierce anode. The ion-source filament power supply was modified to drive to zero when a fault occurs. Various light-link modifications were made to facilitate operation with the revised ion-source parameters. Obsolete wiring was removed from the dome.

In the ion-source test stand, a hydrogen bleed valve was installed together with a NIM-bin and modules to control the valve.

Modifications to the H^- injector control system include the installation of a new current pulse calibrator and amplifiers to condition the video signals. A slow-acting protection circuit is being tested for the arc modulator crowbar system.

Work on the polarized ion source was deferred until the end of the present shutdown.

Data-Acquisition System

A prototype printed-circuit board for the new digital-data receivers in the RICE and RIU was completed and tested successfully. A program to retrofit a number of RICE units and corresponding RIU channels was started and will continue throughout the shutdown. The receivers for this program were fabricated and tested.

CAMAC Data Links

Digital data communications from the central control computer to outlying satellite computer systems are accomplished through CAMAC interface units and data link modules. A design program to upgrade the data links to microcomputer-operated devices began last quarter. Fabrication of the new links will begin next quarter after a period of prototype testing of the concept. The primary motivation for incorporating a microcomputer into each data-link module is the saving of software overhead in each controlling computer and the resultant increase in efficiency of the data transfer process.

Master Timer

A decision was made to fabricate a new Master Timer system. This decision was taken because of the growing number and variety of timing signals needed in the experimental area, and because of the complex timing interactions envisioned when the polarized ion source is added in the future. The process of gathering requirements for the new timer and of developing an initial design for the hardware will be completed next quarter.

Central Control

Control Computer

Because of the accelerator shutdown, the control computer was operated on an abbreviated schedule. Normal preventative maintenance was generally replaced by a series of maintenance tasks designed to correct long-standing problems in the computer. The control computer was put back in operation in April for system and application program developments.

The new instructions developed last quarter for the central processor were installed and tested except for the fast-register save and retrieve hardware which will be installed early next month. The manufacturer-supplied diagnostic programs were revised to provide a diagnostic capability for the new instructions.

The second disk controller for the SEL-840 computer was modified to handle multiple drives. Check-out of the controller will take place on the SEL-810A computer in an off-line mode during the next quarter.

A remote restart unit was fabricated for the 840 computer. This device is useful when troubleshooting peripheral hardware remote from the computer console.

Control Consoles

Expansion of the new communications center into Console 2 is 90% complete and will become fully operational early next quarter.

The prototype touch-panel was relocated to Console 2 late in the quarter. Experience using the panel will be gained during the turn-on process next quarter.

Work continued on the IEC ASCII bus which will become the basis for developing the third console. The design of a CAMAC-controlled module for the new IEC/IEEE ASCII Interface bus is 60% complete, and the message format, control protocol, and basic operational features of console device units to be placed on the bus are specified. Prototype activities, to include the microcomputer-controlled master and one console device, will begin late next quarter.

A decision was made to replace the console vector scopes with color-graphic scopes in order to improve operator interaction and overall reliability. Preliminary discussions aimed at formulating the criteria for selecting a particular device were started.

Information Display System

Hardware and software to implement a write-through cursor with joystick control on the Tektronix 611 storage-tube display scopes in both consoles were completed last quarter. This system is to be used to evaluate the use of the cursor and an associated joystick to provide an interactive capability on the 611 scope. A program in the SEL-840 can display the cursor, control its position, and read its position. The software for controlling the position of the cursor with a joystick was designed and written.

A hardware bootstrap was implemented to remotely restart and down-line load the IDS computer system serving the console display scopes. A similar addition will be made to satellite computer systems, remote from CCR, doing dedicated tasks for the control computer.

Computer System Software

The extended shutdown provided an opportunity to make a number of needed changes in the resident operating system, which are expected to make significant improvements in its speed and reliability and which added new features required for future operation. The data-link software received extensive attention because the use of data links to satellite computers has exceeded original expectations by a large margin and promises to continue expanding. The basic data-link handler was integrated into the resident operating system; the handler for unsolicited messages was revised to provide greater flexibility and versatility; the FORTRAN subroutine interface was modified to make use of the new facilities in the system. The data-link messages for remote console operation were designed and partially implemented. It is now possible for a remote computer to initiate the execution of a program in the SEL-840 through a data-link message.

The disk and tape drivers were modified to take advantage of the new hardware features installed on the computer. In addition, the program which provides the read- and write-by-word capability was reorganized to better assimilate the changes which had accumulated over the past few years.

The program which creates the core image of the resident operating system was revised to take advantage of new machine features and to produce an improved listing. The improvements resulted in a factor of 3 increase in speed for this program.

The relocating loader was modified to use the newly installed facility for easily accessing the total address space of the memory, and was also made a part of the resident system.

A feature was added to automatically inform a task whether it was called with parameters or not.

A facility was added to translate hardware channel numbers into standard operator designators for operating personnel.

A scheme for controlling the access of remote consoles to accelerator control parameters was designed, written, and checked as far as was possible without having a remote console on line. Consoles located in CCR will continue to have free access to all accelerator parameters. Consoles located elsewhere will be permitted to control only a restricted set of devices, specified by the operations group.

Accelerator Applications Programs

The data-scan programs, which monitor and record various accelerator parameters, were revised slightly to take advantage of the large core memory installed last summer, and a facility was provided for starting and stopping the scanning of all channels scheduled for a given interval with a single command.

A beginning was made to the extensive revisions in the channel tables made necessary by the changes in accelerator, switchyard, and beam-line hardware.

Design was begun on a general scheme for controlling more meaningful parameters in the accelerator and the beam lines. The scheme makes use of control vectors which describe parameters such as beam position and angle as incremental functions of set points actually controlled. An initial modest implementation is planned for study and evaluation after which, if the evaluation is favorable, a more elaborate system providing for simple user specification on the control vectors will be provided.

Extensive design work was done on a system of graphical displays diagramming the accelerator for operators and beam-line tuneup personnel. The displays are intended to provide reliable information on positions of devices and on their current states of operability, and to provide interactive capabilities to facilitate control. Design was begun on a data structure to contain the information necessary to draw the displays.

Experimental Areas

Work began on extending the LAMPF communications system to the Area A Hot Cells, Nuclear Chemistry Area, and WNR beam tunnel.

Switchyard

The Fast Wire Scanner System (FWSS) to be installed in the switchyard area is 75% complete, with all components on hand or in fabrication. This system consists of a PDP-11/10 satellite computer and CAMAC-based control and data-acquisition hardware. The system will be coupled to the control computer through CAMAC data links. The wiring of the computer/CAMAC rack and the installation of the data links will be completed early next quarter.

Four stepper motor-control multiplexers were fabricated from an existing design for use in the FWSS. A dual, variable-gain, integrating follow-and-hold amplifier and associated power supply module were designed and prototyped for use in the FWSS. Existing amplifiers could not be used in the new system owing to gain, pulse response, and the different mode of operation of the FWSS compared to the previous 840/RICE-driven system.

Other activities in the switchyard involve the design and modification of many systems. Controls were installed on the power supplies for magnets LA-QD-01, LA-QD-02, LA-SM-01, LX-QM-01, and LX-QM-02. Computer channels were added to monitor the new water system. Several harps were deleted or converted to other devices, thus freeing one harp multiplexer. The associated changes in wiring are in progress. The schedule of cables needed to add a collection field to the wire scanners was given to the electricians. The power supplies to produce the field are in house. The wiring schedules for the trunk lines to carry information and controls from the equipment aisle to the beam line were carried to 90% completion.

Area A

The existing harp system is undergoing a major upgrading, which includes the addition of three new harps.

The problem of protection in Area A against beam-induced damage and burnout generated a great deal of activity. Protection of beam-line equipment will be accomplished by the use of several different and redundant hardware/software systems. Beam transmission will, initially, be monitored by a satellite computer system in Area A. As the average beam intensity is raised, a hardware back-up system capable of shutting the beam off during a pulse will be installed. Main-line magnet currents will be monitored, in a redundant sense, by another stand-alone computer system. Collimator temperatures will be hardwired to thermocouple/overtemperature trip units designed during the quarter. Efforts towards a comprehensive protection system will continue throughout the year.

Wiring instructions were given to the electricians to cover 64 more analog channels in module 65 to accommodate the anticipated beam-line protection meaurements. A contract was given to a vendor to assemble and wire a single rack and junction box for module 67 which will house the data-acquisition terminal for the isotope production facility.

Rack wiring and chassis to control the A-4 vacuum valves were installed. In addition, rack wiring was specified for the vacuum control to water valves. Wiring books were prepared for the electricians. The wiring for the A-1 target-box controls was completed. Controls for the P^3 collimator in the A-2 target box were installed. Installation of the steering magnet cables near A-3 was started.

LEP

New wiring instructions and drawings were issued for the radiation-resisting wiring to the LEP devices which will be in a radiation environment. The installation of wirewrap, duct, and conduit that penetrate the shielding was coordinated with the responsible group. All wire list books were revised to account for the deletion of 2P-JB-01 from the system.

P^3

New device wiring and radiation-resistant wiring drawings for MS-01 and MS-02 were issued to the electricians. Drawings were prepared for the new 12-V CAMAC binary data channel.

SMC

Resistors were substituted for fuses on all magnets in the SMC line. A wiring schedule was issued for a new vacuum valve read-out module.

EPICS

Wire list books were issued for the permanent magnet interlock wiring for BM-01, -02, -03, and -04, and these interlock systems were checked out. The HT interlocks were also checked out after the latest modifications were made.

The wiring between the rack and the junction box for the new binary command to the magnet-power supply was installed. The existing cabling to the power supply was modified for the double command needed for reversing switches.

The Four-Jaw No. 1 was revised with radiation-resistant wiring. The cabling to Four-Jaw No. 5 was installed. The device wiring to Four-Jaw No. 4 was completed.

The old magnet mapper system was removed and a rack for the new system was installed. The integrators from the old system were reinstalled with new cables. Temporary warning lights on BM-01, -02, -03, and -04 were installed in support of the magnet-mapping operation in addition to local/computer controls on the magnet power supply.

Wiring packages were given to the electricians for the focus magnet, the scattering chamber, and the Four Jaw. Drawings for cables were issued to the cable shop for the overcurrent protection system of the HT and FM regulators.

One-hundred-twenty 2-axis sensors from the EPICS taut-wire system were built and tested.

A chart recorder output was added to the overcurrent trip for the EPICS Cockcroft-Walton power supplies. In addition, circuitry for detection of short-duration sparking under load was prototyped and left in operation until final hardware can be completed.

An RSX-11D system was generated and installed on the EPICS computer, and a start was made on converting the DOS-based software to RSX. An MBD code and an MBD driver were put into use. Installation of the CMCSA, the CAMAC single-action subroutine, was completed. Basic functional subroutines for operating DVMs, issuing binary commands, reading the analog data system, reading binary data, and operating stepping motors were checked out.

Biomedical Channel

Work at the biomedical computer was concentrated in operating-system improvements during the quarter. Programs which aid in managing the disk and core were put into operation. They included a facility for checking the validity of disk files, another for examining core usage in the computer in order to move in the direction of more nearly optimum usage, and one for observing the use of RSX-11D "modes," another resource which should be optimized with respect to supply and demand. The status of the three RK disk drives is now displayed on the color display. A "wait" function and a "clear-display" facility were installed.

Six prototype electrometers were designed, assembled, and tested. These units cover the range from 5×10^{-13} A to 5×10^{-9} A. A packaging system is being designed.

Beam Stop Area

A remote read-out of the Beam Stop A position was designed and will be implemented during the next quarter.

Area B/C

Controls were designed, fabricated, and installed for the following devices: HRS magnet power supply, steering magnets LX-SM-03 and -04, NMR-01 through -06, and HRS beam collimator and LC insertable strip ion chamber. Patch panels were installed in the Area C counting house for the detector system, timing system, console, TOF signals, scattering chamber, and experimental signals. Panels for the status monitor and spectrometer pendant were installed along with the harp multiplexer and taut-wire multiplexer.

Instructions were issued to the electricians for wiring the following equipment: stripper controls, ISIC signal cables, TV phosphors and target controls, NMR signal cables, NMR motor controls, conduit, and the fast-wire system.

HRS

A handler for the Kinetic Systems Type U CAMAC crate controller was put into use. It presents the same interface to the user program as the MBD-CAMAC handler. A device handler for the Kinetic Systems color display was installed, and a modification which allows it to emulate the CCI color displays in CCR was written and is ready for debugging. This capability is required for HRS remote-console operation. A data-link handler for exchanging messages with the central control computer was also put into operation. Messages are relayed to CCR through the area B/C PDP-11/10. A program which interprets IDS messages on the HRS Tektronix 4010 was written. The 4010 cannot efficiently perform all the functions of a 611, but a reasonable simulation is possible.

The NMR probe-multiplexer and probe-selection read-back unit was completed this quarter. A tester was also fabricated to facilitate check-out and field maintenance. In addition, five read-out modules have been completed for the HRS target azimuth/elevation instrumentation. Three CAMAC reset modules, of the variety used with harp devices, have been fabricated for use elsewhere in the experimental area.

Three-hundred-sixty cores for HRS taut-wire sensors were handlapped. Assembly of 88 sensors by HRS personnel is being supervised. Assembly of twenty-five 16-channel station units is under way.

Experimental Data-Acquisition System

Experimental Area Computers

Orders were placed for the equipment necessary to upgrade the terminal computer into a multi-user PDP-11/45 system. Core memory and a disk drive have arrived. The central processing unit is scheduled for delivery in May.

Both the terminal computer and the HRS PDP-11/45 computer were supplied with a LAMPF standard CAMAC Branch Driver (MBD). The interface unit is used in all experimental-area computer systems for data acquisition and a small amount of real-time control.

CAMAC scaler modules were added to three experimental-area satellite computer systems for read-back of beam current information. These data are used by both central control and experimenters.

The neutrino area Super-NOVA Computer system was equipped with a new 30-character-per-second printer-keyboard in place of a teletype unit. The new terminal greatly improves operation with the disk-operating-system software, making the system more effective in code development.

Data-Acquisition Software

Considerable effort was invested in the development and check-out of the general data-acquisition program. The principal components of the program were debugged and integrated, including the MBD code, the data-acquisition handler, and various analyzer programs. The histogram package was redesigned to operate under RSX-11D and to manage large-core histograms. It is now in the check-out stage. The various operator commands were written and partly debugged. The DOS-based plotting package was modified to interface with RSX and the histogram package. The plot operator commands are at the design stage.

Interface Hardware

The second CAMAC Serial Driver, for use in CAMAC Serial System check-out and WNR beam-line control, was completed. A test of a two-crate serial system was accomplished using the new driver. Messages were transferred to both CAMAC crates, while asynchronous demand messages were generated by the crate controllers. Installation of the WNR Serial CAMAC system will begin next quarter.

The digital-tablet (Scriptographics) interface design was made available to the UNM Medical School for use on their PDP-11/45 computer. A similar device exists on the computer in the biomedical area.

A programming unit for the SN74188 Programmable Read Only Memory (PROM) was designed and fabricated during the quarter. The programmer electrically loads information into the PROM for use in devices requiring a fixed amount of 8-bit memory.

Nuclear Instrumentation

The prototype Event Trigger CAMAC module awaits receipt of a few integrated circuits. This module will be used with new data-acquisition software developed for experimenters. In addition, a dead-time monitor has been designed and prototyped for use with each Event-Trigger module, allowing experimenters to have first-hand information on the event rate and system dead time.

Modifications to a number of MWPC encoders to 16-hit capability were made during the quarter. The modification increases the capability of each encoder from 8 to 16 simultaneous particle hits.

LAMPF Electronics and Equipment Pool

A total of $235,000.00 was spent for LEEP during FY-75. All orders are on hand except for a few placed during the last quarter.

In order to accommodate LEEP service and storage, the facility has been moved into a two-trailer complex near Area A south. The new location is not only more convenient to experimenters, but better located for service and loan activities. An increase in equipment servicing and testing space with the new location will make the LEEP concept more viable in the future.

Sharing of LAMPF Technology

A member of the staff presented a tutorial lecture on "Human Factors Engineering—Designing the Man-Machine Interface" at the International Purdue Workshop on Industrial Computer Control. This lecture was based on ideas which evolved during the course of developing the operator consoles at LAMPF.

The activities of the NIM/CAMAC Standardization Committee were again supported by one staff member who attended the Dataway Working group and Serial Subgroup meeting in the U.S. as well as the European ESONE Dataway Working Group meeting.

Two members of the staff presented lectures during three IEEE short courses on Computer Automated Measurement and Control. These lectures were an outgrowth of their work in support of the LAMPF experimental data-acquisition system.

Miscellaneous

Assistance was given with the initial setup of a "Par" electric manipulator acquired recently from surplus. The manipulator was rewired to eliminate inconsistent circuit behavior. A smaller electric manipulator was also repaired.

A remote-control system for an alignment telescope using stepping motors was designed.

The initial design of a liquid-hydrogen temperature monitor was completed. Further work will continue during the next quarter.

VI. ACCELERATOR OPERATIONS

General

The accelerator was shut down for upgrading during the entire quarter. Operators were assigned to training and support activities.

Current Monitor Development

A major development effort was undertaken to improve the beam current monitor system.

The toroids were completely rebuilt, rewound with two sets of 100-turn windings, and potted with epoxy to prevent relative motion of core and windings. Reinstallation in the beam line is nearly complete.

A new preamplifier circuit is being tested, and procurement of circuit boards will begin as soon as it is determined that stability specifications are met.

A new current monitor calibration system is under construction. It will provide separate calibration pulses to the linac, Line A, and Lines B-C-X, with computer control of amplitudes and time dimensions.

Accelerator Support Activities

The old North Port beam line was dismantled and the equipment assigned to spares. In the 805-MHz accelerator, all ion pumps drawing over 1 mA were removed, reconditioned, and reinstalled. All vacuum isolation valves were removed and modified, and reinstallation is all but complete. Comprehensive testing of the RICE analog data systems is still in progress; numerous deficiencies were found and corrected. The pulsed signal (video) distribution system was modified to bypass the remote matrixing switches in the sector buildings in favor of a clearly labeled manual patch system; completion of this job awaits receipt of BNC connectors which are on order. A run permit panel was built and installed in the injector control room showing the status of both H^+ and H^- beam transport lines. Warning lights were installed on experimental area magnets to meet safety requirements. The controls for the switchyard and experimental area water systems were modified to provide time delays and front panel jumpers for all interlocks. Soft vacuum interlocks were installed on the drift-tube linac. Assistance was also provided for numerous other jobs during the period.

Closed-circuit-television equipment was acquired, checked, modified, and maintained. The existing coaxial cable system was surveyed and documented. Spare units for the activation protection system were assembled and checked out.

Personnel safety systems for Line B, room B, EPB, and the Line B nuclear chemistry cave were completely redone to make them consistent with operating modes. The switchyard personnel safety system was modified to accommodate changes incident to the WNR line installation.

Documentation

Procedures were developed for checking all fast-protect and run-permissive interlocks. Personnel safety interlock check procedures were updated.

Beam-tuning procedures are under development in collaboration with the accelerator development group. Efforts are being made to develop quantitative criteria for beam diagnostic measurements in order to reduce subjectivity in the beam-tuning process.

VII. EXPERIMENTAL AREAS

Operations and Facility Management

The Experimental Area Manager's Office has continued the supervision of maintenance and operation of the major service systems. A remote computer terminal has been ordered. It will enable continuous knowledge of the status of major service systems and experiment setups, including cryogenic targets, water systems, vacuum systems, ventilating systems, temperatures in target cells, and radiation levels. The staff shop upgrading has continued; all equipment in the shop is now in operable condition. LASL personnel and experimenters can check out from the tool crib a variety of power and hand tools. A powered hacksaw and a low-dust sandblaster have been received and installed. Personnel from the Area Manager's Office are available to instruct in the proper use of all shop equipment.

Water Systems

Modifications and additions have been designed and are being installed that will improve the operation of both the radioactive and the nonradioactive water systems.

The following changes are being made to the radioactive systems that service the permanent beam line components:

1. The basic pump/heat-exchanger packages are being modified to improve the alignment of the pumps and to improve the support mounts of the systems as they are installed in the shielded pits.

2. The control systems will be modified to permit the system parameters to be monitored from CCR. These modifications will also reduce the number of pump shutdowns caused by control-loop troubles or other extraneous causes.

3. Several additions will be made to the valve caves in the experimental areas that will assist in general water management and leak detection and control. These additions will include manifold flow meters, remote valve operators, and manifold strainers.

4. Piping modifications are in progress in the valve gallery which will allow the installation of a spare pump/heat-exchanger package approximately one year from now. The spare system can be valved into any of the radioactive systems should a problem arise that requires a system to be shutdown. Use of this spare system will reduce the shutdown period to 2 h in case of a major component failure.

5. The X03 pump will be replaced with a larger capacity pump to accommodate the greater head load expected with increased beam intensity.

Three additional nonradioactive water-cooling systems are being fabricated. Two of these systems will service the HRS facility and the EPICS facility. The third is designed as a semiportable system that will be used to cool experimental components in the Area A secondary beam lines. This system will help relieve the flow rate restraints that the radioactive systems have been under.

Cryogenics

Performance tests have been made on a Cryotip refrigerator, and some recommendations for more stable operations were formulated.

Warm and cold tests of the bursting strength of several target flask materials have been made, and a promising candidate, scrim-reinforced polyester, has proved disappointing. Tests relating failure by small leaks to pressure and temperature are continuing.

A new design for a target for Exp. 96 is nearly complete. This target will be cooled by a CTi 1022 refrigerator, which is now on order. New designs are also complete for target flasks for four other experiments, and flasks have been built for two more experiments.

Designs of H_2 gas detection and ventilation systems for the experimental areas are in progress, and the purchase of modular target enclosure systems is being studied.

The liquid-nitrogen heat exchanger in the CVI refrigerator has been repaired, and a bellows has been installed to prevent future breakage. A freon chiller for the compressor input gas has been installed. New turbine-speed monitoring electronics are being purchased, and several small improvements in the instrumentation plumbing have been made.

A visit to Fermilab, ANL, and BNL, to look at target systems and discuss operating problems was made; a trip report, dated April 8, 1975, is available.

Main Beam Lines

Switchyard Improvement Program—Line A

At the beginning of this report period, the SWYD front-end optics were fixed to include an 805 doublet at the end of the accelerator (beginning of the SWYD) followed by a 5.08-cm triplet as close to LD-KI as possible. The space between the doublet and triplet was maximized to provide for the largest possible separation between the two strippers LA-ST-01,-02 being placed in Line A to help prepare the H^- beam for Line X. In addition, three actuators equipped with scattering plates for use in beam-halo measurements were added to the SWYD. Fig. VII-1

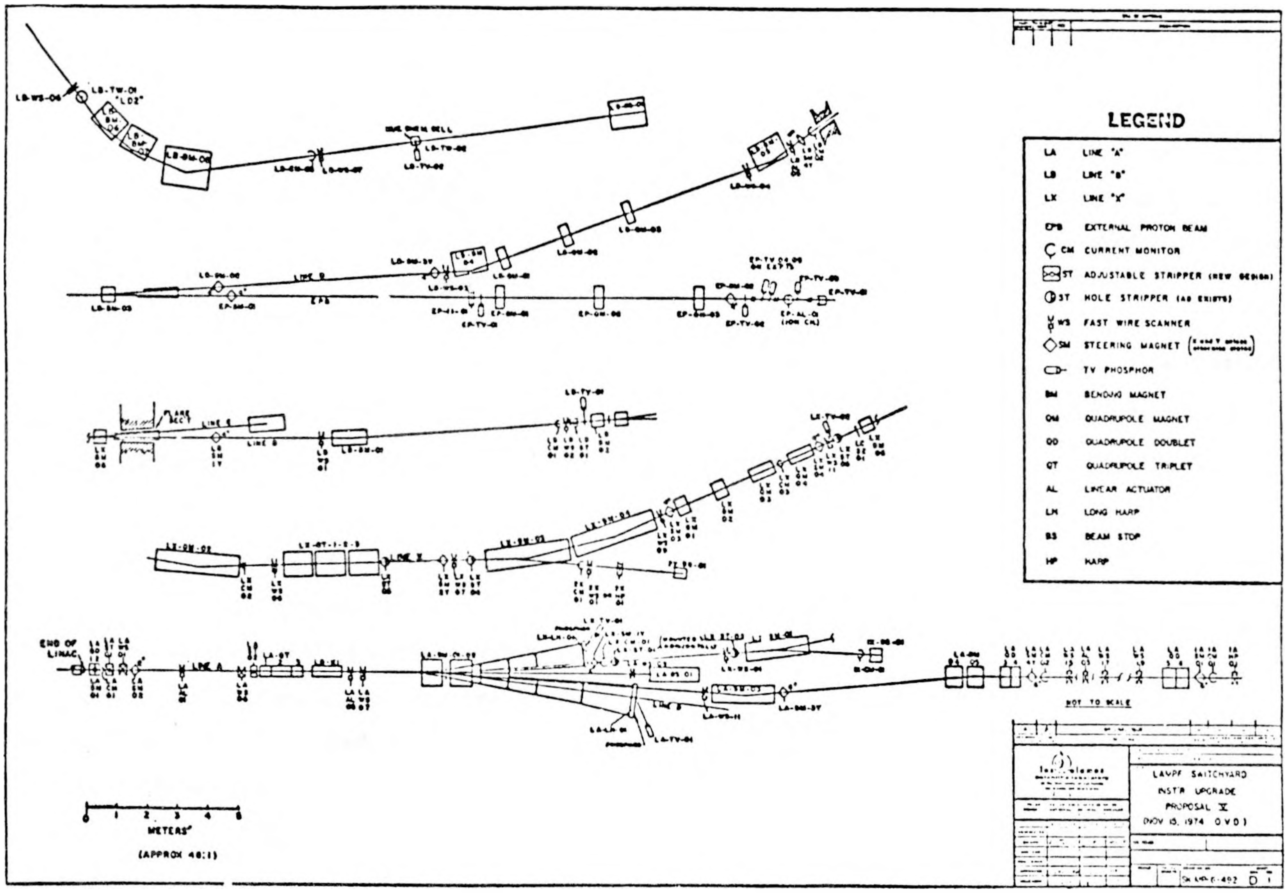


Fig. VII-1.
Revised switchyard layout.

shows schematically these and all other improvements in the revised switchyard.

Most of the rearrangement of components for the revised switchyard layout (Fig. VII-1) has been completed. Two new beam stops are required and are 75% assembled; their support tables have been shipped. The Line A direct beam stop (used for accelerator development and for nuclear chemistry irradiations) can be swung out of the way and replaced by a length of vacuum pipe when it is desirable to run beam straight through to Area A. Numerous pieces of vacuum line are needed to connect the components in their new locations — spool pieces, bellows, and flanges. All are on order or in fabrication.

New turbomolecular vacuum pumps (rated at 500 ℓ/s) are on order for the transition between the switchyard which runs at 10^{-7} torr and Area A which runs at 10^{-3} to 10^{-4} torr. These are needed to eliminate the former vacuum window, which is not expected to be able to stand the full 1 mA beam intensity and which would add to multiple scattering of the beam.

Switchyard Improvement Program—Line X

As a result of further design studies in this period, an additional stripper (LX-ST-03) was added in Line X just after LX-QT-03 to facilitate tailoring the H^- beam for Line C. Calculations were made on the acceptance of Line X as determined by the various switchyard tunes, and various choices of stripper hole sizes and locations. The intent of these calculations was to study the range of flexibility of the Line X design and to maximize the overlap of the Line X acceptance with the linac H^- emittance.

To facilitate these studies, numerous changes were made to TRNSPRT in the acceptance routine to speed up the calculations. Several options in the acceptance routines are now available that aid in the interpretation of the acceptance diagrams: 1) the projected phase ellipse can be drawn on the acceptance diagram; 2) the areas of the acceptance diagram and the phase ellipse are printed on the diagram; and 3) the apertures can be inserted in the deck in any order, as long as the aperture names agree with TRNSPRT element names. Two new programs (CORNERS and STRIP) were written to calculate the amount of beam with a Gaussian distribution that passes through a defined acceptance area.

The results of these calculations showed that Line C phase-space requirements could be met. Previous requirements were that the beam at the beginning of Line C be contained in a four-dimensional ellipsoid whose projections on x,θ and y,ϕ are $\pi/10$ mr-cm in area. These requirements have recently been relaxed somewhat to allow $\pi/3$ mr-cm in y,ϕ. The phase-ellipse orientations must be upright in both x,θ and y,ϕ with $\sqrt{\sigma_{22}} \leq 0.45$ mr and $\sqrt{\sigma_{33}} \leq 0.35$ cm. If the above requirements are met and a ribbon stripper is used to determine $\sqrt{\sigma_{11}}$ at the start of Line C, then phase ellipses of $\pi/3$ mr-cm can be transmitted in both x,θ and y,ϕ. Calculations show that by using a combination of six strippers before Line C in the switchyard (three for x,θ and three for y,ϕ), greater than 95% of an H^- beam from the linac which has $\pi/30$ rms projections can be transmitted to the beginning of Line C with $\pi/3$ mr-cm projections. The use of six strippers greatly simplifies the construction of the stripper foils as each one only needs to operate in one dimension (x or y). Also, greater separation can be obtained between successive x (or y) strippers and the matching to the linac is improved.

Line B

During the past quarter, attempts were made to look for a design of Line B transport elements that could give the desired spot sizes ($\sqrt{\sigma_{11}}$ = 0.5 cm, $\sqrt{\sigma_{33}} \leq$ 1.0 cm), double-waist and achromaticity at the liquid deuterium target and minimal beam blowup to the beam stop. Many configurations have been tried, using as many as six quadrupoles in Line B. The position of quadrupoles throughout Line B were varied, as were field strengths, in attempts to meet the above requirements; none of these attempts has been successful. Apparently, the $\sqrt{\sigma_{11}}$ requirement is incompatible with achromaticity. Achromatic tunes require spot sizes very much smaller than can be tolerated by the target. The best tunes that fit the spot size and double-waist requirements have a spatial chromaticity of 5 cm/% $\Delta p/p$ in Line X. Work is continuing on this project.

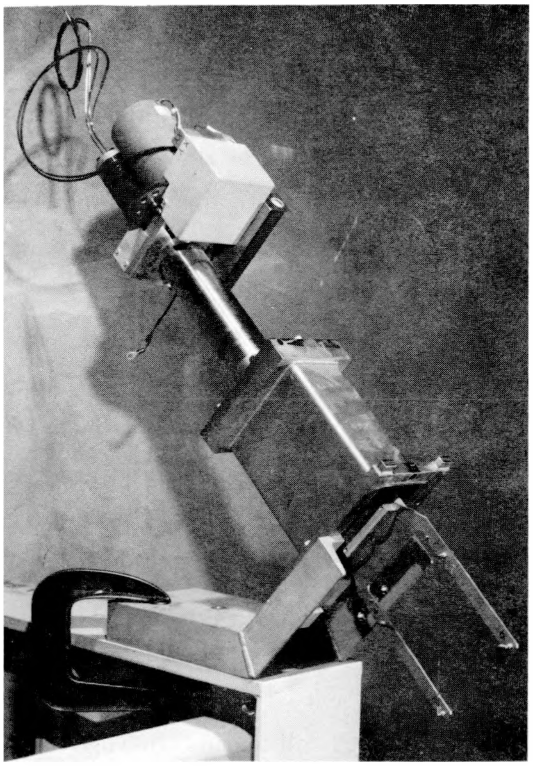


Fig. VII-2.
Switchyard wire scanner.

Instrumentation

A great deal of redesign of instruments for the previously reported upgrade program has been completed. Components for the fast (read-on-the-fly) wire scanners for the switchyard are in fabrication. Figure VII-2 shows one of the present wire scanners. Harps for the main beam line have been redesigned to use ceramic printed circuit boards and to accommodate collection fields for the secondary-emitted electrons. Recent experiments at the LASL Van de Graaff accelerator indicate that the collection field may not be as effective at increasing signal levels as expected, but provision for applying it will exist. New "moving-shutter" strippers, which can use 0.01-mm-thick carbon foil, have been built.

Line A Improvements

Line A optics calculations and design studies addressing the special problems of high intensity were continued. Many hardware improvements suggested by these studies were selected for inclusion in the Great Shutdown effort and are in the process of being implemented. Among these are 13 collimators, 10 secondary-emission/guard-rings, 3 additional harps, 6 additional toroids, redesign of harps and harp electronics, relocation of one A-5 harp and the 5A-QT-4,5,6 triplet, addition of beam-halo shields in the TCTs, and 3 beam-on-target monitors, plus additional spill monitors.

Beam-halo calculations have continued using both TRANSPORT and a Monte Carlo ray tracing code PIFLUX. To date, calculations have been made for the old configuration (preshutdown) of harp locations. These numbers confirm TRANSPORT studies which suggest that tungsten wires produce too much phase-space growth in the beam and thus unacceptable losses. The postshutdown beam line is being modeled with nickel foils in the large harps. These calculations are used to 1) make a more detailed test of the tunes generated from TRANSPORT, 2) study allowable target configurations, 3) estimate heat loads in collimators, 4) check heat loads and radiation damage to quadrupole inner boxes, and 5) test the hypothesis that there exists a tune which would be acceptable for both A-5 target-in and target-out.

Collimators are used for two main purposes: 1) to protect harp cards and toroids from levels of radiation which produce spurious signals or otherwise degrade performance, and 2) to limit beam halos and protect downstream components such as triplets from levels of radiation which can cause excessive heating. The three collimators downstream of targets were chosen to limit the beam divergence emanating from a small production target to a 30-mr (1/2 angle) cone. Other collimators had apertures chosen to be small enough to shield the appropriate components, yet large enough to let through at least $\pm$ 3.5 σ of the worst case beam size.

Studies were continued to find additional methods of estimating spot sizes at production targets which might provide better accuracy than the present method using three harps separated only by drifts. The problem is most severe at A-1. A proposal for a new harp, 1A-HP-04, was put forth, with arguments showing that the additional measurement should provide a real-time measure of the spot size on the A-1 target with considerable provision for self-checking. A box for this harp will be installed during the Great Shutdown, but development of a special harp to fit in this location will be done at a later date.

This new harp (1A-HP-04), located halfway between 1A-HP-03 and 2A-HP-01, would give a third profile measurement in this drift space and thereby permit an accurate and unambiguous determination of the exit emittance from the A-1 target, which in turn would allow inference of the target spot size. This arrangement would have some self-consistency which would enhance confidence in the results. It would also back up some measurements which can be made with the upstream wire scanners and harps. Finally, the three-harp arrangement could supply enough data rapidly for real-time tuning.

The outgoing emittance measurement gives the target spot size W_x under the conditions of small incoming emittance and known multiple scattering angle W_θ through the relation $E/\pi = W_x W_\theta$, where E, W_x, and W_θ are consistent measures, e.g., W = rms size and E is derived from rms profile widths.

Optimum accuracy on the emittance measurement is obtained when the spot size is minimized on 1A-HP-04, which simultaneously equalizes the spot sizes on the end harps. Under these conditions, the waist at 1A-HP-04 is also an image of the A-1 spot size with known ($\sim$2.4) magnification, thus giving a second estimate of the spot size.

These measurements may be made in parallel with observations on the upstream profile instruments, LA-WS-15,17,19 and 1A-HP-01,-02, and with special tunes on the magnets. For example, it is possible to move the beam waist from the A-1 target back to 1A-HP-02 with a few percent change in magnet strengths. Under this condition, which should be verifiable by measurement on the upstream instruments, the spot size on target approximately doubles, and this should be seen in the downstream measurements.

Line A Harps

The entire harp system has been studied in great detail during this quarter. The initial work was to study the existing system to determine what noise was present, its source, and possible solutions to eliminate it. Many potential problems were located: cable grounds were not connected, software and hardware timing problems, shorted cables, and a host of other problems. Base line shifts were induced on the harp profiles by adjusting magnet currents; in addition, SCR spikes were quite evident and contributed to noise on the harp wires. The noise problems appeared to be caused by ground loops, and a major part of the system overhaul is directed toward ground isolation; consequently, the existing multiplexers will all be modified. In addition, the rerouting of harp cables is being recommended. Keeping harp cables away from all magnet and ac cables should reduce the noise pickup.

The study relating to using an amplifier on every wire of the harp is another major effort. This modification is expected to reduce the noise level, since the signal is amplified before it is transmitted over the longest, noisiest signal path between the harp and the multiplexer. E-Division has been breadboarding a prototype amplifier with a sensitivity of 1 pA, which should allow good profile information at 1 μA average beam. An amplifier box that is capable of handling one entire harp should be ready for testing early this summer.

The large harps were redesigned to accommodate collector planes. The harp is made from thin strips of alumina mounted on a thin piece of stainless steel. Procurement of these alumina boards is under way.

A number of research runs have been held at the tandem Van de Graaff. These were designed to measure the secondary emission properties of various materials (nickel, aluminum, carbon) and also to study radiation damage to harp boards made of G-10, alumina, and porcelainized steel. Results showed that alumina and G-10 behaved reasonably well, whereas the porcelainized steel showed more severe degradation of electrical properties; the G-10 board suffered structural damage at an earlier stage than the other materials, but still retained reasonable electrical properties (i.e., $>10^{10}-\Omega$ resistance) when the board was discolored and warped.

The secondary emission characteristics of the various materials produced some rather puzzling results: in two separate experimental runs, the secondary emission from the carbon wires did not increase with the application of a collector voltage. However, a 40-mil nonoxidized nickel ribbon had approximately a 50% increase in secondary-emission current, and an oxidized ribbon had an increase of 250% on the first run but only 10% on the second run. The setup was identical for both runs. Additional runs are planned to explain this discrepancy.

Beam Burnout Protection

System planning is under way to provide burnout protection for main beam lines in the experimental areas. Initially (at the end of the Great Shutdown) protection will consist of a computer-based beam-transmission monitor, magnet-current monitoring, collimator water temperature and flow interlocks, vacuum gauges, temperature trip-outs on air-cooled collimators, standard spill monitors between target cells, and some radiation monitors.

Additional devices such as secondary-emission/guard-rings, beam-on-target monitors, and additional toroids will be installed in the beam lines but will not be part of the initial protection system. Electronics and information processing equipment for these will be developed later. Some electronics will be available for trial use shortly after the Great

Shutdown. A trip to SLAC to review their beam containment and machine protection systems provided a valuable stimulus to this effort.

Calculations are under way to estimate the worst case time-to-failure for the situation which occurs if the beam at A-1 suddenly moves and strikes a tungsten or copper collimator. Crude analytical estimates indicate that failure may occur within one 500 μs, 17 mA macropulse. If this is true, the protection system must be capable of detecting this condition and shutting off the beam in less than 100 μs. These and other calculations are under way to help define the level of protection needed as a function of average beam current.

Redundant Monitoring

Discussions on redundant monitoring focused attention on the magnet shunt amplifiers as the weakest link in magnet control system, since both the control loop and the measuring devices operate from the amplified voltage. This problem also arises in monitoring the magnet currents for burnout protection. The addition of an independent metering loop is therefore being considered. It appears that individual 3- or 4-digit DVMs ($200-$400) on a separate measuring shunt in each power supply would be most cost-effective; a trial installation is planned.

Alignment

A scheme for remote monitoring of long-term position shifts of selected equipment along Beam Line A has been devised. Mirrors with cross-target patterns are fixed on some components and telescope mounting brackets are fixed on others. A reading is taken by placing a standard optical-tooling telescope equipped with remote controls and a television camera on the bracket and observing the mirror. Two rotations and two translations can thus be found at one setting. In general, the mirrors will be on brackets fixed to the profile monitor bases, and the telescope mounts are on selected magnets. Mounts for target cells A-1 and A-2 are almost completely designed, and Target Cell A-5 is being studied.

Secondary Beam Lines

The major activity on the secondary beam lines during this quarter has been to prepare P^3, SMC, and LEP for high-intensity beam operation. The most significant accomplishments are given in the following paragraphs.

The upstream horizontal and vertical adjustable jaws for P^3 have been redesigned. Both sets of jaws have been built, and they are undergoing assembly and check-out in preparation for final installation and alignment; they are designed to be radiation-hardened and remotely handled.

The four 4-jaw collimators in LEP have been reworked, rewired, remounted, and realigned. Final check-out is about to begin. The control cabling for these devices (with radiation-hardened cable for the two upstream sets of jaws) will be done shortly.

The complete vacuum system for SMC is on hand; it has been vacuum-leak checked and is leak-tight. Included in the package are the downstream beam plugs for the west and south caves. Installation of the system is 70% complete. The BM-02 vacuum box has been reworked to allow for remote separation from the second doublet of SMC (QM-03 and QM-04). Problems with the installation of the front-end-beam plug vacuum window (which isolates Line A vacuum from SMC vacuum) have been encountered. The upstream vacuum section (part of Line A vacuum) will be completed in the near future. The pump package for SMC vacuum is on hand.

The first doublet (QD-01 and QD-02) and bending magnet BM-01, as well as the first two 4-jaw collimators and beam plug of LEP, have been made remotely handleable and radiation-hardened; the same has been done to the first two doublets (QM-01/QM-02 and QM-03/QM-04) and the first bending magnet (BM-01) of SMC and the first two doublets (QD-01/QD-02 and QD-03/QD-04) and the first bending magnet (BM-01) of P^3. This involved:

1. The design of vacuum flange clamps, clamp stands, and bellows retractors for the vacuum connections to the above-mentioned devices, as well as the procurement of the SMC pieces which are now being installed.

2. The development of lifting techniques for these devices and the design of the lifting fixtures that will be used (all of which will be removed by the Monitor system—not Merrimac).

3. Preparation of flange surfaces to accept K-seals to make the vacuum seals. The K-seals are on hand for SMC and LEP, and have been ordered for P^3.

4. The design of LEF and SMC direct current power buss lines for the upstream magnets. The buss work has arrived and is being installed by ZIA electricians.

5. The design of remotely handleable and radiation-hardened direct current magnet terminals and jumpers from buss lines to magnets for SMC, P^3, and LEP. Material has been procured and assembly is being carried out.

6. The installation of radiation-hardened interlock and control cables for the above devices is being accomplished.

The interfacing between the first quadrupole of each line (SMC, P^3, and LEP) and their respective main beam-line target boxes has been designed, and will be implemented shortly.

It is obvious that our primary effort during this report period has been to make the front-end components of the secondary beam lines radiation-hardened and remotely handleable, as well as reliable. In addition, the SMC canyon fill has been designed, cut, and partially installed by Zia; the remainder of the canyon fill will be completed after reassembly of the remainder of the upstream portion of SMC. The P^3 canyon fill is being designed; LEP will be done last.

The designs for the removable Merrimac ways above LEP, the test channel, and SMC have been completed. Plans for the bulk shield stacking around LEP and the adjacent valve caves have been worked out, and design is being completed. This design package includes the shield, bridges across the LEP, and the rerouting of magnet power-supply cables and instrumentation cabling.

Together with Alex Zehnder and James Miller of Caltech, preliminary work has been done on a design for the east leg of SMC. As an extension of this work, the previous calculations were reviewed, and new calculations for the channel as a whole are in progress.

The five P^3 magnet power supplies just west of the P^3 channel have been moved and reconnected to allow the placement of the A-2 Merrimac ways.

The magnet power supplies of the three beam channels are being refitted and repaired by the magnet power-supply section of Group MP-11. Preparations are under way to replace three SMC power supplies; also, extensive modifications are planned for the southeast section of Area A (including experimental magnet power-supply shifting, cable tray rerouting, etc.) to allow for the installation of SMC-East (parasite cave) and the setting up of an experimental staging area.

Finally, at a low level, some work is being carried out in Area B. This includes 1) the setting up of the rabbit system in the nuclear chemistry cave, 2) improving the vacuum pipe support system in this area, 3) improving the radiation shielding in the area, including steel shielding around the Line B beam stop, and 4) preparing the new fast-wire scanners, television beam monitors, and new steering magnets for mounting.

Magnets

There has been an increase in magnet-related construction and reconstruction this quarter because of revision required during the shutdown. Figure VII-1 shows the new switchyard layout; its implications for magnets are:

1. A hole is required in the yoke of LX-BM-01 to accommodate stripped H^- which will be collected in a new beam stop, LX-BS-01.
2. Several new 10-cm-bore steering magnets are required in Lines X, A, B, and EPB. The power supplies for these will also be consolidated from individual bipolar units to a bulk supply plus an arrangement of individual series regulators.
3. Quadrupoles are required at the end of the linac (LA-QD-1 and -2) and in Line X (LX-QM-1 and -2). An 805-linac-type doublet and two ex-CEA 10-cm-bore quadrupoles will be used in these positions.

In Experimental Area A, the main-beam-line triplets in Target Cells A-1 and A-2 are being changed to a radiation-hardened installation. This involves laying water-cooled m.i. cable from outside the shielding to a bulkhead on the target-cell wall adjacent to the magnet, and fabricating a remotely removable jumper to connect from the bulkhead to the magnet terminals. Figure VII-3 shows a similar bulkhead and jumper arrangement at Target Cell A-5, which has been in satisfactory operation during the last running period (the magnet is on the right). All insulators are ceramic, and the jumper cables (which are probably most susceptible to mechanical damage) are isolated and connected to the magnet ground fault detector.

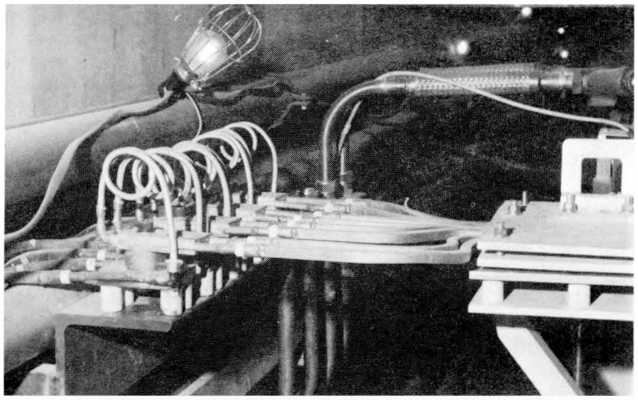


Fig. VII-3.
Radiation-hardened jumpers for target-cell quadrupoles.

The magnet measurement effort continues on the magnets listed above (Items 1 and 3) and other beam line magnets. A total of eleven 3Q14/8, ten 3Q11/4, and six 3Q7/8 quadrupoles for WNR have been measured, plus a H4II20/3 laminated-core-bending magnet. A long series of measurements on the elliptical bore quadrupole 8QE18 for Line C has been completed and reported. The final configuration of this magnet for minimum n = 4 and n = 6 (0.04 and 0.06%, respectively) has no field clamps, no chamfers on the pole ends, and no shims on the poles.

A field map was made of the high-field H-frame magnet intended for polarized target work at fields up to 2.4 T.

The repaired target-cell triplet was remeasured to check its performance and, using individual excitation, to give data on single quadrupoles compatible with the TRANSPORT hard-edged model. A replacement 15-cm-bore quadrupole for the switchyard was also remeasured.

Polarized Proton Target Development

At the end of March 1975, repairs and refabrications on the prototype polarized proton target cryostat were completed by the MP-Division shop. The cryostat was brought back to the laboratory space at the Equipment Test Lab (ETL) and was reassembled. It is now in the process of undergoing cryogenic preliminary tests. So far, the liquid nitrogen test and the unpumped liquid ^{4}He test show satisfactory results. We were able to ascertain the collection of liquid ^{4}He at 3.9 K on the ^{3}He condensing plate.

The next test, which will commence shortly, will be to recirculate ^{4}He gas in ^{3}He space. We anticipate recirculation of ^{3}He and the test for refrigerator characteristics to be completed by the end of May. Starting in June, we will proceed to try polarizing in the transverse polarization target configuration; this phase of development should be completed during the first part of FY-76. It is our projection that the polarized target in this configuration be ready for operation when the shutdown is over and the experimental program resumes.

The ^{4}He pumping system, a large microwave source power supply, a superconducting magnet power supply, an electromagnetic power supply, and a pair of pole caps for the Varian 55-cm electromagnet (on loan from ANL) are on order. This magnet has been tested for over-powered operation to provide a 7.5-cm gap at 2.5 T, using 25 gpm of cooling water at 16-K inlet temperature. It operates satisfactorily. We expect to test it at doubled cooling water-flow rate and 22-K inlet temperature soon.

The NMR system is now being tested on the Varian 55-cm magnet for its performance.

Radiation Effects and Isotope Production Facility (RADIP)

Fabrication of redesigned components for this facility is now well along. Design of the isotope production stringers and handling facilities was handled by Groups CNC-11/ENG-6, while a CMB-8/Q-23 team revised the radiation effects irradiation facility. Shielding calculations were provided by MP-DO, and MP-7 serves to coordinate all construction effort—a more demanding task now that more groups are involved in design, fabrication, and installation.

The revised shielding (without direct line-of-sight paths to the beam stop and with increased mass of iron and concrete around the mechanism housings) is anticipated to decrease dose rates at operator locations, but will still require movement of the beam stop when isotope samples are changed, since removal of a stringer leaves a direct channel to the beam stop cavity.

The major changes (cutting and welding) to the previous steel shielding have been completed; new piping for cooling water is being installed, and the shield design has been started.

Remote Handling and Targeting

Merrimac

The lead-glass windows in the Merrimac shielding box are installed, and the window oil-expansion system has been finished. All pass-through ports in the shielding roof are established, and the port plugs are being completed. The defect in the lifting mechanism of the $\sim 2 \times 10^5$-kg steel box has been rectified, and the whole assembly will be mobile again shortly.

A manual-control system, using television viewing, is being implemented that will permit a single operator to maneuver Merrimac in reasonable safety. A decision as to whether to speed up such maneuvering by automating the steering system has been deferred to allow operational requirements to crystallize.

Monitor

Monitor is a new remote-handling system which will start operational development in June. Monitor can be easily deployed anywhere on site. It is expected that Monitor will be used for operations which will not require Merrimac's extreme form of shielded handling, but would incur too much man-dose if undertaken manually.

Monitor consists of a 1000-kg, remotely controlled, articulating hydraulic crane, with an electric manipulator attached to its boom end in place of the regular hook. This assembly is mounted on a heavy trailer whose wheels are retractable to lower the trailer bed to the ground for stability. In practice, the trailer may be towed by a forklift or lifted in by crane wherever it is required.

The manipulator can reach out from the trailer 9 m horizontally in any direction, or 7 m below ground level. Using television, all Monitor movements may be controlled from a distance of 30 m or more. Most operations in Area A involving the removal of shielding will be effected in conjunction with the house crane, also operated with extended-pendant control and television viewing. Initially, the manipulator used will be a salvaged PAR-150, but the system would ideally suit a servo master/slave manipulator.

Shielding

A major effort on shielding design, particularly on steel cutting details and installation drawings, was carried out during this past quarter. Overall general patterns were completed, and shield envelopes were defined.

Because of complicated and expensive fabrication, the large shield doors over Target Cell A-1 were redesigned; this work has been completed, and fabrication is under way. The A-2 door has been fabricated.

Extensive changes have been completed in the bulk shielding around EPICS. The horizontal shield plug for the separator access has been designed, and most of the components have been fabricated. The large box has been test-assembled and installed; the track system has been fabricated and delivered. Final installation of this shield system will be made next month.

All design work for the ways that support the shield doors over A-1 and A-2 has been completed. The A-1 ways are installed except for the removable sections that pass over the LEP and EPICS beam lines; they cannot be placed until final hardware installation is complete. Sections of the A-2 ways that pass over the target cell and SMC will be installed after completion of hardware and in-cell shielding.

The in-cell shield, steel shielding immediately around the targets and the main beam line hardware at A-1 and A-2, has been designed and partially fabricated. The lower half of the A-1 in-cell shield is ready for installation.

Steel shielding is being fabricated to fill the upstream sections of the secondary beam lines at A-2 and installed in SMC. Fabrication of this shielding for P^3 is in progress, and installation will proceed when hardware work will permit.

During this past quarter, about 2.23×10^6 kg of shielding material was installed in final form in Area A. About one-third of this was reinstallation of shielding modified to accommodate increased complexity of hardware and instrumentation along Beam Line A and EPICS.

Most of the major shielding materials are now on hand. The structural steel sections for the removable ways above LEP and EPICS are scheduled to be delivered during June. Twenty-five cast iron counterweights have been obtained and will arrive during the summer. Excess armor plate, 2.7×10^5 kg, was received this month and will be used for shield door fill.

Installation work will continue on a night-shift schedule in Area A. Completion of A-5 target area and A-6 beam-stop shielding design is being pushed. A day-shift installation crew has started work in the A-5 target area and will continue on A-5 and A-6.

High Intensity Modification Program

As of April 30, 1975, the PERT system contained 810 work packages that need to be accomplished before low-current tune-up of Area A can begin. This represents nearly 70 000 man-hours of work that must be done during the next 16 weeks in order to meet the scheduled date of August 18. An average removal rate of 51 work packages per week is therefore necessary. Statistics kept for a 15-week period indicate an average removal rate of 36 work packages per week; at this rate, 23 weeks are needed. In reality, new work packages are frequently added to cover unforeseen or unplanned work, or to better define existing work packages, resulting in an even lower net removal rate.

Approximately 20% of all the PERT work packages have negative slack (i.e., they cannot be completed by the scheduled date). Work paths with negative slacks have been shortened by reducing activity duration and by restricting the logic to less ideal, but shorter, game plans. The former large positive slacks on some paths are dwindling away; the durations have been cut to marginal levels, and the logic options are becoming fewer.

PERT predicts that extremely close coordination and resource allocations are required to prevent a delay longer than one month beyond the scheduled date.

VIII. LARGE-SPECTROMETER SYSTEMS

Energetic Pion Channel and Spectrometers (EPICS)

EPICS Construction

A trial assembly of the EPICS spectrometer magnet EA-BM-05 was completed. No significant problems with the steel components were found, so that we proceeded to assemble, align, and dowel the magnet. The coils do not fit properly in the magnet. This problem was traced to a design error in the region of the power terminations. Approximately two man weeks of work are required per coil to correct the problem, which also occurred on EA-BM-06. The next step in the assembly of this magnet is the welding of the vacuum chamber assembly. All work on the spectrometer has stopped pending completion of the EPICS channel installation. The requirement that all available manpower be used on the channel installation has delayed the spectrometer completion date by at least one month. We expect that the delays will stop accumulating when we get additional summer help, approximately May 20. At the present time, we expect that the EPICS spectrometer will be ready to accept beam approximately February 1, 1976.

The last of the EPICS channel magnets, 1P-BM-01 and 1P-BM-04, were completed early in the quarter. After measuring and shimming, vacuum flanges were attached to 1P-BM-01 and 1P-BM-02, and magnet 1P-BM-01 was prepared for installation in the shielding. Four jaw slit assemblies 1P-FJ-01, 1P-FJ-02, and 1P-FJ-05 were completed and vacuum tested. Components for collimator 1P-CL-01 were received from the Univ. of Virginia. The assembly of this device proved to be more difficult than anticipated, and completion is expected to take another two weeks. Multipole magnets 1P-FM-01 and 1P-FM-02 were received from the Univ. of Colorado. Magnet 1P-FM-01 was installed on the 1P-FJ-01 assembly and is awaiting power and water tests. The second multipole 1P-FM-02 will be assembled when the vacuum pipe arrives from the Univ. of Texas. The major beam line components which are not yet complete are the collimator (1P-CL-01), the four jaw slit (1P-4J-04), the third multipole magnet (1P-FM-03), and the steering magnet (1P-SM-01Y).

The support structure for the power, water, and compressed air services for the EPICS spectrometer was constructed and installed. All of these services were installed on the support structure. It was necessary to do this work now so that the remaining installation work for the spectrometer can be accomplished in a short shutdown without affecting the LAMPF operating schedule.

Particle Separator

High-voltage testing of the separator components began early in February. Initial testing was performed with the flexible hv cable connected to the oil and SF_6 filled rigid hv line, but with no connection to the separator electrodes. This portion of the system was run for several hours at 325 kV (the maximum required), but eventually reached a condition where arcing would occur at voltages over 250 kV. During this testing period, improvements were made in the vacuum pumping equipment which brought the pressure in the separator box to 1×10^{-5} torr. At this point, the separator electrodes were connected, the voltage divider installed, and testing of the complete separator begun.

The first test was to determine if the presence of the magnetic field caused breakdown in the hv section. With 100 kV applied to the electrodes, the magnet could be run from no field to full field with no effect on the hv.

The second test was to determine the ultimate voltage capability of the separator. The separator was slowly conditioned to 250 kV. Normal conditioning occurs as the voltage is raised, as evidenced by loading of the driver stage, substantial production of x-rays, and occasional sparks in the system.

A slow N_2 leak was installed and some testing done with box pressures around 3×10^{-4} torr. At this pressure, very stable operation was achieved with the complete system at 220 kV. Voltage fluctuations were typically ± 1 kV compared to ± 5 kV at higher vacuum. At higher voltages, the rigid hv line would arc.

These tests satisfied us that the separator box was capable of handling hv better than the rigid hv delivery line, so the line was disassembled for inspection. Several conditions were noted: 1) the series resistance, made up of three 200-MΩ resistors in parallel, had suffered substantial spark damage; 2) there was no evidence of any other sparking in the SF_6 filled portion of the line; 3) the oil filled canister was badly contaminated with dirt and showed signs of considerable sparking; and 4) there was no damage to the voltage divider. Testing is currently suspended pending fabrication of several improvements in the hv delivery system, and installation of the new separator box.

Magnet Measuring, Shimming, and Analysis

Magnets 1P-BM-01 and 1P-BM-04 were measured at 12 kG. Several methods of shimming were considered, and it was decided that shims would be put on the field clamp nosepieces of the entrance side of 1P-BM-01 and the exit side of 1P-BM-04.

After installation of the shims, both magnets were mapped at 4.6, 9.2, 12.4, 15.7, 17.0, and 18.0 kG. Program MOTER was run on the set of maps of the EPICS channel and the resolution was computed. The results are tabulated below.

Although the shims provided a significant improvement, the design resolution was not achieved in the first iteration. Because of the variations observed at different fields, it was decided that a second iteration on the shimming would not be of great value. Instead, we chose to depend on the multipole magnets for fine tuning. The optimized resolution using the three multipoles (with fields constrained to be equal in all multipoles) is also shown in Table VIII-I. Since the resolution equals the design resolution, we conclude that the magnets are adequately shimmed. In addition, we have decided to eliminate all further work on the H_t trim windings and power supplied, both on the EPICS channel and the EPICS spectrometer.

Considerable work remains to be done. Since 1P-BM-02 and 1P-BM-03 were not measured at 18 kG

TABLE VIII-I

EPICS CHANNEL RESOLUTION

Field (kG)	RMS Momentum Resolution (Before Shimming)	RMS Momentum Resolution (After Shimming)	RMS Momentum Resolution (With Shimming)
4.6		3.8×10^{-4}	1.2×10^{-6}
9.2		3.2×10^{-4}	0.9×10^{-4}
12.4	7.6×10^{-4}	2.1×10^{-4}	1.0×10^{-4}
15.7		1.7×10^{-4}	0.8×10^{-4}
17.0		2.4×10^{-4}	0.9×10^{-4}

(because of power limitations in the original test setup), we will map these magnets at 18 kG. We must study the effects of field components which do not obey midplane symmetry, since some of our data indicates that these field components may be too large to be ignored. We must consider more complicated adjustments of the multipoles, as it may be possible to improve the resolution. Finally, we will study tune-up procedures using a monochromatic alpha-particle source.

Alpha-Particle Tune-up

An alpha source has been mounted on 1P-BM-02, and tests are in progress. At this point in time, it appears that we have observed: 1) significant effects due to field components which do not have midplane symmetry; and 2) that symmetric field components are well described by our field maps and ray tracing. Further data will be taken to elucidate the effects of midplane asymmetry on the channel resolution.

A new source has been ordered for use in the channel tuneup early this summer. This source will be located on the vacuum window separating the EPICS vacuum from the Line A vacuum. We will have the option to place a helical chamber detector at any of the three crossovers in the EPICS channel. Work is in progress on a tune-up procedure using these detectors to obtain an optimum adjustment of the three multipole magnets. By using singly and doubly charged alphas, we will be able to tune up the channel at 4.6 and 9.2 kG using this method.

High-Resolution Proton Spectrometer (HRS)

Handsanding of the pole-pieces of HS-BM-01 has been finished, and the magnet has been reassembled and vacuum checked. Water and electrical connections to this magnet have also been made. Measurements on HS-BM-02, the first large dipole on which handsanding was carried out, show significant improvement. Gap-height integrals measured before and after the sanding show a peak-to-peak improvement over the full solid angle of more than a factor of 4. The corresponding azimuthal field integrals at 10 kG over nearly the full solid angle on this magnet show a peak-to-peak improvement of a factor of 5. The resulting field integrals are now sufficiently good to show that a significant fraction of the peak-to-peak variation is directly correlated with the location of the pole-piece tie-bolts which are spaced azimuthally along the magnet at constant radii. A number of different mechanical measurements have been made on this magnet—partly in preparation for mounting it in the spectrometer frame. The expected resolution of the combined system in its current state is now about $\pm 10^{-4}$. It is hoped that further improvements which are currently in progress can again lower this number significantly.

Other results accomplished during this quarter include the design of a staging and assembly area, final design of the sliding-seal curtain-retractor mechanism, final design of the TOF detector frames and initial layout of the spectrometer frame 2-ton jib crane. Design of the TOF support structure has begun, and orders for the remaining scintillation counters and electronics which are required are out for bid. An elevator for the spectrometer frame has been acquired as well as all of our graphic display terminals for CCH. Final modifications to Line C are nearly complete except for the ISICS and the taut-wire monitor system. A multipole magnet for the beam line is in construction. The power supply for HS-BM-01 has been installed and checked out in the B/C Equipment building. We expect to be running

HS-BM-01 in its final control configuration either from CCH or CCR during the next quarter.

Line C

A considerable amount of work was accomplished on the Area C counting house (CCH) during this quarter. The bulk of the cabling from the HRS hodoscope (MWPC and TOF system) was installed together with most of the control cabling. The ability to communicate with CCR was demonstrated, and installation of several components in the control console was completed.

The first spectrometer dipole power supply was installed in the equipment building and checked out. The controls interface to the CCR computer is now being checked out in preparation for the first run tests from CCR and CCH.

The taut-wire monitor system has been laid out and the bulk of the cabling pulled. The magnetic pickups have been assembled, and the construction of the electronics is in progress. The design of the support structures from the individual magnets has begun.

The design of the TOF detector supports has been completed, and these items are in construction. Design of the overall support structure, as well as the variable solid-angle feature, is in progress. Orders have been placed for the remaining scintillation counters (1.0- and 1.25-cm thick) and the associated electronics. The MWPC box and chambers built by BNL are now at LAMPF and in the initial stages of check-out.

The first toroidal current monitor in Line C has been installed as well as the octupole steering magnets from Line X. Design of the Line C ISICS has been completed and the associated cabling and multiplexer installed. A multipole magnet for the beam line allowing quadrupole, sextupole, and octupole fields is currently under construction at the Univ. of Texas. A similar system will be built for the spectrometer with the exception that it will provide higher multipoles.

HRS Optics and Dipole Magnets

Figure VIII-1 shows the results of a series of measurements on HS-BM-02 both "before" and "after" pole-face sanding, and the geometrical disposition of the H_t windings and pole-piece tie-bolts. The grinding region roughly corresponds to the design solid-angle of the instrument.

The grinding operation was performed for several reasons, all of which can be summarized by the fact that the mechanical gaps varied by as much as 233.6 μ (HS-BM-02) and 327.7 μ (HS-BM-01) out of a design gap of 0.1016 m; that is, mechanical homogeneity was good to ~ 2 to 3 parts in 10^3.

Correlation of several magnetic field and mechanical-countour maps for each magnet made possible the construction of polar grids for each pole piece, on which the amount of steel to be removed

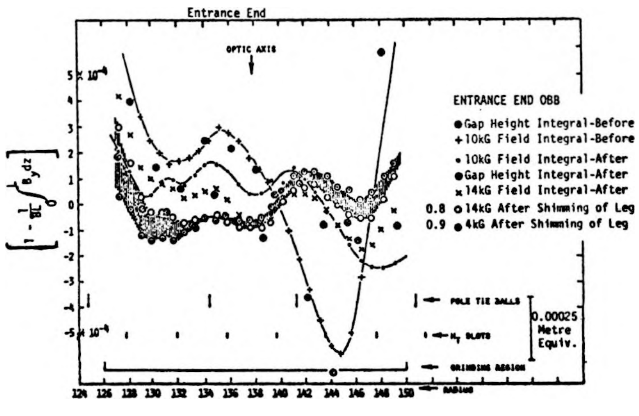


Fig. VIII-1
Results of a series of measurements on HS-BM-02.

was known. The grinding operation consisted in removing the specified amount of steel from a polar area element about the grid point in question to as close a tolerance as possible, and to do so in such a fashion that neighboring area elements would blend continuously into one another. This was done for four pole-pieces with a total area of $\approx 16.72\ m^2$.

For HS-BM-02(the first magnet that was ground) there were 585 polar area elements of approximate dimension 5.08-cm radial by 10.16-cm azimuthal. Upon completion and reassembly, a mechanical contour map indicated that the following improvements could be implemented for the grinding of HS-BM-01:

1. An azimuthal "sine wave" variation in the gap height, with wavelength ~ 10.16 cm, indicated that the polar area element should be changed to ~ 5.08-cm radial by 5.08-cm azimuthal.
2. Results at innermost and outermost radii indicated that mechanical contour maps on HS-BM-01 should have a larger radial extent so that a better job could be done on "blending" the base take-off amounts into the Rojowski edge profiles.

These adjustments were incorporated into the HS-BM-01 operation and gave 1290 polar-area elements/pole to be ground. Another improvement in the HS-BM-01 operation was the realization that if too much steel was removed from a given area element, an integral compensation could be made by reducing the amount of steel to be removed from the azimuthally adjacent element by an amount equal to the depth of the error.

In order to convey and compare the mechanical results of the grinding operation itself, we have 1) tabulated the distribution of the measured deviations from the desired values for the total grid, and 2) calculated the departure from the desired mechanical line integrals, for fixed R, through the total azimuth.

Distribution of Deviations from Desired Values

Let Δy represent the total deviation from the desired amount of removal (of the combined poles) at some arbitrary grid point. Then a table can be constructed showing the distribution of these deviations for 585 (r,θ) coordinate measurement *points* for HS-BM-02 and 1290 such *points* for HS-BM-01 (not area elements, only *center points* of area elements).

Departures from Desired Mechanical Line Integrals

The departure from the desired mechanical line integral is given by

TABLE VIII-II

DISTRIBUTION OF DEVIATIONS

Range	No. of Grid Points (HS-BM-02)	No. of Grid Points (HS-BM-01)
$\lvert\Delta y\rvert \leq .05$ mil	281	1206
.05 mil $< \lvert\Delta y\rvert \leq 0.1$ mil	208	44
0.1 mil $< \lvert\Delta y\rvert \leq 0.2$ mil	82	19
0.2 mil $< \lvert\Delta y\rvert \leq 0.5$ mil	11	19
0.5 mil $< \lvert\Delta y\rvert \leq 1.0$ mil	2	1
1.0 mil $< \lvert\Delta y\rvert \leq 1.5$ mil	1	1
	585	1290

Note: In order that these Δy's represent deviations from the desired gap, it must be assumed that the magnets can be reassembled to coincide precisely with their original mechanical configurations.

$$J = \frac{\int [y(\text{actual}) - y(\text{desired})]/y(\text{desired})\, dz}{\int dz} \quad (1)$$

for each R. The results for the two magnets are shown in Table VIII-III. Two comments can be made. First, the average of the deviations for the second magnet to be ground (HS-BM-01) is a factor of 4 less than the first magnet (HS-BM-02); that is, $\langle J \rangle$ (HS-BM-01) = 0.334×10^{-5} and $\langle J \rangle$ (HS-BM-02) = 1.338×10^{-5}. Second, the peak-to-peak difference in J values is a factor of 1.8 improved between the two magnets, that is, ΔJ (HS-BM-02)/ΔJ (HS-BM-01) = 1.8.

TABLE VIII-III

RESULTS FOR MAGNETS HS-BM-01 AND -02

R (Inch)	$J \times 10^5$ (HS-BM-02)	$J \times 10^5$ (HS-BM-01)
125.8	1.733	0.758
127.8	2.097	0.379
129.8	2.013	0.284
131.8	1.619	0.253
133.8	1.789	0.316
135.8	1.845	0.221
137.8	1.510	0.458
139.8	0.867	0.506
141.8	0.224	0.521
143.8	0.783	0.348
145.8	0.671	0.395
147.8	0.867	-0.253
149.8	1.370	0.348

Note: In order that the J values represent deviations from the desired field-line integrals, it must be assumed that the magnets can be reassembled to coincide precisely with their original mechanical configurations.

One should recall that the handsanding operation was necessary because of the existence of a number of machining inaccuracies in the dipole components which essentially negated the usefulness of the H_t correction windings as well as the fact that the response function of the H_ts was considerably broader than their spacing. Based on this situation, we have decided to use the H_t-windings primarily to correct for saturation effects at inner and outer radii as a function of field level. Operated in this way, the system can be tuned more quickly and simply and will ultimately produce more data.

One outcome of this decision is that we intend to make as many mechanical corrections as are practical from the standpoint of the time, the costs, and the net improvement in resolution. At present, the addition of leg-to-yoke shims after sanding has yielded a magnet with an rms variation of the azimuthal field integrals of $\leq 8 \times 10^{-5}$. We will not go into detail here except to list those areas where other significant corrections could result. The addition of tie-bolts, as well as some tie-bolt retorquing consistent with vacuum and field loading, has already shown improvements. Pole-face shims, nosepiece shims, the addition of a multipole magnet between the two dipoles, and accurate field maps can all be expected to help achieve the design resolution after the magnets are mounted. A pole-face shim holder has been designed and is currently under construction in the LASL shops.

IX. RESEARCH

Tests, Data Runs, and Analyses of Experiments

Pion Total Cross Sections (Exp. 2)

(Univ. of Montana, LASL, Univ. of Washington, Stanford Univ.)

The analysis of the data from the first run is near completion. Three remaining problems have been identified which require further refinement. They are pion-decay corrections, finite beam geometry corrections, and Coulomb-nuclear interference corrections. The Monte Carlo computer code for pion decay appears to give reasonable corrections, but there are still differences between this one and a similar program from the Brookhaven National Laboratory which are being explored. Another Monte Carlo program is being developed to check the validity of assumptions made for finite beam corrections.

Development of a procedure for doing Coulomb-nuclear interference corrections which are not model dependent is making progress. A redefinition of the total cross appears necessary, but the new definition will make it easier to interpret measurements on heavy nuclei and at low energies. A full report on this work is in progress.

Preparations for the next run are beginning. One interesting result of the previous run appears to be an anomalously large $\pi^{\pm}-{}^{4}He$ cross section at 25 MeV. The cross section in ^{12}C is analogously large. In order to pursue this fact more completely and accurately, the ^{4}He target is being refurbished. All targets for the next run will have a rapid cycling capability between blank and full positions. A second, thinner transmission stack more appropriate for low energies is being constructed.

To better explore the isotope comparisons, new targets of enriched ^{11}B and ^{48}Ti are being obtained which will give the capability for comparing neutron and proton excesses for the sets $^{6,7}Li$, $^{10,11}B$, $^{12,13}C$, $^{16,18}O$, $^{40,44,48}Ca$, and ^{48}Ti. Excitation functions for these elemental comparisons will give a detailed picture of the tail-of-nucleon density distributions since the opacity of the nucleus-to-pions changes across the 3,3 resonance.

Spectrum and Shielding Measurements of Neutrons Produced by 800-MeV Protons (Exp. 26)

(LASL)

We finished the analysis of our measurements of neutron transmission through a thick shield. Our results indicate that the shielding being installed for the WNR target should be adequate as planned, as the shielding calculations tended to predict more emerging neutrons than we observed.

We stopped the LAMPF proton beam in a thick uranium target and measured the spectra of neutrons emerging from the surrounding shield as a function of angle and shield thickness. The experimental setup is shown in Fig. IX-1.

We calculated the neutron-shielding spectra using the Monte Carlo programs,[1,2] NMTC, and MCNG. The calculations were found to overestimate the numbers of low-energy neutrons emerging at all angles. For most angles, reasonable agreement was obtained between calculations and measurements for neutrons above 1 MeV, but for the most forward angles the calculated results are again too high. Figure IX-2 shows some of our results. The "thin," "medium," and "thick" notation refers to shields ~ 0.5-, 1.0-, and 1.5-m thick, respectively. Results at

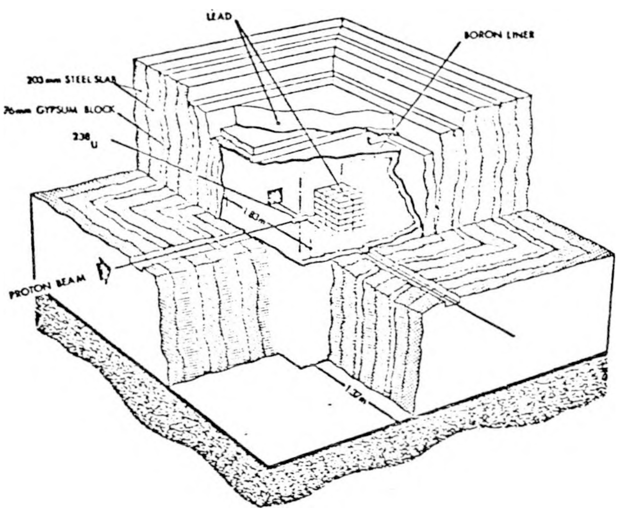


Fig. IX-1.
Schematic of the uranium target and shield around it. To measure thinner shields, layers of steel and gypsum were removed from the outside. The hole at 90° to the proton beam was used to measure the source spectrum and was filled with lead for the shielding measurements. the pile of lead bricks inside the shield served as a secondary beam stop to prevent protons from penetrating the shield if they missed the target during tuning.

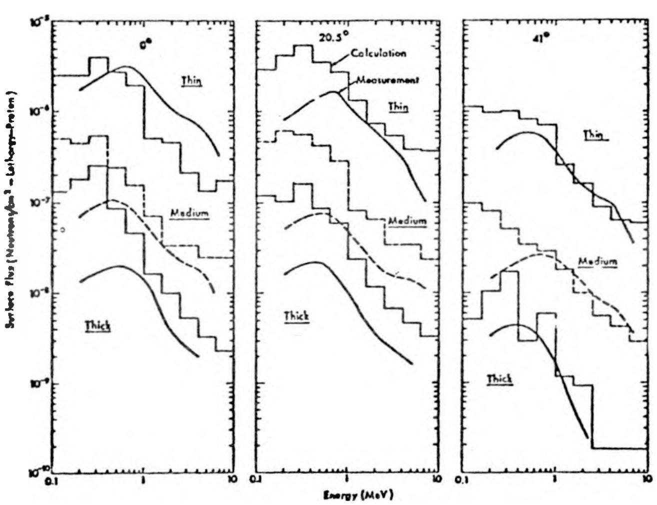


Fig. IX-2.
Shielding results at 0°, 20°, and 41°. The histograms are calculations, and the smooth curves show the measurements. Uncertainties in the measurements are about 30%.

59°, 90°, 117°, and 135° are qualitatively similar to those shown for 41°.

A Neutrino Experiment to Test Muon Conservation (Exp. 31)
(Yale Univ., Saclay, LASL)

Analysis of the background measurements taken in December is now complete. The amount of shielding between the detector and the beam stop was 4 m, which could be reduced to 3.25 m by removal of a specially constructed plug near the beam stop.

The completed neutrino detector, a 5500-kg water Cerenkov counter viewed by 96 phototubes, was used for the first time this month. Thermal neutron rejection, defined as (thermals with E>20 MeV)/(thermals with E=0 MeV) was $\sim 10^{-7}$ as planned. The gain of the counter, designed for 5 photoelectrons/MeV, was measured to be 5.4 p.e./MeV.

The Cerenkov counter is insensitive to recoil protons, so the most dangerous background consists of neutron-induced high-energy electrons. The number of such events with energy from 20-60 MeV was measured to be (43 ± 6)/μA-h with 4 m of shielding. Reducing the shielding to 3.25 m increased this rate by a factor of 16.9 ± 2.5. This translates to a neutron factor of 10 attenuation length of (61.0 ± 3.5) cm. From this we conclude that, at full beam intensity, 7 m of shielding will be necessary to sufficiently attenuate the neutron flux. Our thermal background at full beam intensity with 4 m of shielding at 20 MeV will be 3300/day. The thermal neutron flux was found to be highest near the floor indicating some sort of ground-shine problem, but the rates are low enough that the additional shielding should be enough even if this problem is not dealt with directly.

Pion-Deuteron Elastic Scattering (Exp. 34) (Univ. of Virginia, LASL)

We have continued with the analysis of data. Much of our effort has been spent on development of programs to reduce the magnetic field maps of our spectrometer to a useful form. The programs are complete, and we are now testing them in a variety of ways before making production runs. The computer time required is large so that we must take considerable precautions to keep our expenses as low as possible.

We have also developed procedures to carry out preliminary data reduction on the PDP-11/20, and this activity is currently being completed. We have also essentially completed the analysis routines to be applied to the data.

To test the experiment in at least a preliminary way, we have made a rough analysis of the data at 350 MeV/c. Both π-d and π-p elastic scattering were treated in the same way, and the known π-p cross sections were used to obtain π-d cross sections. The corrections for pion decay, deuteron breakup, etc. have yet to be made. Since these effects are expected to be less than 10%, we believe the preliminary cross section gives some notion of the validity of the experiment. These data are shown in Fig. IX-3 along with data of Norem[3] at 290 MeV/c and of Gabathuler *et al.*[4] at 370 MeV/c. Our data seem reasonably consistent. Except for 160°, the errors shown on our points are statistical only. The point at 160° represents only part of our data so that it will be considerably improved. In addition, the error represents an uncertainty in solid angle associated with the particular data analyzed. The additional data to be analyzed will not contain this uncertainty, nor will the data shown, once we complete the analysis of solid angle using a Monte Carlo routine which is now almost ready for production runs.

At higher energies our data extend to somewhat smaller angles (to about 35°) than shown for the 3500 MeV/c run. We must state again that the data shown here are preliminary and subject to corrections of uncertain magnitude at this time.

Neutron Background Study for Exp. 53 Study of the Neutrino Capture Cross Sections in ^{37}Cℓ with μ^+ Decay Neutrinos (Exp. 53) (BNL, Purdue Univ., Northwestern Univ.)

In order to measure the neutrino capture cross section in ^{37}Cℓ, sources of experimental background must be well understood and minimized. The two dominant sources of background are cosmic rays and energetic neutrons associated with the incident proton beam. The cosmic-ray background is well un-

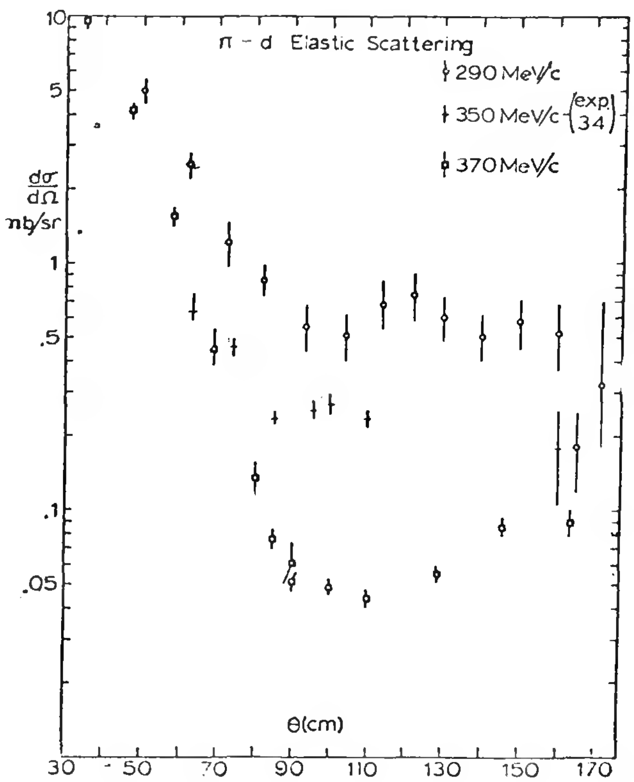


Fig. IX-3.
$\pi-d$ Elastic Scattering.

derstood from previous experience with the ^{37}Cl system. It will be minimized by adequate shielding to remove the hadronic component of cosmic rays (3 m of iron). A machine-associated neutron background can simulate a neutrino signal and must be totally eliminated or accurately estimated. An experimental program has been initiated to measure the neutron background with the following major goals: ultimate feasibility of a cross-section measurement at various beam current levels; minimum shielding requirements; and optimal detector configuration in the neutrino house.

The present experimental configuration is shown in Fig. IX-4. The two BNL detectors (A1,A2) are simply 2.1 m by 2.1 m by 0.6 m 2700-liter flat steel tanks. A1 is currently filled with $Ca(NO_3)_2$ solution for increased neutron sensitivity while A2 is a 1/4-scale prototype of the final detector filled with C_2Cl_4. The calcium detector makes use of the $^{40}Ca(n,\alpha)^{37}Ar$ reaction to detect neutrons. Neutrons register in chlorine by a two-step process, $^{35}Cl(n,p)S^{35}$ followed by $^{37}Cl(p,n)^{37}Ar$. The sensitivity of the two detectors is dependent on energy. Calcium is about 2000 times more sensitive than chlorine for 14-MeV neutrons, but only 60 times more sensitive to the hadronic component of cosmic rays. This wide range in sensitivity complicates interpretation somewhat. Argon-37 is purged from either tank by a helium gas stream, and is removed from the gas stream by a gas-handling system in the Yale-LASL experimental trailer. Gas purification is carried out at the LOB in laboratory space provided by CNC-11. Final purification and counting is done at BNL. Results are summarized in Tables IX-I and IX-II. A series of measurements were made with a 0.75-m iron plug (D) removed from the area directly in front of the beam stop. In principle, this allowed a measurement of the mean attenuation length of neutrons in iron. The measurement must be viewed somewhat with suspicion since

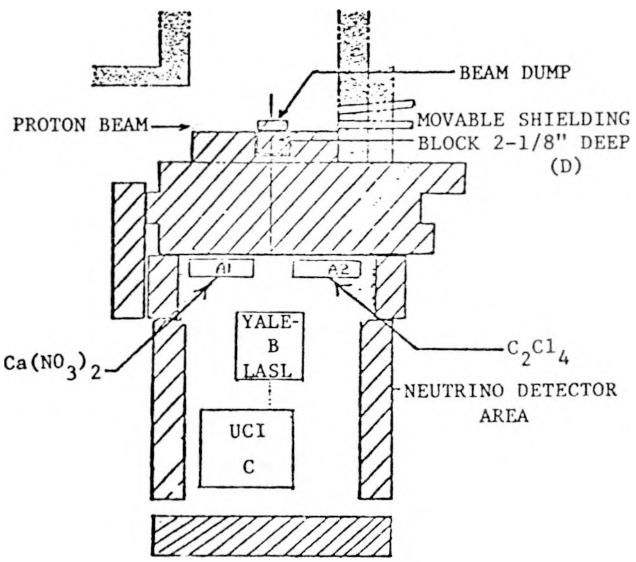


Fig. IX-4.
Experimental configuration in the neutrino house.

TABLE IX-I

2700-LITER CALCIUM TANK MEASUREMENTS

4 Meters of Iron Shield

Run #	μa·hrs	^{37}Ar atoms per μa·hr	
7	69	356	Average = 360 ± 65
8	37	385	
9	131	272	
11	126	425	

3.25 Meters of Iron Shield

Run #	μa·hrs	^{37}Ar atoms per μa·hr	
12	36	13,700	Average = 11,000 ± 4,000
13	89	8,050	

Mean Attenuation Length in Iron = $171 \pm ^{38}_{22}$ gms/cm^2

TABLE IX-II

2700-LITER CHLORINE TANK MEASUREMENTS

Run #	μa·hrs	^{37}Ar atoms/μa·hr	
	4 Meters of Iron Shield		
1	258	50	Average = 45 ± 8
3	238	39	
	3.25 Meters of Iron Shield		
4	118	570	

Mean Attenuation Length in Iron ≈ 230 gms/cm^2

some shadowing was experienced by the BNL detector. The Yale-LASL(B) and UCI(C) detectors were set far enough back to be completely unshadowed when the plug was removed. The mean attenuation length found for calcium is 171 gm/cm^2 in good agreement with the value found by the UCI group (UCI-Neutrino No. 11, internal report, Feb. 1975) by proton recoil studies, and with that calculated by a nucleon-cascade model. Because of the large discrepancy between the last two measurements, however, the error is large. The discrepancy appears to be real and is not easily understood. It may be related in some way to biomed operations. This will have to be carefully investigated in the future. The chlorine tank gave a considerably higher result, possibly indicating a harder neutron component forward of the beam stop (see Fig. IX-4). These measurements must be repeated, however, since there were known experimental difficulties with the C_2Cl_4 detector. At 4 m of iron shielding, the ratio of production rates between the calcium and chlorine tank was only 8:1. This ratio is impossibly low and cannot by any known process be less than 60:1. This indicated a large spatial anisotropy of energetic neutrons in the room of a factor of at least 7 or 8. Such an anisotropy is not surprising, since for incident protons of 800 MeV the secondary neutron flux should be forward peaked in the laboratory system. This suggests that the geometrical configuration for the detectors originally proposed for this experiment is not optimal. This effect needs to be explored further.

Further experiments are clearly needed before the final shielding arrangement can be decided with certainty. However, measurements at this point seem to indicate a rather unfavorable background situation with at least 6.5 m of iron required, and all four tanks located near the A1 position shown on Fig. IX-4 (alternatively, it might be desirable to move the beam stop forward). At that distance a full 1 mA beam at the beam stop is required.

We wish to express our gratitude for the great deal of assistance given us by members of the LASL-LAMPF community too numerous to list, without whose generous cooperation such a geographically extended venture could not be attempted.

Chemical Effects in the Capture of Negative Mesons in Matter (Exp. 60)
(LASL, Princeton Univ., Munich Tech. Univ., Washington State Univ.)

All of the data collected at the Stopped Muon Channel last year have been analyzed, and a paper describing our results is being prepared for publication. In addition to results and conclusions regarding alkali-halide salts reported earlier, the following were found for the remaining targets:

1. No significant differences in the muonic x-ray spectra of water and ice were observed.

2. No significant differences between two

crystalline forms (diamond and graphite) of carbon nor the same crystalline forms of boron nitride were observed.

3. The B/N capture ratio for both boron-nitride targets deviates sharply from the Z-law—about a factor of 3 too small, whereas the C/N and 0/N ratios in other nitrogen compounds measured lie within ~25% of the Z-law.

4. The Lyman intensity patterns for all carbon data fall roughly into two families — one for graphite and diamond (symmetric bonding), and the other for all other carbon compounds (more asymmetric bonding). The same division, to a lesser degree, is observed for nitrogen.

5. The capture ratios for metal oxides exhibit the same periodic variation with Z as reported earlier by Zinov.

6. Both oxides and chlorides exhibit a smooth dependence on the (pure) metallic electronegativity.

Gamma Spectra from Pion and Proton-Induced Reactions (Exp. 62/121)
(Utah State Univ., Univ. of Texas, LASL, Florida State Univ., Coll. of William and Mary, Argonne National Lab.)

The following are titles of papers describing some of the results to be presented at the Washington Meeting of the American Physical Society, April 28-May 1, 1975:

1. "Fast Pion Induced Processes in Complex Nuclei: Cross Section and Alpha Removal," V. G. Lind, E. N. Hatch, O. H. Otteson, and R. E. McAdams.
2. "Fast Pion Induced Processes in Complex Nuclei: Projectile Systematics," D. G. Kovar.
3. "Fast Pion Induced Processes in Complex Nuclei: Systematics in Product Nuclei," R. E. Segel.
4. "Neutron 'B(E2)' from Inelastic Pion Scattering," J. P. Schiffer, H. E. Jackson, D. G. Kovar, R. D. Lawson, L. Meyer-Schützmeister, R. E. Segel, S. Vigdor, and T. P. Wangler.

Forward Elastic Scattering of π^+ and π^- from ^{12}C, ^{16}O, ^{40}Ca, and ^{208}Pb (Exp. 80)
(Rice Univ., Univ. of Houston)

Experiment 80 determines the real and imaginary parts of the elastic-scattering amplitudes of pions from nuclei through Coulomb-nuclear interference at small angles. The magnitude of the interference is proportional to the ratio of the real-to-imaginary

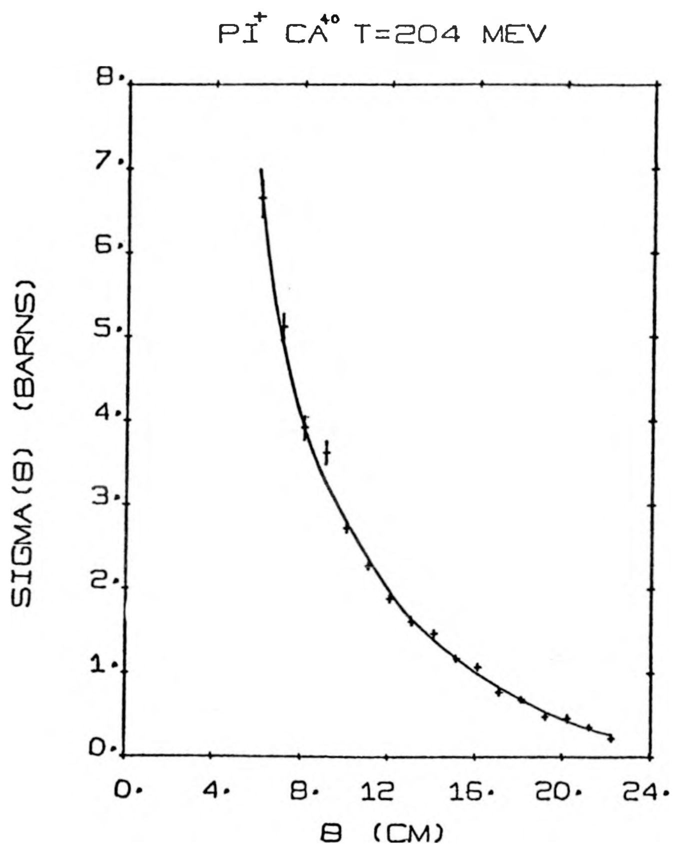


Fig. IX-5.
$d\sigma/d\Omega$ vs Θ for $\pi^+ - {}^{40}Ca$ elastic scattering at 204-MeV laboratory kinetic energy. The solid wave is a least squares fit to the data.

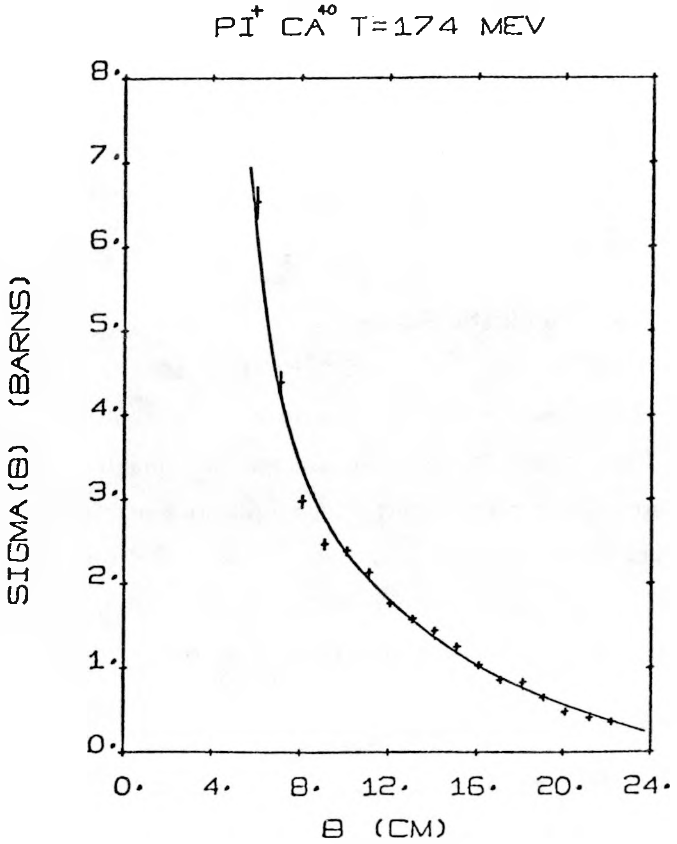


Fig. IX-6.
$d\sigma/d\Omega$ vs θ for $\pi^+ - {}^{40}Ca$ elastic scattering at 174-MeV laboratory kinetic energy.

parts of the pion nucleus-scattering amplitude. The imaginary part of the amplitude is obtained from the total cross section through the optical theorem.

Calculations of solid angle and purity have been finalized. In addition, preliminary angular distributions of $\pi^+ - {}^{40}Ca$ at incident laboratory kinetic energies of 204 MeV and 174 MeV have been calculated. Figure IX-5 is the angular distribution at 204 MeV. The plotted error bars are the statistical uncertainty in each angular bin. The solid line is a theoretical fit based on the Bethe model as used by Binon *et al.*[5] Figure IX-6 is the elastic $\pi^+ - {}^{40}Ca$ differential cross section at a laboratory energy of 174 MeV. In both figures the enhancement of the cross sections resulting from constructive nuclear-Coulomb interference is seen. These results were presented at the April meeting of the American Physics Society.[6] The analyses of ^{12}C, ^{208}Pb, and ^{40}Ca at other energies are continuing.

Deuteron Breakup by Protons and Pion Production in Proton-Proton Interactions at 800 MeV (Exp. 81)
(Rice Univ., Univ. of Houston)

The analysis of Exp. 81 data is continuing at a steady pace. The apparatus, which was described in a previous progress report, consists of a spectrometer arm in coincidence with a TOF arm. All of the data have been analyzed at least once. Most of the data will be reanalyzed to incorporate minor improvements and corrections.

The most common mechanism for p-d breakup is quasi-free scattering, in which one nucleon is a spectator to the reaction. In the simple impulse approximation (SIA), the cross section is directly related to the deuteron wave function and to the free nucleon-nucleon elastic-scattering cross section. Shown in Fig. IX-7 is the neutron momentum spec-

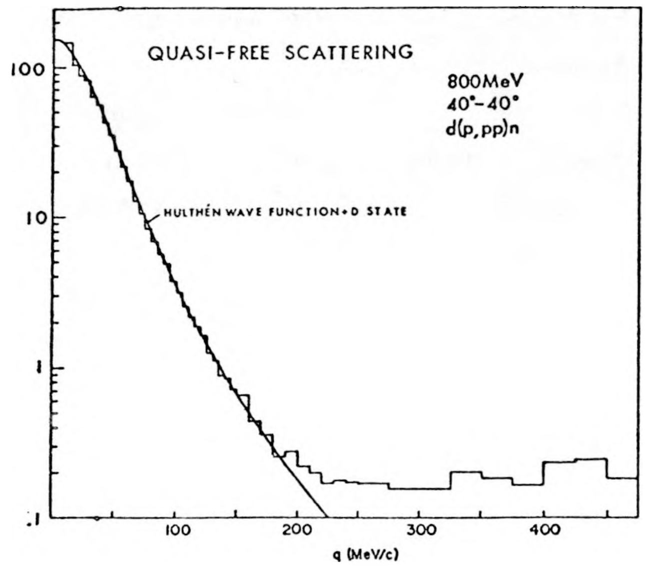


Fig. IX-7.
Neutron momentum for the reaction d(p,pp)n.

trum which was calculated from the momentum and angles of one proton, and the angles of the other proton. The data have been corrected for solid-angle variation and divided by phase space. The Hulthén wave function fits the data well out to 200 MeV/c at which point there is a sharp break in the data. For other angles the neutron momentum spectra are similar. The normalization is not final, but the absolute fit to the SIA is generally within 15% depending upon the p-p elastic-scattering cross sections used.

At angles corresponding to p-d elastic scattering, low n-p relative energies are possible. The proton momentum spectrum is presented in Fig. IX-8. The first angle is the n-p or magnet angle and the second is the TOF angle. The arrow gives the position of zero relative energy at which point there is a well-defined peak in all cases. The curve in the 44°-54° data gives the relative energy as a function of momentum. The relative energy distribution divided by phase space is illustrated in Fig. IX-9. Using the theory of Goldberger and Watson, these spec-

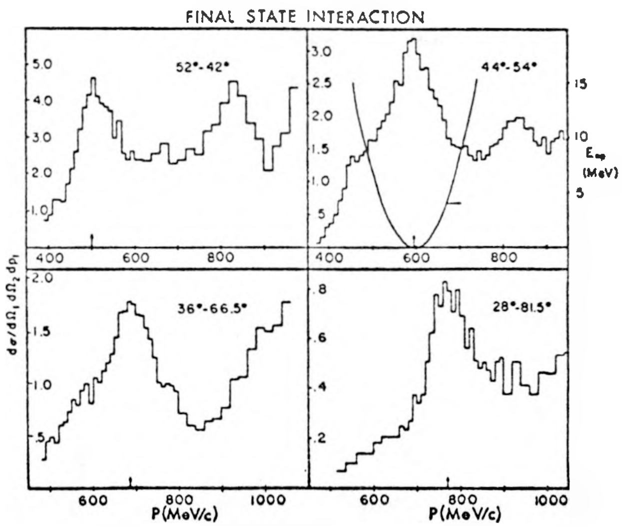


Fig. IX-8.
Proton momentum spectrum showing final state interaction.

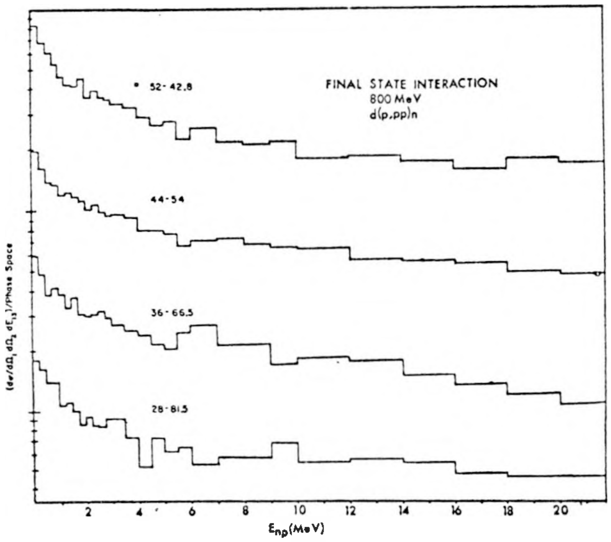


Fig. IX-9.
Relative neutron-proton energy.

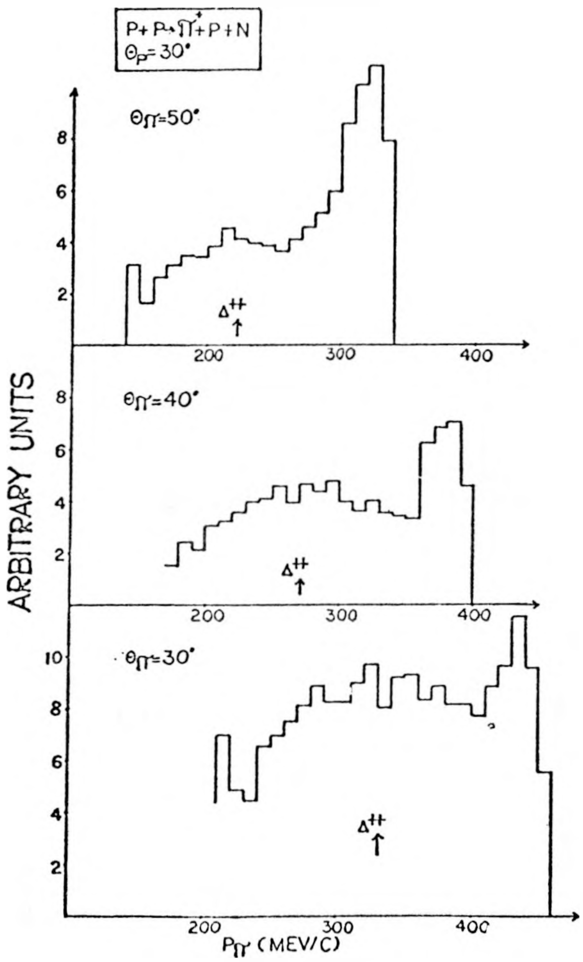


Fig. IX-10.
Pion momentum spectra after being corrected for the solid angle and pion decay.

tra can almost be fit by a constant plus the low-energy n-p triplet interaction. However, a small amount of singlet interaction is necessary. The cross section becomes smaller for forward n-p angles.

The pion production in the reaction $p + p \rightarrow \pi^+ + p + n$ was studied by detecting the pion through the magnet arm and the proton through the TOF arm. The differential cross section is expressed two different ways: in terms of the pion momentum, and in terms of the π^+-p relative energy in their center of mass. The solid angle of the system is divided out in both cases. Figure IX-10 shows the differential

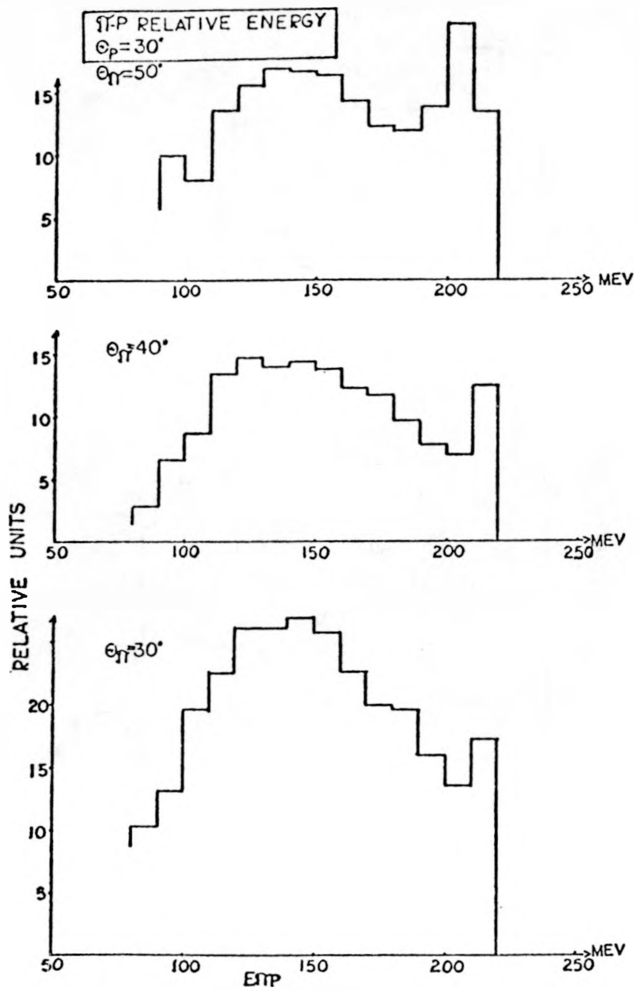


Fig. IX-11.
π^+-p relative-energy spectra corrected for solid angle, phase space, and pion decay.

cross section in arbitrary relative units after correction for the pion decay. The arrows indicate the peak of the cross section which occurs at a pion momenta for which the π^+-p relative energy is equal to that of the Δ^{++} (3/2,3/2) resonance. The peak at the maximum pion momenta results from the phase-space projection on the pion momentum axis. Figure IX-11 contains the same data in terms of the π^+-p relative energy after correction for the solid angle, phase space, and pion decay. It is evident from both figures that the pion production proceeds through a formation of the Δ^{++} resonance with the correct half-width and position. The cross section has a tendency to peak at more forward angles of the pion in the laboratory coordinate system. Further theoretical interpretation of the data is in progress.

Characteristics of Low Z Fragments Produced in the Interaction of 800-MeV Protons with Uranium. (Exp. 86)
(LASL, Texas A&M Univ., Oak Ridge National Lab.)

The energy spectra of light nuclear fragments produced by the interaction of 800-MeV protons with uranium have been determined at three laboratory angles by means of dE/dx-E measurements with silicon-detector telescopes. Individual isotopes of the elements helium through boron were resolved by utilization of the power law particle identification technique. The evaporation-like energy spectra were integrated to obtain angular distributions and formation cross sections.

The experiment was done in the LAMPF Thin Target Area, which is located upstream of the first pion production target, at an average proton intensity of 5 μA. The detectors were 4.6 m from a 3.5 mg/cm^2 uranium target, and they subtended a solid

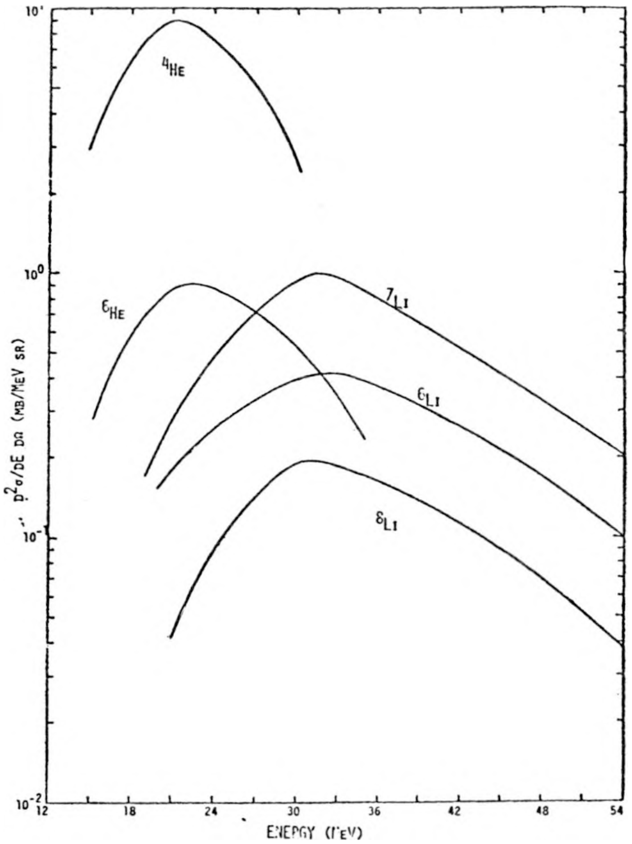


Fig. IX-12.
Laboratory energy spectra at 90 deg to the beam. For clarity, only a smooth curve drawn through the data points for each nuclide is shown. The ordinate has been normalized to an extrapolated value of 0.5 mb for the cross section of ^{7}Be from uranium, which has not been measured absolutely at 800 MeV.

angle of 10^{-6} sr. Two silicon-detector telescopes were used to measure the energy spectra at 45, 90, and 1135 deg, with one detector telescope always at 90 deg in order to normalize the individual runs.

Energy spectra at 90 deg (lab) for helium and lithium nuclides are shown in Fig. IX-12. In order to integrate the energy spectra to obtain laboratory angular distributions, it was necessary to extrapolate the data below and (in some cases) above the energy cutoffs of the detector telescopes. The angular distributions tend to be forward peaked, with ^{7}Be having a forward/backward ratio of 2. The angular distributions were extrapolated to 0 and 180 deg and then integrated to obtain formation cross sections. A future radiochemical determination of the cross section for the formation of ^{7}Be from uranium with 800-MeV protons is essential in order to establish the absolute magnitude of these cross sections. The most significant difference between the results of this experiment and the results of comparable experiments at higher proton energies is that the cross sections at 800 MeV are smaller by factors of 10 to 40, with the cross sections for the higher Z nuclides falling off more rapidly. Also the energy spectra have much smaller high-energy components and somewhat higher peak energies.

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

Plans are being made for the continuation of data taking for Exp. 96. A complete redesign of the target system is under way. We plan to allow either liquid or pressurized cold gas H_2 and D_2 through interchangeable inner flasks within an outer vacuum jacket. The target temperature and pressure read-out system is being significantly improved.

The multiwire proportional counter read-out is also being revised. Work is under way with the development of a delay line read-out system for our chambers. This should be much less cumbersome to install and significantly easier to debug than the Martin encoder system which we were using before.

The analysis of data taken last summer is proceeding. The editing of our 250 data tapes onto photostore is well along. Preliminary laboratory angular distributions for our 70-MeV data are shown in Figs. IX-13 and IX-14. Work is continuing on the absolute normalization of the data. At 50 MeV, the composition monitor system and the $\pi \rightarrow \mu$ decay

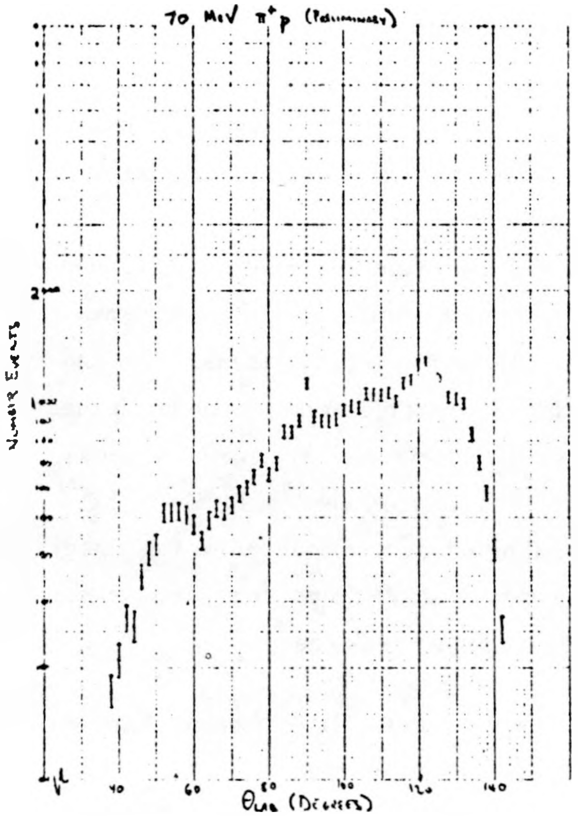


Fig. IX-13.
Number of events vs laboratory scattering angle for 70-MeV π^+p. Data are uncorrected for detection efficiency.

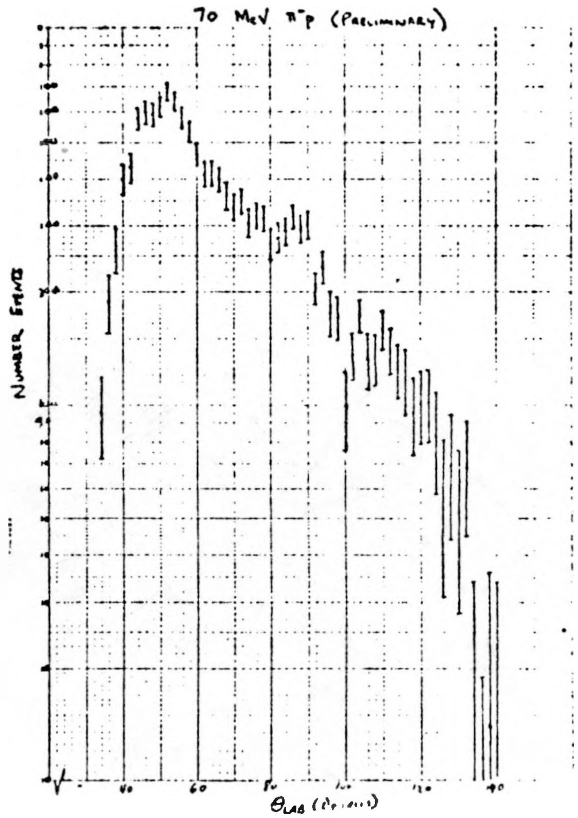


Fig. IX-14.
Number of events vs laboratory scattering angle for 70-MeV π^-p. Data are uncorrected for detection efficiency.

system give agreement of the incident pion flux at the 5% level. The H_2 density question is turning out to be a harder problem for some of the data runs than previously thought.

Results to date are to be presented at the VI International Conference on High Energy Physics and Nuclear Structure to be held in Santa Fe in June 1975.

Measurement of the Cross Section for $\pi^- + p \rightarrow \pi^- + \pi^+ + n$ with a Magnetic Spectrometer (Exp. 99)
(Colorado Coll., Univ. of Virginia, Univ. of Wyoming, LASL, Massachusetts Inst. of Tech.)

The several computer routines that are used to merge and fit data, and to adjust it for the variation

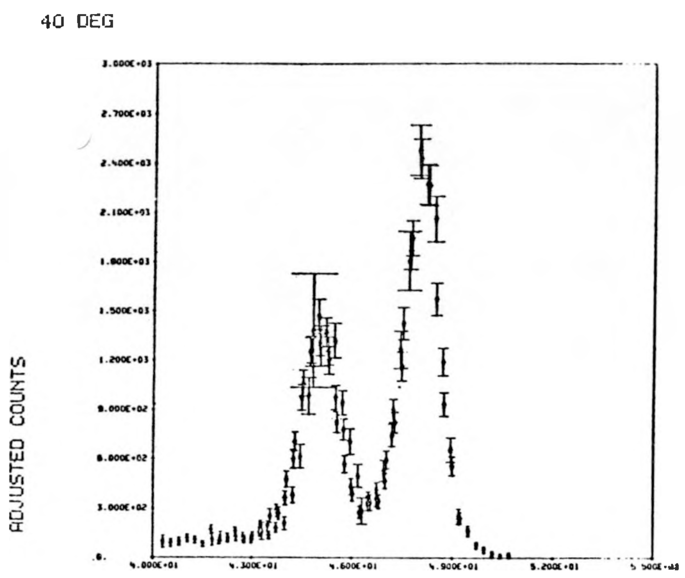


Fig. IX-15.
Shunt voltage in MV at 40 deg.

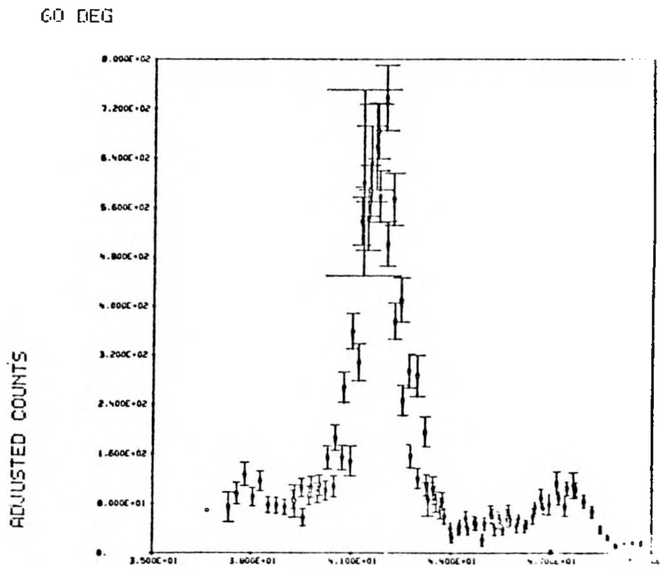


Fig. IX-16.
Shunt voltage in MV at 60 deg.

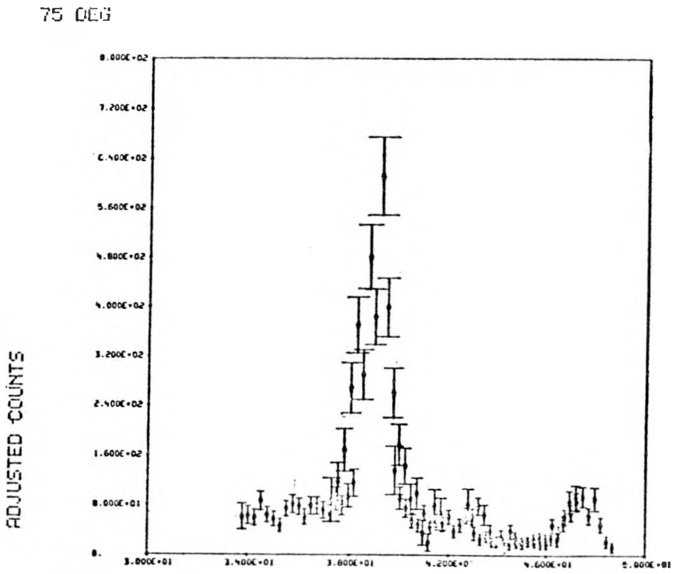


Fig. IX-17.
Shunt voltage in MV at 75 deg.

of acceptance across the detector array, are coming into routine operation. These are needed to make a more refined analysis of data from which we have so far extracted cross section by hand. Examples of some data merged from several calibration runs are shown in Figs. IX-15, IX-16, and IX-17. The two big peaks are $\pi^+ - {}^{12}C$ and $\pi^+ - p$ elastic scattering at 40°, 60°, and 75°, all at 146 MeV. We are experimenting with a peak extraction program with which we hope to find the inelastic levels, at least to the extent of being able to correct for their contribution to elastic peaks.

Search for New Neutron-Rich Nuclides Produced by Fast Neutrons at LAMPF (Exp. 111) (Iowa State Univ., Univ. of Oklahoma, Baylor Univ., LASL)

Analysis has been completed on cross sections for the reactions (n,2pn), (n,α), (n,2p), and (n,3pn) measured using fast neutrons generated at beam stop A. An "effective" cross section of 18 mb was assumed for the reaction standard ${}^{12}C(n,2n){}^{11}C$. The results of these measurements are shown in Fig. IX-18. The (n,2pn) reaction should be useful for generating new neutron-rich nuclides over the whole periodic table, and (n,2p) and (n,3pn) should be useful in searches for new nuclides with $Z < 60$.

The magnitude of interference from neutron-deficient nuclides in chemically separated sources was investigated for the (n,2pxn) reaction using ${}^{133}Cs$, ${}^{51}V$, and ${}^{45}Sc$ targets. Although interference is appreciable, generation and study of new neutron-rich nuclides, appear possible.

In most searches for new nuclides separated targets are required in order to minimize interference from neutron-deficient species. Because of low-proton currents at the beam stop, the fast-neutron flux was too low to produce appreciable quantities of neutron-rich nuclides for study. This type of experiment will become attractive when the proton beam reaches the 50-100 μA level.

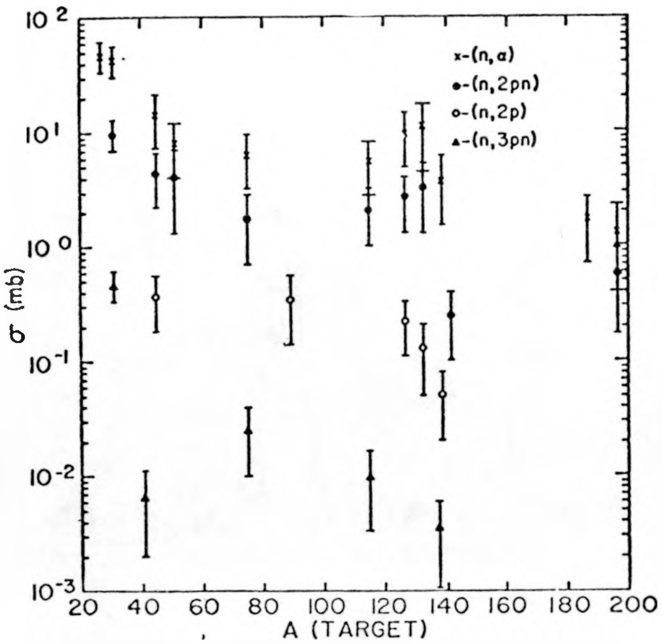


Fig. IX-18.
Cross sections for (n,2pn), (n,2p), (n,3pn), and (n,α) reactions.

Proton-Proton Elastic Scattering (Exp. 132/160/42)
(LASL, Virginia Polytech. Inst., State Univ. of New York at Geneseo, Texas A&M Univ.)

We are continuing to analyze our preliminary results to determine the ability of one experimental technique for rejecting quasi-electric p-p scattering without a conjugate arm. Within the validity of our experiment data, and taking into account the magnetic field shape of the 18D40, we obtained a S/N of ~3:1 for elastic p-p scattering from CH_2 targets.

Partial difficulty encountered in our preliminary data was due to insufficient helical-chamber resolution and insufficient on-line checks on the operation of our detectors. We are now correcting these deficiencies, and it is expected that our spectrometer would be adequate for Exp. 42 as modified. It would also be adequate for Exp. 132/160.

Final design parameters have been worked out with the USC/UCSB collaborators on the heavy particle arm of Exp. 42, as well as the changes needed in the spectrometer arm. We anticipate the hardware to be ready for check-out before July 1, 1975.

The data-acquisition system is now being overhauled to accommodate Exps. 42 and 132/160. A few bugs still need to be found so that the data acquisition program will readily include the necessary kinematic constraints of each experiment.

The polarized target prototype cryostat is now being cryogenic-tested. We expect to start polarization measurements for a transversely polarized target sometime in early FY-76.

Parity Violation in p-p Scattering at 15 MeV [Exp. 137(A)]
(LASL, Univ. of Illinois)

Two experimental runs were completed at the Tandem Van de Graaff during this quarter. Further progress was made on measuring and controlling sources of systematic error at levels below 10^{-7}. A data run with an H_2 target confirmed our published result with an independent limit on parity violation of $(-3.5 \pm 3.5) \times 10^{-7}$. A run with a D_2 target indicated that better control on residual transverse polarization will be required before significant results can be obtained.

Parity Violation in p-Be Scattering [Exp. 137(B)]
(LASL, Univ. of Illinois, Univ. of Chicago)

Encouraged by the success of our October data run, we undertook to improve our apparatus and procedures in order to measure the longitudinal asymmetry in the p-Be scattering cross section to a precision of 10^{-6}. An elaborate array of scintillation detectors of improved design was constructed to measure the average position, angle, and size of the incident beam in the horizontal and vertical directions for each pulse. The transverse polarimeter was redesigned to be less sensitive to beam motion. The thickness uniformity of the transmission and incident intensity detectors was improved. A target of better than 10^{-4} uniformity was constructed. The design of the ionization chambers was improved. A solenoidal magnet was added to the beam transport system to enable adjustment of the horizontal transverse polarization. The design of the light pulser was improved and signals were injected into all scintillation detectors to monitor their relative drifts. Circuitry was developed to measure the integrated square of the instantaneous beam intensity. A computer program to carry out regression analysis at ANL with a few hours turn-around was written to assess the performance of the apparatus while the experiment was in progress.

A new approach was taken to the control of the systematic error arising from residual transverse polarization. We assume the polarization dependence of the transmission Z to be of the form

$$Z = \beta P_z + \alpha P_x(T_y T_y^\circ) + \alpha P_y(T_x - T_x^\circ 1)$$

where β is the longitudinal asymmetry in the transmission, T_x and T_y are the positions of the beam centroid on the transmission detector in the horizontal and vertical directions, T_x° and T_y° are the positions at which the analyzing powers of the transmission detector vanish, p_x, p_y, and p_z are the components of polarization and α is a constant. Since we measure p_x, p_y, p_z, and T_x and T_y for each pulse, we can correct for the effects of transverse polarization p_x and P_y if α T_y° and T_x° can be measured.

A 20-shift run at the ZGS was completed this quarter. The analysis of the data is under way. Preliminary results indicate that we have a statistical accuracy of a few parts in 10^6 for the longitudinal asymmetry and that systematic errors are negligible. The ratio of the actual statistical error to that predicted by proton statistics has been improved from 6 to 2 for the ion chambers and from 3 to 2 for the scintillation detectors, while the number of protons per pulse increased from 5×10^7 to 4×10^8.

Muon Lifetime Measurements in the Actinide Elements (Exp. 142)

(Univ. of Rochester, Univ. of Tennessee, LASL, LLL)

Preliminary measurements of muon lifetimes in ^{232}Th and ^{238}U have been made by the μ^--decay-electron (μ^-DE) detection technique. With this technique, the time delay between a μ^- stop and a μ^-De event is measured. Because of the arrangement of the electronics (Fig. IX-19), the normal time

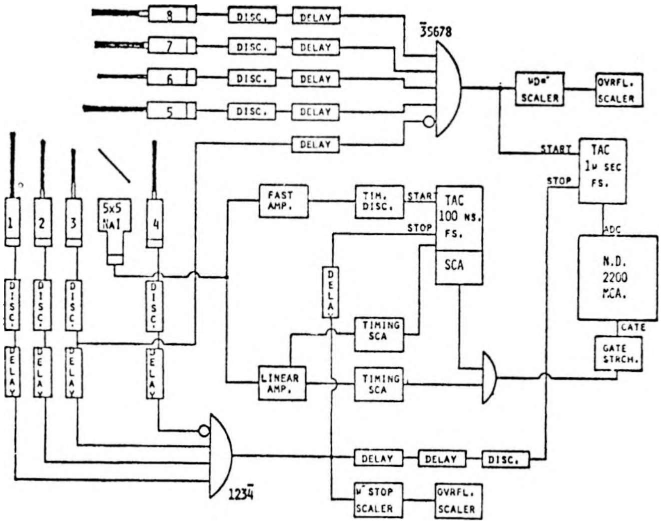


Fig. IX-19.
Block diagram of the electronics setup used for measuring muonic-atom lifetimes.

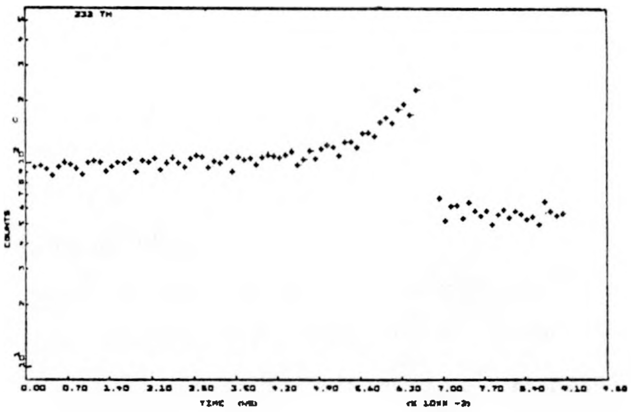


Fig. IX-20.
Time spectrum obtained from μ^- – Mesic ^{232}Th.

sequence of events is reversed. This can be seen in Fig. IX-20 where the raw data from the ^{232}Th run is shown. Because the time axis is reversed, the lifetime curve begins at about 650 ns and decays with decreasing time. The portion of the graph to the right of 650 ns represents the random contribution to the background.

Our results are shown in Table IX-III.

TABLE IX-III

MUONIC ATOM LIFETIMES

	^{232}Th	^{238}U*
Measured lifetime $\tau\left(\frac{1}{\lambda}\right)$	88 ± 6	68 ± 4 82 ± 6

*The two τ presented differ because of a μ^- stop rate dependence not fully understood at this time.

These preliminary results are being presented at the spring APS meeting.

Charged Particle Emission from Nuclei Bombarded with 235-MeV Pions and 800-MeV Protons (Exp. 153)
(Carnegie-Mellon Univ.)

The mechanism by which energy and momentum are transferred to a nucleus in a high-energy scattering event has been studied extensively for the case of incident protons.[7] Particle emission spectra for outgoing p, d, t, ^{3}He, ^{4}He particles have been observed as well as lithium through sulfur ions in very energetic (5 GeV) collisions.[8] Although both the pre-compound model of Griffin and intranuclear cascade calculations give reasonable agreement with the lower energy part of the emitted proton spectra, they underestimate the higher energy proton cross sections and all the complex particle cross sections.[7] An attempt to calculate the inflight pion-induced proton-emission spectra in the intranuclear cascade model has been reported,[9] but no data were available for comparison. The observed singles gamma-ray spectra induced by stopped and inflight pions and protons have been discussed in terms of the removal of one or more "α clusters." Low energy ($\leq$25 MeV) alpha emission has been observed[10] for 70 MeV-π on Al.

We have made a direct measurement at LAMPF of the cross section at 90° for p, d, t, ^{3}He and ^{4}He emission induced by 235-MeV positive pions and 800-MeV protons from ~500 mg/cm^2 targets of magnesium, nickel, and silver. The detector system was a four-element telescope consisting of two silicon surface barrier detectors (250μ and 500μ thick) followed by a dual crystal intrinsic germanium spectrometer (3-cm thick). With this system, we had excellent particle identification and were able to measure proton (α particle) spectra from 20(50) MeV up to 110(400) MeV with a resolution of 1-10 MeV determined by the target thickness. The beam energy spread was ±20 MeV. The solid angle (6.5 msr), detection efficiency and effects of energy loss in the target were determined from Monte Carlo calculations. The absolute cross section should be determined to ±20%.

For all targets with either pion or proton bombardment, the various particle emission spectra were characterized by an exponential fall-off of the type $d^2\sigma/d\Omega dE = N_0 \exp(-bp_n^2)$, where P_n is the momentum per nucleon. For pions the slope parameter b increases with outgoing particle mass A_0 but is roughly independent of target mass A_T. The parameter N_0 decreases rapidly with A_0 but increases slowly with A_T; e.g., nickel gives $b \propto A_0^{3/2}$ with a much larger value of b than suggested by the proton-emission calculations of Harp *et al*.[9] Their characterization of pion absorption is apparently not correct. Our results are similar to calculated spectra for 250-MeV proton bombardment of nickel. We are investigating whether a pick-up mechanism could explain the large number of complex particles detected.

An abstract was submitted to the VI International Conference on High Energy Physics and Nuclear Structure to be held in Santa Fe in June.

The Microdistributions in Natural Materials (Exp. 161)
(California Inst. of Tech., Jet Propulsion Lab., Martin-Marietta, Denver)

The purpose of this series of experiments is to create and utilize a thorium micromapping technique. The micromap shows which minerals of polished rock surface are thorium-rich and what their thorium concentrations are. The mapping method employs fast neutrons from the A-6 beam stop to induce fission in thorium and U, producing fission tracks in a sheet of mica placed in direct contact with the polished rock surface. The uranium contribution to the fission track density is delineated in a similar experiment using thermal neutrons.

Our earliest experiments with uranium and thorium foils and low-proton fluences ($< 0.1\ \mu$A h) proved the method to be workable.

Experiments performed during the summer of 1974 at proton fluences of $\sim 50\ \mu$A h revealed recoil tracks in the mica detectors. The low-damage density in the recoil tracks relative to fission tracks permitted us to anneal them out (1 h at 375°C) without appreciably affecting the fission tracks.

In our October run (run 161-Y) we discovered that the effective fission cross-section ratio for thorium and uranium, $\bar{\sigma}_{Th}/\bar{\sigma}_U$, was ~0.2, compared with ~0.3 for the early metal foil experiments. Three possible explanations were set forth: 1) the thorium standard glass has a lower concentration than the literature value; 2) the neutron beam now has a larger low-energy component than earlier; 3) fast neutrons are being thermalized by the mounting and packing media inside the cadmium shield. Experiments were devised to test all three possibilities and performed in our December run 161-Z. The literature concentration of the standard glass was confirmed by comparing track densities produced by the glass and a primary standard, thorium metal, in a specially designed vacuum chamber. The neutron-energy spectrum was shown to be unchanged when stand thorium glasses enclosed in cadmium with little other thermalizing media present gave $\bar{\sigma}_{Th}/\bar{\sigma}_U$ = 0.28, essentially the same as the earliest runs. These standards, when compared with standards among the nearby samples, showed that the mounting and packing media were indeed thermalizing a portion of the beam, thus increasing σ_U and diminishing the ratio. This problem will be solved in future runs by using boron in powder and solid form as thermal and epithermal sinks throughout the experimental package.

Given the low-intensity beam levels, only high thorium-uranium samples could be used in our October and December runs. Two principal experiments were attempted: 1) measurement of thorium/uranium for some high thorium-uranium lunar rocks, and 2) measurement of the thorium partitioning in some coarse-grained terrestrial granites.

Lunar soil samples were irradiated in run 161-Z, and analysis of the thorium/uranium ratios of a number of soil minerals is nearing completion. The granite samples analyzed were unique in that they were known to have suffered large scale lead redistribution, i.e., some of the lead produced by radioactive decay in uranium and thorium-rich minerals has diffused into the lead-rich minerals. We wish to study this lead migration on a microscale by mapping the ^{208}Pb distribution, which is done with a cyclotron irradiation. The LAMPF run is to provide the thorium distribution which is necessary in order to determine what fraction of the ^{208}Pb observed at each point on the rock can be accounted for by local *in-situ* radioactive decay. The analysis of these granite samples is still in progress.

Differential Production Cross Sections of Multiply-Charged Fragments in Proton and Pion-Induced Spallation of Light Nuclei (Exp. 179)
(LASL, California Inst. of Tech., Univ. of New Mexico, Washington State Univ., Munich Tech. Univ.)

Work is progressing on the test chamber set up to measure the time resolution of the solid-state channel plate counter system, initially with an α-source. A turbomolecular vacuum pump and a mechanical forevac pump have been procured and attached to the test chamber. At present the pumping speed is being improved by the addition of a cold trap so that a vacuum of $<10^{-6}$ torr can be routinely achieved when all of the test apparatus is installed.

Techniques for fabricating Formvar windows $\simeq 100\ \mu g/cm^2$ thick and $\simeq 1\ cm^2$ in area have been investigated. These windows will be used in the gas proportional counter.

The electrostatic accelerating structure has been built and will be tested soon. Self-supporting 200 $\mu g/cm^2$ carbon targets have been purchased and will be used in the initial data-taking experiments.

Elastic and Inelastic π^+ Scattering at 25, 50, and 75 MeV (Exp. 180)
(Carnegie-Mellon Univ., Lawrence Berkeley Lab.)

During December approximately six shifts of LEP beam time were allocated for a feasibility study of Exp. 180. In this time, we have thoroughly investigated the usefulness of the CMU 2-crystal intrinsic germanium spectrometer[11] for this type of experiment; we conclude that this detector is well suited for use as a pion spectrometer. In addition, we have obtained as a test case an angular distribution for 50-MeV π^+ elastic scattering on ^{12}C, as well as reasonable inelastic spectra at two angles. The experimental findings are described in more detail below. A preliminary analysis of the elastic angular distribution has been made; the results show surprising disagreement with the theory for this energy region.

For this experiment a 50-MeV π^+ beam from the LEP channel was brought to a double-waist focus at a point 1.5 m downstream of the last quadrupole magnet. The beam travelled this distance in air. The resulting beam spot was typically 2-cm high and 6-

cm wide. The channel solid-angle settings used during data collection varied between 10 and 17 msr, and the momentum slit settings varied between $\Delta p/p$ of $\pm 0.75\%$ and $\pm 2.0\%$. The detector and associated scintillators were mounted on a platform capable of rotation around the target center. The monitor telescope and ion chamber were set in position and left alone. Targets used were graphite plates which varied in thickness from 0.4 to 1.2 gm/cm^2.

A principal aim of this work was to determine the extent to which the spectrometer could distinguish π^+ from μ at mometa ~ 130 MeV/c (50-MeV π kinetic energy). At this energy these particles travel well into the second crystal before stopping, and hopefully allow the use of particle identification techniques. The major problem is that dE/dx for these two particles is nearly the same; however, the extra 4 MeV deposited when $\pi^+ \rightarrow \mu^+ + \nu$ gives us added leverage in the identification. The quality of particle identification is shown in Fig. IX-21; a clean separation of π and μ is possible. It is clear that separation of π's from heavier particles is not a problem.

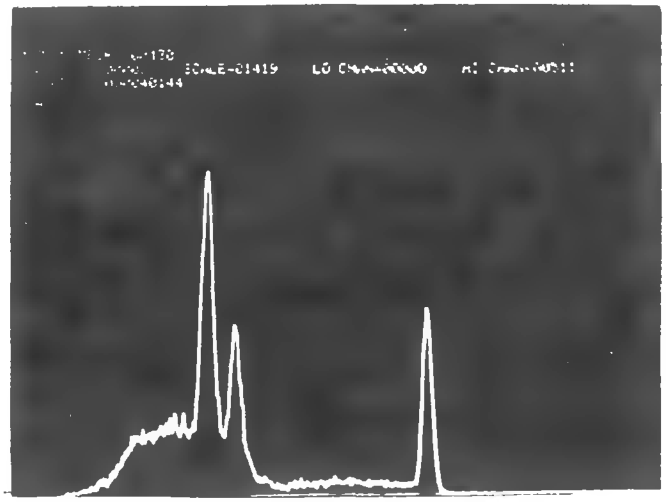


Fig. IX-21.
Particle identification spectrum.

Figure IX-22 shows the stopped π-decays in the crystal, shifting the entire π-energy spectrum upward by a constant 4 MeV. The subsequent μ decay has the effect of add-ing a high-energy tail to all peaks.

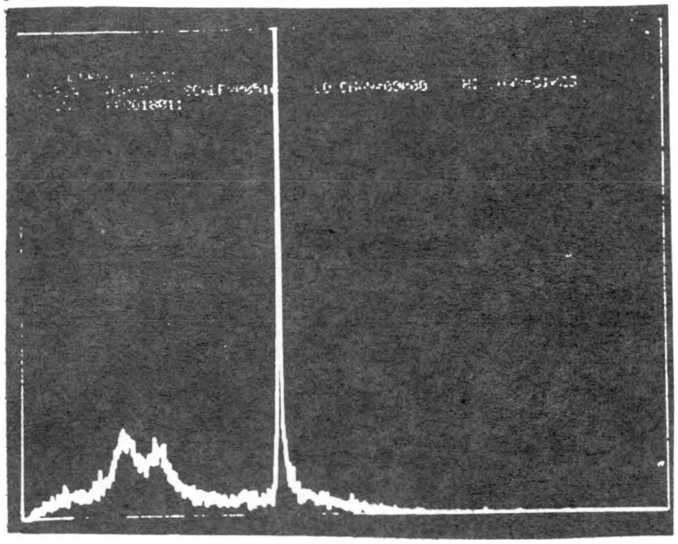


Fig. IX-22.
Energy spectrum with no particle identification and 1 μs charge collection.

Since the μ-decay half life is much longer than that for π decay (2.2 μs vs 25 ns), we use charge collection times of 1/4 μs to avoid collecting charge from most μ decays. A substantial improvement in peak shape is observed. (See Fig. IX-23.)

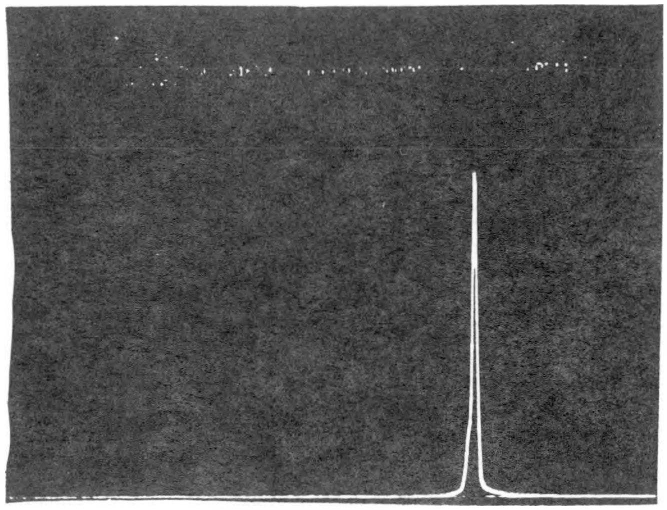


Fig. IX-23.
Energy spectrum with particle identification and 0.25 μs charge collection time.

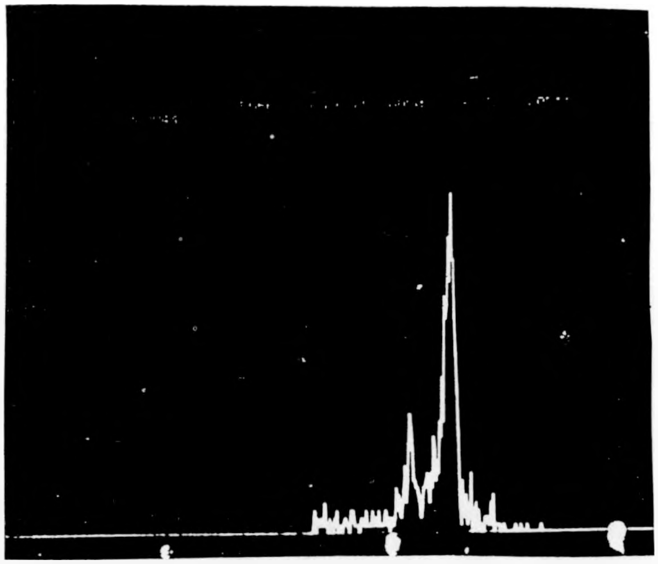


Fig. IX-24.
$\pi^+ + {}^{12}C$ energy spectrum at 120°.

In order to simulate a complete experiment in the time available, the remaining beam time was devoted to obtaining an angular distribution for elastic scattering of π^+ from ^{12}C, as well as to observing inelastic scattering to the 2^+ state at 4.4 MeV. Energy and angular resolution were sacrificed in order to increase the event rate. The inelastic spectrum obtained at $\theta = 120°$ is shown in Fig. IX-24; the inelastic level is clearly resolved and is about 15 % of the elastic peak.

The elastic-scattering angular distribution[12] was measured at eight angles from 30° to 120°. The overall cross-section normalization was obtained by measuring the scattering from carbon and hydrogen in polyethylene at 60°. The relative normalization of data was achieved using the monitor telescope and ion chamber. Repeat measurements show good consistency.

Figure IX-25 shows the experimental angular distribution compared to various theoretical predictions (Kisslinger, Laplacian, Londergan, McVoy, and Moniz) with free π-nucleon parameters. None of these theories predicts a minimum as far forward as 60° or as shallow as the experimental result. The 30-MeV π^+ data of Marshall ≥*et al.*[13] is also in substantial disagreement with the predictions of Kisslinger's model using free π-N parameters. (See, however, Ref. 14.) It appears that π-nucleus theories in this energy range are not as accurate as they are at 120 MeV and above. We conclude that elastic-scattering measurements at energies below 100 MeV are important input to an improved π-nucleus optical model.

We believe that this short study has clearly demonstrated not only the technical feasibility of these experiments but also that there is an important need for π-nucleus elastic data in this energy region.

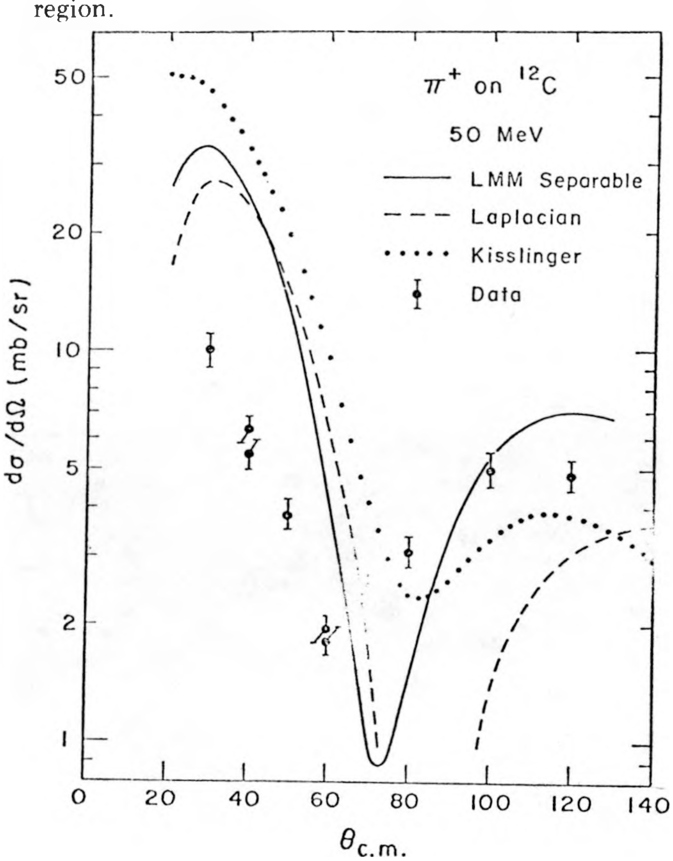


Fig. IX-25.
50-MeV π^+ elastic scattering on ^{12}C, also showing predictions of various models using free nucleon parameters.

When the Great Shutdown ends, we will continue these experiments with emphasis on the inelastic scattering.

An abstract was submitted on this work to the VI International Conference on High Energy Physics and Nuclear Structure to be held in Santa Fe in June.

Measurement of Low Energy $\pi^- p \rightarrow \pi^\circ n$ Angular Distributions and Calibration of the π° Spectrometer (Exp. 181)
(Tel Aviv Univ., Case Western Univ., LASL)

A proposal to study the differential cross section for the reaction $\pi^- \ p \rightarrow \pi^\circ n$ (CHX) at incident energies of 30, 50, 70, 90, 120, and 160 MeV has been submitted to and approved by the Program Advisory Committee. The intended precision for the experiment is about ±2%, and thus this measurement should nicely compliment the high-precision elastic-scattering measurements being carried out by the Exp. 96 group on the LAMPF low-energy pion channel. The complete set of high-precision low-energy πN data will provide much improved values for the isosinglet and isotriplet S-wave scattering lengths and the smaller of the P-wave phase shifts as well as rovide self-consistent tests for the Coulomb corrections made in extracting these values. Tests of charge independence at the few percent level will also be possible.

In addition, the CHX reaction will be used as a calibration to measure the energy and angular resolution of the spectrometer. This will be accomplished by measuring an $n\gamma\gamma$ coincidence, thus providing tagged π°s as calibration particles.

In the last progress report, the effect of restricting the range of X value on the π° line shape was shown [$X = (E_1 - E_2)/(E_1 + E_2)$, where E_1 and E_2 are the

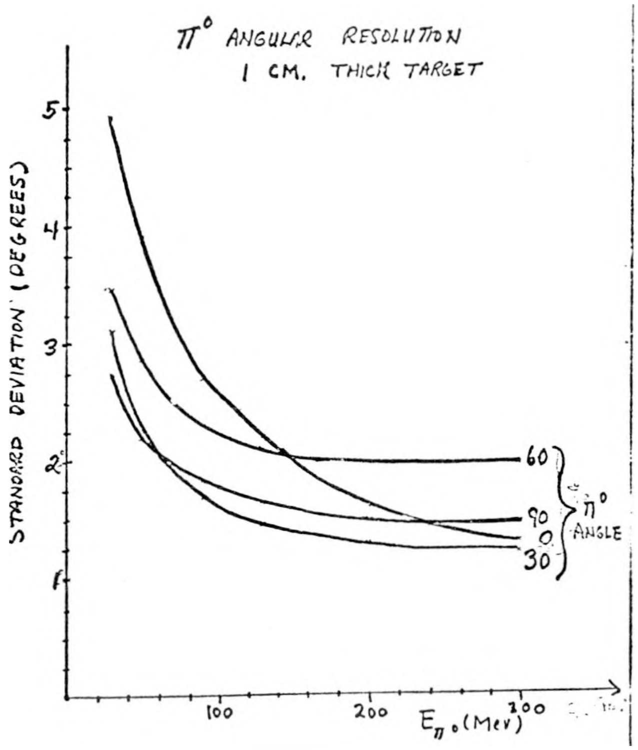


Fig. IX-26.
Calculated standard deviation in Θ_π as a function of π° kinetic energy for lead-glass converters at different π° outgoing angles. The distribution is approximately Gaussian. The $X = E_1 - E_2 / E_1 + E_2$ values are restricted to $|x| \leq 0.1$.

measured gamma-ray energies]. These Monte Carlo calculations for the energy and angular resolution have been refined to include the effects of finite target thickness, beam size, and angular acceptance. The calculated angular resolution is shown in Fig. IX-26.

The finite target thickness causes a spreading of the actual π° energy (due to dE/dx losses) and introduces an uncertainty in the photon-opening angle because of the uncertain interaction point in the target. It has been found that displacements of the interaction point along lines perpendicular to the detector bisector do not significantly alter the calculated photon-opening angle, but displacements along the bisector do. This result implies that the

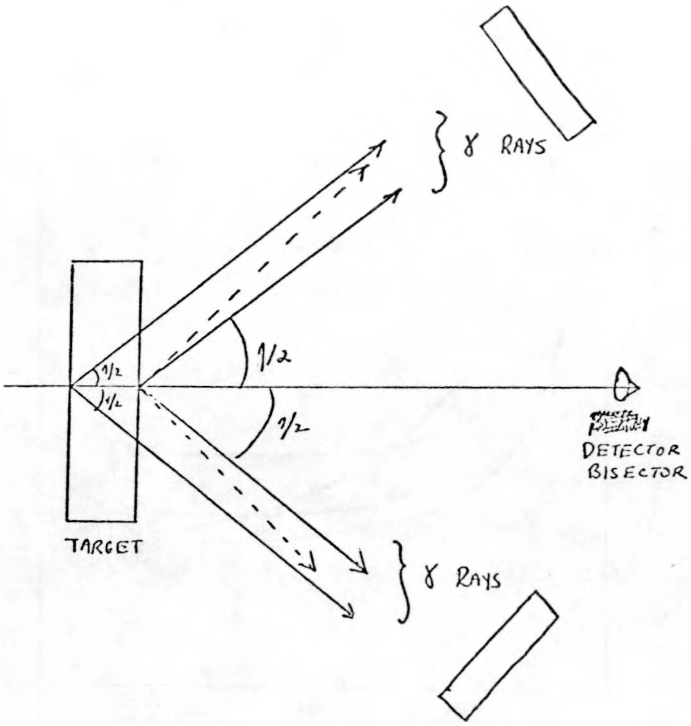


Fig. IX-27.
The effect of finite target thickness on the gamma-ray opening angle is shown for the special case of $\theta_{\pi^0} = 0$ and $X = 0$ (symmetric decay). The solid lines are emerging photons which come from charge-exchange reactions assuming no dE/dx losses in the target. The dotted lines are for the case of non-zero dE/dx and hence the gamma opening angle is larger. The effect of dE/dx and of finite target size on the π^0 energy resolution is discussed in the text.

difference between a line beam and finite beam will be negligible to first order. Second order effects have been investigated and were found to be negligible for detector-target distances $\geq$ 1 m. The resultant uncertainty (caused by the uncertain interaction point) in the π^0 energy is proportional to the variables t/r, where t is the target thickness (along the bisector) and r the target-detector distance. The distribution is rectangular in the π^0 energy, and the width has been calculated analytically and is given in Fig. IX-27 for $t/r = 0.01$.

The dE/dx loss subtracts from the above smearing at forward detection angles and adds to it at backward angles. Figure IX-28 shows the case at forward angles where the dotted line is from a π^0 decaying at the downstream edge of the target but which has a lower energy because of the dE/dx loses. Since these gamma rays tend to intersect the detector planes at the same points as those from π^0s at the front of the target, and because dE/dx is also linear in t, there is a compensation. This compensation will be used in the calibration of the spectrometer discussed above.

Figure IX-29a shows a sample calculation of the π^0 line shape for 160-MeV π^0 energy, a 2-cm CH_2 target, and $\Delta\eta \simeq 0.005$ radians FWHM using lead-glass photon detectors ($\Delta E_\gamma/E_\gamma = 3/\sqrt{E_\gamma}$ MeV FWHM), and Fig. IX-29b shows the same calculation assuming sodium photon detectors ($\Delta E_\gamma/E_\gamma = 0.05$). The bin size is 0.5 MeV. These spectra contain all effects of finite target and beam size and are calculated at forward angles where target thickness

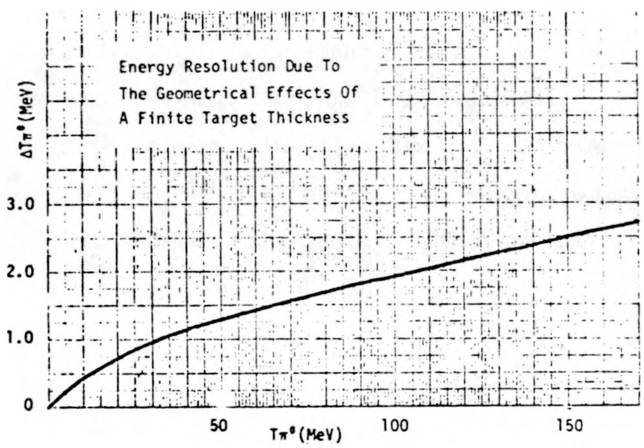
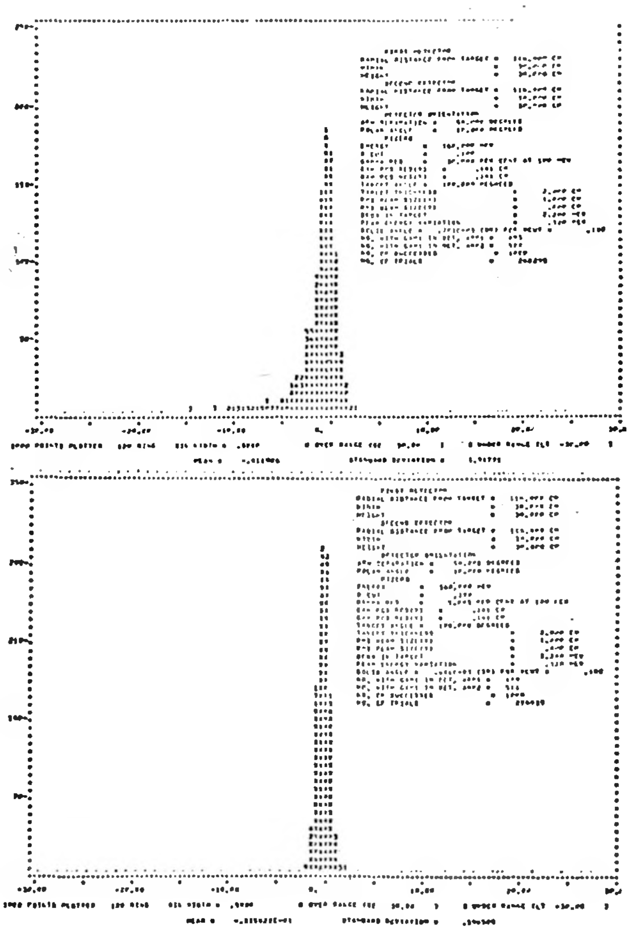


Fig. IX-28.
A finite target thickness broadens the energy resolution due to geometrical effects. The graph displays the width of the broadening for $X = 0$ and for a ratio of the thickness to the detector distance of 0.01. The distribution is rectangular and is proportional to the quantity t/r.



Figs. IX-29a and IX-29b.
Monte Carlo calculations for the line shape at a π° energy of 160 MeV for a 2-cm CH_2 target and $\Delta\eta$ = 0.005 radians FWHM. Figure IX-29a is for lead glass, and IX-29b for sodium iodide. All effects of finite target and beam size are included.

compensation can be used. At backward angles the resolution will not be as good.

The problem of what kind of photon energy counters to use has been under study. The chief disadvantages of sodium iodide relative to lead-glass are cost and sensitivity to background radiation. In spite of this, however, it has been concluded that sodium-iodide photon detectors will probably be necessary to resolve nuclear levels, and thus make possible the systematic study of single-charge exchange reactions on nuclei. For the CHX experiment discussed above, energy resolution is not crucial, however, and thus the cheaper and easier to use lead-glass will be employed as a first case.

π^+-Nucleus Inelastic Scattering to Giant Resonances (Exp. 191) (Carnegie-Mellon Univ., LASL, Univ. of Washington)

Besides general setup overhead, three shifts of this feasibility study were used to obtain spectra which provided information on the performance of the counting system. The primary purpose here was to demonstrate that the events observed at high-excitation energies were, in fact, pions which lost energy in an inelastic nuclear collision rather than background events (e.g., elastic scatterings of low-energy pions in the beam, elastically scattered pions which undergo a nuclear interaction in the detector, or events caused by protons, muons, or electrons).

A sketch of the experimental arrangement is shown in Fig. IX-30. The heart of the counting system was a pair of 1.5-cm-thick intrinsic germanium detectors which were used as a particle-identification telescope. The following will briefly summarize what was learned during the initial run.

1. The detector telescope effectively distinguishes pions from muons and other particles. For each event observed, a particle identification value was calculated from the formula

$$PID = C[(E1 + E2)^{1.73} - (E2)^{1.73}]^{1/2}$$

where E1 and E2 are the energies deposited in the first and second detectors, respectively. A sample PID spectrum for the target (zirconium) used in the feasibility study is shown in Fig. IX-31.

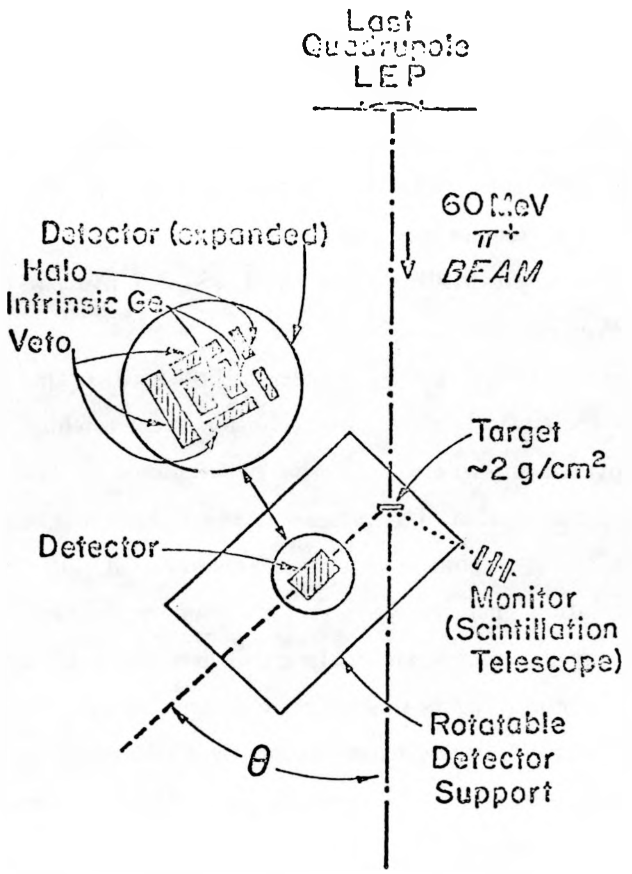
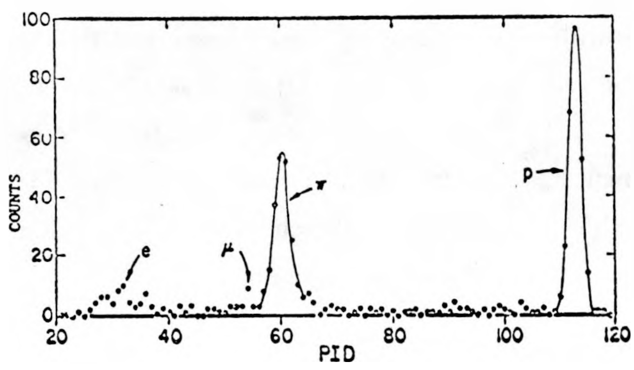


Fig. IX-30.
Schematic diagram of the experimental arrangement.



IX-31.
Spectrum of PID values for inelastic scattering of 60-MeV positive pions from zirconium at Θ = 100°. The peaks corresponding to electrons, muons, pions and protons are identified.

2. At an angle of 100°, it is observed that the contamination of the inelastic-pion spectrum by background events such as nuclear interactions in the detector and events caused by protons, muons, and electrons is insignificant. This conclusion is based on the assumption that contaminant events would produce a broad background in the PID spectrum. For the spectrum shown in Fig. IX-31 (zirconium at 100°), elastically scattered pions were sufficiently energetic to pass through both germanium detectors and were rejected by the veto detector. Thus the peak in the PID spectrum arises entirely from inelastic pions. Note that in the region of the pion peak, the background from all contaminant events is less than 10%.

3. Low-energy (i.e., degraded) pions in the primary beam do not produce severe contamination of the spectrum. This conclusion was obtained by reducing the beam intensity and moving the germanium detector into the primary beam. The number of detected pions which had energies from 5-20 MeV below that of the nominal beam energy was a small fraction (0.5%) of the total number of pions.

4. The energy resolution in the feasibility study was that of the primary pion beam (~2 MeV). This was confirmed by passing the scattered pions through an absorber to bring the elastic pions into the detector range. The width of this degraded elastic peak was ~ 2.5 MeV. Incidentally, by varying the absorber thickness, it was confirmed that the detector resolution and efficiency are uniform throughout the energy region of interest.

5. The counting rate of inelastic scatterings was sufficiently high that one should be able to obtain enough statistics to observe any significant structure in the region of the giant resonances. The energy spectrum of pions inelastically scattered from zir-

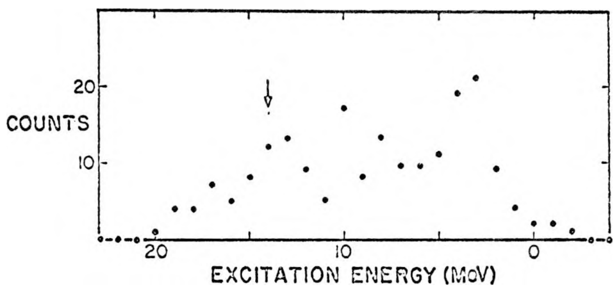


Fig. IX-32.
Energy spectrum of pions inelastically scattered from zirconium at 100°. The elastically scattered pions do not appear in the spectrum since they pass through both germanium counters and are rejected by the veto detector. Similarly, pions which lose more than about 18 MeV do not appear since they stop in the first germanium detector. The arrow indicates the expected location of the giant quadrupole resonance.

conium at 100° is shown in Fig. IX-32. This spectrum, which contains 10-15 counts per MeV of excitation energy, was obtained in less than 1 h. With a 10-fold increase in the beam intensity (to ~100 μA), it will be possible to obtain, in a few hours, enough counts to see the expected structures.

This feasibility phase of the experiment is complete, and the next step is to have a data-taking run to study in detail the inelastic scattering of pions by a few nuclei. In particular it is proposed to:

1. Measure, with high statistical accuracy, the spectrum of pions inelastically scattered from four isotopes at one angle.

2. Measure angular distributions of the inelastic scattering from ~ 40° to 120° in 10° steps for two isotopes.

3. Measure crude angular distributions of elastic scattering and inelastic scattering to the first 2^+ state of the same two isotopes. These data will be used to test the reliability of the optical-model potentials and the distorted-wave theory which are used in the analysis of inelastic scattering to the giant quadrupole resonance. These last measurements may be unnecessary if the corresponding data have already been obtained elsewhere.

Measurement of the Emittance Growth in H^- Stripping (Exp. 192)
(LASL)

During the Great Shutdown, a number of equipment changes are being prepared for Exp. 192 (a measurement of emittance growth in H^- stripping). These changes are designed to simplify beam tuning for the experiment and facilitate the changeover between Exp. 192 and other EPB experiments.

The mechanical beam chopper has been rebuilt so that it can be physically removed by remote control from Line B. The gas target has been redesigned to reduce its restrictive vertical geometry, and to allow it to be positioned with respect to the beam without breaking vacuum. The new target design also incorporates two intensified TV systems, which will permit viewing the beam immediately before and after the gas target.

The third major modification has been to design a 3.048-m-long beam plug which can be inserted through the beam line in the back of the EPB beam stop. This beam plug can be inserted and withdrawn without breaking vacuum. The beam plug is about 50% fabricated at the present time.

The final modification, which has not been completely designed at the present, consists of a remote film changer and a third intensified TV system to observe the beam at the detector location.

All of these modifications are expected to be in position well before the anticipated beam date in EPB.

Nuclear Resonance Effect in Pionic Atoms (Exp. 195)

(LASL, Univ. of Mississippi, National Research Council of Canada)

The first phase of this experiment, on pionic cadmium, has been completed and published.[15] The second phase, which will determine the sign of the p-wave pion-nucleus interaction in ruthenium and palladium, is in preparation. This involves construction of a stopping telescope and a more elaborate data-acquisition system.

Pionic x-Ray Absolute Yields as a Function of Z (Exp. 214)

(LASL, Univ. of Mississippi, National Research Council of Canada)

A proposal to measure pionic x-ray absolute yields as a function of Z has been prepared. This experiment would measure the pionic equivalent of the *kaonic* x-ray absolute yield variations discovered by Wiegand and Godfrey,[16] with the ultimate goal of shedding some light on the initial atomic capture and deexcitation processes which determine these yields.

General Research Projects

Accelerator Retuning Assistance

MP-4 provided some initial assistance in tuning the module 13 bridge coupler. Tuning on modules 12 and 13 has now been completed. The amplitude distribution in each tank of the two modules is within ± 0.2% rms (which is the limit of the reproducibility of the field measurement) of the reference bead pulls of April 1972. The differences in average tank amplitudes across the two untouched bridge couplers on module 12 is less than 0.5%.

MP-4 also provided assistance in modifying the 805-MHz bead-pull capability to meet the needs of the Alvarez tuning effort. To adapt the small perturbation of the Alvarez bead pull to the existing program, an analog-frequency multiplier consisting of an F-V converter followed by a V-F converter was designed. After resolving several problems with the bead-pull hardware, the reproducibility of the cell average field data was better than 0.5% rms per run with no modification of the existing computer program. A minor modification of the program was made to permit averaging several bead-pull data sets for better statistical resolution. Tuning of modules 3 and 4 has been completed with field distribution and tilt sensitivity equal to or better than the 1972 results.

Line-A Guard Rings

Quadrant secondary-emission monitor (SEM) devices are currently being constructed to go into Line A. Eleven of these devices will be installed in front of and behind various collimators in the line upstream and downstream of each of the targets as well as before the beam stop. The primary purpose of these SEMs is to provide a fast-protect system with a response time on the order of one beam pulse to turn the beam off if mis-steering could cause a collimator to melt. The four quadrants of each SEM will also provide a continuous monitor of the beam halo.

Programming for Experiments

The TRANSPORT acceptance-diagram routines were completely rewritten. Running speed decreased by a factor of 10 to 15. The new code allows for diagrams to be produced at any beam element, includes additional checks on data, corrects earlier errors in plots for round slits and elongated plots, and computes the area within the diagram. It also has an option for producing a plot of the beam ellipse superimposed on the acceptance diagram, and another option for producing film plots. Two additional subroutines were written to compute percentage of acceptance, assuming a bivariate normal beam distribution, and to compute the coordinates of corners on the acceptance diagrams.

The general histogram and scatter-plot subroutines were revised to allow a variable number of titles, clarify the output, and avoid the printing of empty plots. A routine was written to reproduce printer histograms on the Tektronix 4010 through the use of a film file. Very slow line speeds precluded any practical use of this routine.

An off-line analysis program was written and debugged on the 360 for the ZGS Parity Violation experiment [Exp. 137(B)]. The program paralleled an earlier analysis program on the CDC but included the following enhancements: the data were altered in format and included two additional counters; delta quantities were computed to remove long-term fluctuations; data were written to a scratch disk file to allow for as many scatter plots as desired; and sequential regressions were included to remove correlations with variables two at a time.

A least squares regression program was developed for analysis of experimental nuclear-coulomb displacement energies for isospin multiplets within the $1d_{5/2}$, $1d_{3/2}$, and $1f_{7/2}$ shells. The program includes computation of regression coefficients and X^2 using weighted data and a back substitution to show differences between observed and calculated values.

Two different scattering subroutines were tested and compared using various materials, particles and path lengths.

LEP Spectrometer

An order has been placed for new coils for the spectrometer magnet. The new coils will enable the magnet gap and solid angle to be increased to 5 cm and 8 msr, respectively; delivery is scheduled for September 1975.

Design work is proceeding on the support stand. The spectrometer can be positioned at several points along the LEP beam line allowing angular coverage of $-50°$ to $+120°$ in the forward position and $-20°$ to $+150°$ in the back position. Design of detector systems and target chambers is being done at the Univ. of South Carolina and the Virginia Polytechnic Inst. and State Univ.

Beam-on-Target Monitor

A prototype ion chamber is ready. It will be tested during May with high-energy protons.

Beam-Profile Monitor

The Mark II version of this device is nearly complete. Some cross-talk problems in the umbilical and on the new circuit boards have been overcome. The new wire chamber is wound, and the electronics box is finished. Tests of the completed system are under way.

Theory

The E2 nuclear-resonance-effect calculations have now been extended to $\bar{p}$ and Σ^- atoms, and some spectacular effects in $\bar{p}-{}^{100}Mo$ have been predicted. In addition, earlier calculations for π^- and K^- have been generalized to odd A nuclei with arbitrary ground and excited state spins.

Nuclear Matter Theory of Pion Scattering from Nuclei

A previous work[17] dealing with this same subject omitted effects of correlations between nucleons. We now feel that this omission resulted in a greater model dependence than necessary, and we have therefore undertaken a new approach to the nuclear-matter theory with this in mind. We have begun with a study of pion scattering in the vicinity of the 3-3 resonance. Near the resonance the nucleus is black to pions except in the surface, where the density is low. Therefore we expand the interaction as a power series in the density and study the lowest order terms. We find three effects in order p^2 which lower the resonance energy. One is the Lorentz-Lorenz Ericson effect (i.e., correlations); the others are the fermi motion of the nucleons and the small phases. We estimate a net down-shift of 10 MeV.

Nuclear Matter Theory of Pion Interactions at High Density.

At energies substantially away from the resonance, the pion can penetrate into the nuclear interior where the low-density expansion is no longer valid. We have begun to investigate a theory in which correlations and multiple reflections play a very important role. The latter effect vastly reduces the effective p-wave amplitude.

Coulomb-Nuclear Interference

We have investigated the possibility of extracting from transmission experiments an integrated cross section which is "model independent," in the sense that the cross section does not depend on imperfections in any theory which may be introduced to analyze the data. We have found self-consistency to be a crucial concept and have successfully explored this condition to extract a model-independent integrated cross section.

Depolarization of μ^- in Helium

In an earlier progress report, we examined the spatial distribution of ion pairs formed in the slowing down of a negative muon in liquid helium. In slowing down from an energy of the order 2500 eV to capture, we estimated that about 50 ion pairs would be formed in a volume of dimensions $1000a_0(a_0 = 5.2917 \times 10^{-9}$ cm). We would like to determine if these ions can have significant effect on the depolarization of the muon. In our previous analysis we assumed that elastic collisions were the predominate mechanism by which the ejected electrons dissipated their excess kinetic energy. There is considerable theoretical and experimental evidence[18,19] to indicate that thermalization of electrons in liquid helium involves an inelastic transition to a localized or "bubble" state. The experiments of Hernandez and Silver[19] suggest that electrons ejected into the fluid with energy ≤ 30 eV will exhibit a mean thermalization time 5×10^{-11} s and a mean thermalization length of 70 Å.

This mode of thermalization has several important implications for the problem we are considering:

1. Thermalization of the electrons does not significantly effect the distribution of ion pairs.
2. Both positive and negative ions will have achieved thermal equilibrium before the muon cascade is complete.
3. The thermalization length is less than our estimate of the mean separation of ionization events; consequently, the field of the parent ion will predominate during the recombination.

Mozumder[20] has investigated the recombination of isolated ion pairs in liquids. His model predicts that the probability to escape recombination for a time t is related to the thermalization length R_T by

$$W(t) = \exp[-R_c/R_T \,\mathrm{erfc}\,(R_T/[4Dt]^{1/2})] \qquad (1)$$

where R_c is the radius at which the coulomb potential energy equals kT and D is the diffuse coefficient for ions in the liquid. Figure IX-33 shows W(t) for thermalization lengths of 70 and 100 Å in liquid helium at 4.2°K. The time scale of recombination is of the order of 2×10^{-9} s.

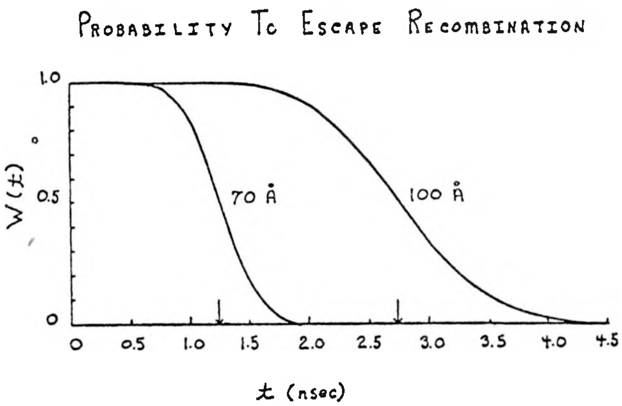


Fig. IX-33.
Rate of recombination in the isolated ion-pair approximation for thermalization lengths of 70 and 100 Å.

These results do not apply to ions formed in the cascade because in this case the density of ions is too great to make the assumption of isolated ion pairs. However, there is no reason to assume that these ions should escape recombination for times greater than the isolated ion pairs. Thus we conclude that the time scale of recombination is a small fraction of the muon lifetime. Consequently, interactions between the muon spin and the ion pairs must be strong in order to produce depolarization on this short time scale. There seems to be no reason to suppose that the mesic helium ion should be more successful in escaping recombination than normal helium ions. Consequently, our analysis suggests a high probability to form the neutral mesic helium atom $\alpha\mu e$. If this species is formed, the muon will share its polarization with the electron, and strong depolarization will result if the polarized electron can be exchanged several times with unpolarized electrons from the medium. One mechanism to achieve this is by elastic exchange collisions $\alpha\mu e + e' \rightarrow \alpha\mu e' + e$. The frequency for this type of exchange is

$$\nu = \sigma_{ex} v_r \, \eta_-(t) \sim 4 \times 10^{-3} \, \eta_-(t) \quad \text{(atomic units)} \qquad (2)$$

To obtain this estimate, we have used the hydrogenic exchange cross section and mean thermal velocity of helium atoms at 4.2°K. The exchange frequency would be about 100 times larger if the velocity of relative motion were determined by free electron motion; however, this seems inconsistent with the localized state of excess electrons in liquid helium. Since recombination removes the source of unpolarized electrons, an upper limit on the effectiveness of this mechanism for depolarization is obtained by taking the initial ion density for $\eta_-(t)$ and multiplying the resulting frequency by the recombination time. The result is $\nu\tau_R \sim 2 \times 10^{-2}$, which shows that no significant depolarization results from this mechanism.

The metastable $He^*(2^3S)$ has been observed as a product of the electron degradation in liquid helium, and its measured lifetime is 15 μs.[21] It is reasonable to suppose that this state is produced by recombination since statistical weights favor recombination into the triplet manifold. This metastable product can provide a source of unpolarized electrons through Penning ionization followed by recombination.

$$\alpha\mu e(\uparrow) + He^* (\downarrow\downarrow) \rightarrow \alpha\mu^+ + He(\uparrow\downarrow) + e^-(\downarrow)$$
$$\alpha\mu^+ + e^-(\downarrow) \rightarrow \alpha\mu e(\downarrow) \quad (3)$$

The frequency of the ionization reaction is $\nu = \sigma_{PI} v_r \eta_H \sim 0.7 \times 10^{-10}$ (atomic units) for a metastable density of half the initial ion-pair density. This reaction is slower than the recombination step which has an approximate frequency of $\eta = T_R^{-1}$. Nosov and Yakovleva[22] have analyzed depolarization by processes such as Eq. (3) and find that in the limit $\eta >> \nu$

$$P(t) = P(O) \exp(-\gamma t/2)/2 \quad (4)$$

Because of the long lifetime of $H_2^*(2^3S)$, reactions [Eq. (3)] can operate over the full muon lifetime, and a significant depolarization can result.

Atomic Capture of Negative Mesons—Fuzzy Fermi-Teller Model

The Fuzzy Fermi-Teller model (FFT) is a generalization of the Fermi-Teller model[23] (FT) which allows for the probabilistic nature of the response of the atomic electrons to the invading meson. The probability per unit time of a collision at the point r(t) on the meson's classical orbit is

$$\Gamma(t) = \int d^3\vec{k}\, f(k,r) v_{rel} I_{cm}\, d\Omega_{cm} \quad (5)$$

where f(k,r) is the phase-space distribution of the electrons, v_{rel} the relative velocity of the meson and an electron of momentum $\vec{k}$ and I_{cm} is the Rutherford scattering cross section in the center of mass coordinates of the electron and meson. For the electron distribution function we use the Thomas-Fermi approximation

$$f(k,r) = 2/(2\pi)^3\, \Theta[p_F(r) - k] \quad (6)$$

where p_F is the Fermi momentum of the electrons at position r(t) which is related to the electron potential energy $\phi(r)$ by $p_F = (2\phi)^{1/2}$. Atomic units are used throughout this discussion. The integrals in Eq. (5) are over electron momenta in the Fermi sphere and all angles of scattering for which the meson loses energy. To avoid the well-known Coulomb singularity, a minimum momentum transfer of $2p_F^{1/2}$ is introduced and $\Gamma(t)$ is set to zero when $p_F \leq 1$.

Using the techniques described in Ref. 24, Eq. (5) is reduced to the form

$$\Gamma(t) = \frac{4}{\pi V(r)} \int_{2p_F^{1/2}}^{2p_F+\delta} q^{-4} dq \int_{\varepsilon g}^{V(r)q} (\varepsilon - \varepsilon g) d\varepsilon \quad (7)$$

where V(r) is the velocity, Eg is the energy gap at the Fermi surface, and δ is the corresponding momentum gap. By interchanging the order of integration in Eq. (7) and performing the integral over momentum transfers q, we obtain the distribution of energy losses

$$\frac{d\Gamma}{d\varepsilon} = \frac{4V^2}{3\pi}(\varepsilon - \varepsilon g) \begin{cases} (\varepsilon_o^{-3} - \varepsilon_{max}^{-3}) & \varepsilon_g \leq \varepsilon < \varepsilon_o \\ (\varepsilon^{-3} - \varepsilon_{max}^{-3}) & \varepsilon_o \leq \varepsilon < \varepsilon_{max} \end{cases} \quad (8)$$

where $\epsilon_o = 2p_F^{1/2}V$ and $\epsilon_{max} = (2p_F + \delta)V$. The FT model would be justified if this distribution were concentrated about its mean value. Figure IX-34 shows that this is not the case.

The total probability of a collision on the unperturbed orbit of a meson of energy E and angular momentum ℓ, $P_T(E,\ell)$, is obtained by integrating $\Gamma(t)$ over the classical orbit r(t). For most orbits

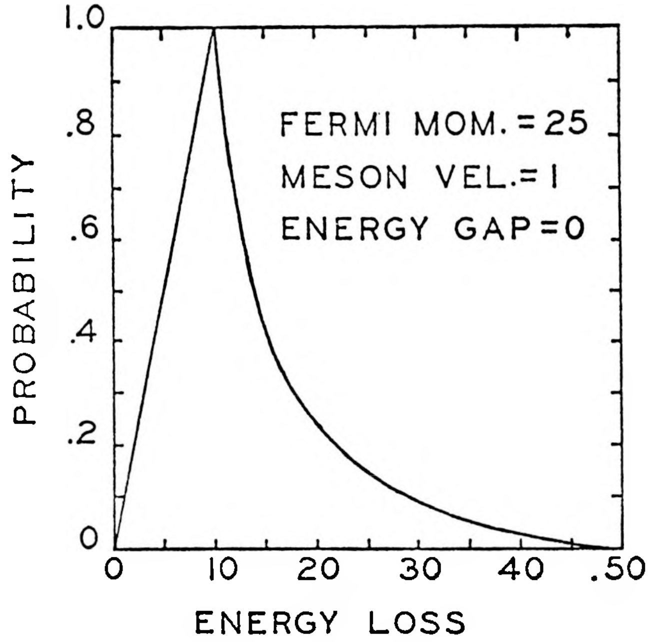


Fig. IX-34.
An example of the probability distribution for energy loss by the meson in a single collision with atomic electrons. Energy loss is in hartrees.

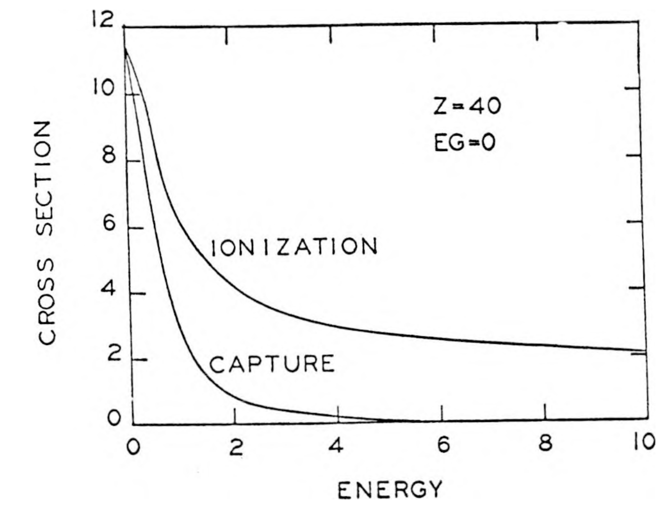


Fig. IX-35.
Ionization and capture cross sections for muons incident on an atom with Z = 40. EG is the energy gap at the Fermi surface.

$P_T(E,\ell) << 1$. This simplifies the computation since we may omit the usual exponential factor expressing the probability that the meson has escaped a collision up to the point r(t). In effect we average over "landing points" in the orbit, as is the case in quantum calculations. Capture and cascade are analyzed by a Monte Carlo program which follows a larger number of mesons (typically ~5000) as they perform a sequence of transitions through classical orbits. The sequence terminates when the meson has binding energy greater than a hydrogenic orbital of principal quantum number $n = m^{1/2}$, where m is the meson's mass.

Figure IX-35 shows the total ionization cross section

$$\sigma_T(E) = \int_0^{P_{max}} 2\pi p dp \, P_T[E,\ell(p)] \tag{9}$$

where p_{max} is the maximum impact parameter at which the meson can penetrate the atom because of the centripetal barrier. Rosenberg's[24] calculations of ionization by negative mesons have a cross section which decreased as meson energy decreased. The opposite is true for our results. A possible source of this difference is the fact that Rosenberg assumed constant velocity trajectories for the meson whereas in our model the meson "falls into" the atom because of nuclear attraction. Our method does not allow for distortion of the election cloud by the meson. This distortion would probably decrease the cross section at small meson energy, since the collision would become more adiabatic.

Figure IX-35 also shows an approximate capture cross section obtained by multiplying the total ionization cross section by the ratio of the number of mesons captured to the number incident on the atom at each energy. Figure IX-36 shows the distribution in energy of mesons before and after the capture event. The latter distribution shows that some mesons are captured at positive energy because of the centripetal barrier.

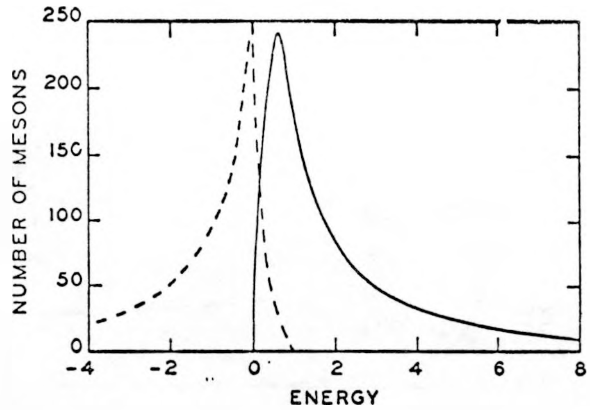


Fig. IX-36.
Energy distribution of muons before (solid curve) and after (broken curve) the capture event in an atom with Z = 40.

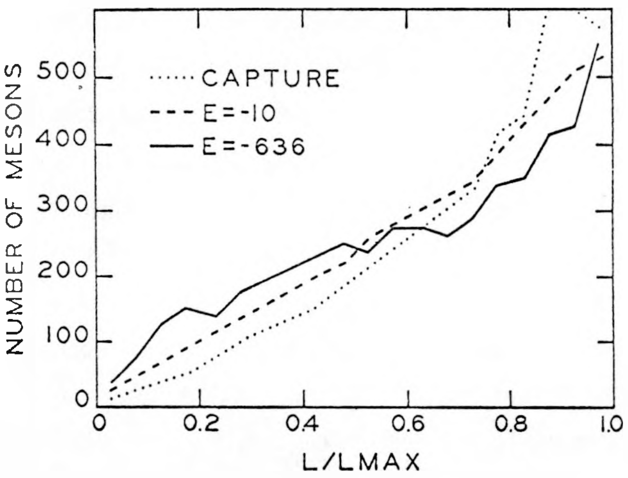


Fig. IX-37.
The angular momentum distribution of muons passing various energy levels in the cascade. The energy at which the classical cascade was terminated is E = −636.

The quantity of most direct physical interpretation is the ℓ distribution of the mesons when the classical cascade is terminated. This distribution will play a major role in determining the relative intensity of mesic x-rays. Figure IX-37 shows the development of this distribution as the meson deexcites. A gradual diffuse away from circular orbits, $\ell = \ell_{max}(E)$, is evident.

REFERENCES

1. W. A. Coleman and T. W. Armstrong, "The Nucleon-Meson Transport Code NMTC," Oak Ridge National Laboratory report ORNL-4606 (1970).

2. E. D. Cashwell, J. R. Neergard, W. M. Taylor, and G. D. Turner, "MCN: A Neutron Monte Carlo Code," Los Alamos Scientific Laboratory report LA-4751 (1972).

3. J. H. Norem, Nucl. Phys. **B33** 512 (1971).

4. K. Gabathuler **et al.**, Nucl. Phys. **B55** 397 (1973).

5. F. Binon **et al.**, Nucl. Phys. **B33**, 42 (1971).

6. M. Warneke **et al.**, Bull. Am. Phys. Soc. **20**, 662 (1975).

7. J. M. Miller, **Proc. of the Int. Conf. on Nucl. Phys., Munich,** North Holland, p. 597 (1973); H. Feshbach, ibid., p. 631; K. Chen **et al.**, Phys. Rev. **C4**, 2234 (1971); and C. K. Cline, Nucl. Phys. **A193**, 417 (1972).

8. R. Korteling and C. Toren, Phys. Rev. **C7**, 1611 (1973).

9. G. D. Harp **et al**, Phys. Rev. **C8**, 581 (1973).

10. A. Doron **et al.** Phys. Rev. Letters **34B**, 485 (1975) and reference cited.

11. "Use of High-Purity Ge Detectors for Intermediate Energy Physics," J. Amann, P. Barnes, S. Dytman, J. Penkrott, A. Thompson, and R. Pehl (submitted to Nucl. Instr. & Methods.)

12. A preliminary report on this measurement has been submitted to the Washington meeting of the APS.

13. J. F. Marshall, M. Nordberg, and R. Burman, Phys. Rev. C1, 1685 (1970).

14. G. A. Miller and S. C. Phatak, Phys. Letters, **51B**, 129 (1974).

15. J. N. Bradbury, M. Leon, H. Daniel, and J. J. Reidy, Phys. Rev. Letters **34**, 303 (1975).

16. C. E. Wiegand and G. L. Godfrey, Phys. Rev. **A9**, 2282 (1974).

17. H. A. Bethe and M. B. Johnson, "Theory of the Scattering of Pions by Nuclear Matter," LA-5842-MS (1975).

18. J. Jortner, N. Kestner, S. Rice, and M. Cohen, J. Chem. Phys. **43**, 2614 (1965).

19. J. Hernandez and M. Silver, Phys. Rev., **A2**, 1949 (1970).

20. A. Mozumder, J. Chem. Phys. **48**, 1659 (1968).

21. J. Keto, F. Soley, M. Stockton, and W. Fitzsimmons, Phys. Rev. **A10**, 887 (1974).

22. V. Nosov and I. Yakovleva, Nucl. Phys. **68**, 609 (1965).

23. M. Leon and R. Seki, Phys. Rev. Letters. **32**, 132 (1974).

24. R. Rosenberg, Phil. Mag., **40**, 749 (1949).

X. PRACTICAL APPLICATIONS OF LAMPF

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

Biomedical Research Facility

Most of the past three months were spent working on a variety of hardware improvements appropriate for accomplishing during the shutdown.

The hardware task included the following:

1. A graphics tablet interface to UNM was provided, and fabrication was started on a second unit for local use. Fabrication is about 75% completed.

2. Work is about 65% done on design, parts procurement, and fabrication for the solid-state magnet set-point controllers.

3. Two local control modules, with digital set-point read-outs for use with the new magnet set-point controllers, were designed and fabricated.

4. A special circuit board to permit reading the storage display screen on a Tektronix 4010 back into the computer for subsequent output to a Versatec printer-plotter was designed and built. This device has taken considerably longer than anticipated, and work is being suspended for a few weeks to avoid holding up other projects. Some design changes are needed to get proper operation.

5. The design for the CAMAC interface for the solid-state detector scanner was completed, and fabrication is 90% completed. Testing will be delayed until delivery of the PROM memory chips.

6. Extensive modifications were made to one of the scanner control units to allow use with the above interface. The other three control units also need to be modified, but we are waiting to complete testing on the first unit with the computer interface.

7. The elapsed time-clock and pion-flux counters were modified to allow easier servicing and to correct an intermittent bit "0" problem on the output.

8. A second CAMAC crate was installed in the upstairs power supply room.

9. Design work was done for an interface between the Tennelec PACE ADC and CAMAC. The ADC has been received, and the interface design is 95% completed with fabrication expected to start before June 1.

10. Design work was done for a permanent gas system for ion chambers and the beam-line helium system, and for computer-interfaced pressure and flow monitoring of the gas systems. This work is being done jointly with the engineering department, and the design is about 30% completed. Construction has not begun.

11. Remote computer terminal connection using telephone lines and acoustic couplers was tested with borrowed equipment. These tests were completely satisfactory (the system was operated from Livermore, California through FTS lines briefly), and a proposal was written to obtain GSA approval for remote terminals on any of the experimental area PDP-11 systems using local phone lines to transmit data between the CCF and the PDP-11 s. Purchase requests were written to cover four terminals and three modems for use on both the MP-3 experimental computer and on the biomed computer.

12. The memory on the biomed computer was increased from 96K to 124K to better accommodate the many users now running on the system.

Considerable time was spent on procurement, with capital equipment being ordered to interface the SHM scanner, to measure magnet current more accurately through the computer, to interface the Keithley electrometer, to add a second video display channel, to add 20 million words of disk storage on the computer, and to build a good dose integrator system for the orthovoltage x-ray machine, in addition to the items mentioned above.

Software effort during the last quarter included directing the activities of the following people engaged insoftware development for the biomed control computer: George Atkinson and Marilyn Leiber (UNM consultants), Richard Kittell (MP-1), Delores Mills (MP-1, data analyst), and Martin MacRoberts (E-5). Time was also spent consulting on the hardware design of systems to operate 1) the solid-state detector scanner, 2) the PACE ADCs, and 3) the Tektronix hard-copy device.

Software tasks accomplished include the following:

1. **FORTRAN IV Plus.** A FORTRAN IV Plus compiler was acquired from Digital Equipment Corporation and installed for use on the biomed computer. Libraries and compiler tests were assembled. FORTRAN compiled with this compiler occupy approximately two-thirds of the space and run 2 to 3-1/2 times faster than code compiled with the standard DEC FORTRAN.

2. **System Maintenance.** Changes in the operating system have been necessary to support 124K memory, additional terminals, and the Q Data Acquisition software, in addition to the normal load of documentation and system back-up activities.

3. **PIPLAN.** Changes have been made in PIPLAN to speed up the transfer of dose data to the disk storage array. Conversion of PIPLAN subroutines to FORTRAN IV Plus is in progress. A second version of the computational routines is being prepared. In this version, individual rays will be selected from an input phase space describing a fixed beam in a Monte Carlo fashion. Dose from the individual rays will be summed into the calculational arrays using the same input (patient) geometry developed for PIPLAN.

4. **Scanner Task and Subroutines.** An interactive scanner task has been written to set up the solid-state detector scanner for computer control. A series of subroutines has been written to allow data-acquisition programs to manipulate the scanner under program control.

5. **Experiment 179.** A preliminary data-acquisition program has been written to check out the hardware for Exp. 179. This experiment in its final form will need a PACE-6 ADC system to fully realize the experimental resolution. The PACE CAMAC interface will not be ready for several months.

6. **Tektronix Hard Copy.** Software was written to debug the hard-copy hardware. This project has been temporarily suspended.

7. **Character Scope Software.** A series of programs have been written to maintain color character displays in an operator interactive fashion. Work is continuing on this project to unify displays and display allocation.

8. **Digitizing Tablet.** A handler has been completed which takes input graphic data from the digitizer and stores data as binary coordinate pairs. The digitizer is now being used at UNM. A second digitizer will be available for use on the biomed computer when the second interface is completed.

Biomedical Pion Channel Development

Results from the tuning of the first section of the biomedical channel have been published.[1] The third bending magnet in the channel (BM-03) serves as a magnetic spectrometer to measure momentum resolution at the intermediate focus and momentum distributions from a beryllium wedge placed at the focus. The momentum resolution of the first section of the channel combined with the resolution of BM-03 is 0.88% $\Delta p/p$ (rms).

The beryllium wedge compresses a very wide momentum bite into a small momentum interval, the purpose being to produce a relatively narrow depth-dose distribution. The measured momentum spectrum leaving the beryllium wedge is given in Fig. X-1. The standard deviation of the distribution is 1.45% $\Delta p/p$ when the tails below 15% of the peak height are replaced by gaussian tails.

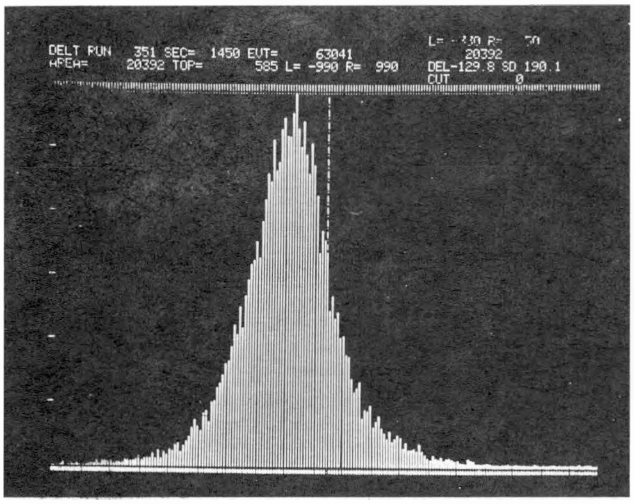


Fig. X-1.
Measured momentum spectrum $\Delta p/p$ out of beryllium wedge. Scale ±10%, center 171 MeV/c.

The momentum distribution entering the wedge is obtained by computationally unfolding the effect of the wedge, knowing the momentum leaving the wedge and the path length that each pion traversed through the wedge. This process is accurate to 0.65% $\Delta p/p$ (rms), limited by scattering, straggling, and measurement error. The resulting distribution is shown in Fig. X-2. The wedges reduce the momentum spread by about a factor of 5; note that the scales in Figs. X-1 and X-2 differ by a factor of 2.

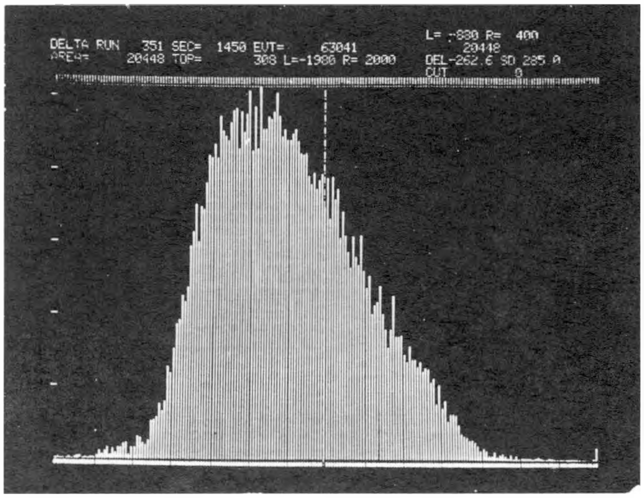


Fig. X-2.
Momentum acceptance of channel $\Delta p/p$ with a wedge degrader; $\Delta p/p$ is calculated by unfolding the effect of the wedge. Scale ±20%, center 190 MeV/c.

Pion Dosimetry Program

Analysis of the dosimetric data taken during the final beam cycles is continuing. Computer codes have been written to perform the necessary data smoothing and curve fitting, and several options are now available for off-line plotting of all dosimetric data (on Cal-Comp, zeta plotter, and the HP 9830). Efforts will begin shortly to modify these codes for use on the biomed computer to allow on-line data analysis next fall.

In addition to these software problems, work has been continuing on modifying existing equipment, and on designing new equipment for dosimetric studies of scanning pencil beams and sausage-shaped beams at the biomed channel. Projects now under way in this regard include new waterproofing systems for all dosimeters, redesign of the 40-cm monitor, computer interfacing of scanner, and design of new inexpensive electrometers.

Analysis of biological data, as well as specific dosimetric data for biological experiments, continues also.

We have been collaborating with T. W. Armstrong (Applied Research Institute) on theoretical calculations related to dosimetry and microdosimetry for pions. Armstrong's results have been an invaluable source for interpreting experimental results.

Microdosimetry Program

Analysis of the microdosimetric data taken during the final beam cycles is also continuing. The mean energy and the mean energy loss of the ^{241}Am alpha source used for calibration purposes has been measured with a solid-state detector so that absolute energy scales are now accurately known for all lineal-energy spectra. Previous curves were based on the calculated values of energy loss for the ^{241}Am source which differed from the measured values by about 2%.

Existing programs for data anlysis described in previous reports have been modified to allow for curve fitting and off-line plotting on cal-comp. Dose distributions as a function of lineal energy (y) and also linear energy transfer (LET) have thus been obtained in a liquid phantom at eight different depths for π^- and at two different depths for π^+.

Using these data and algorithms developed by Kellerer and Rossi[2] and Katz *et al.*,[3] theoretical values of RBE and OER have been generated for pions. For the latter theory, survival curves and RBE vs dose curves have also been generated. Figures X-3

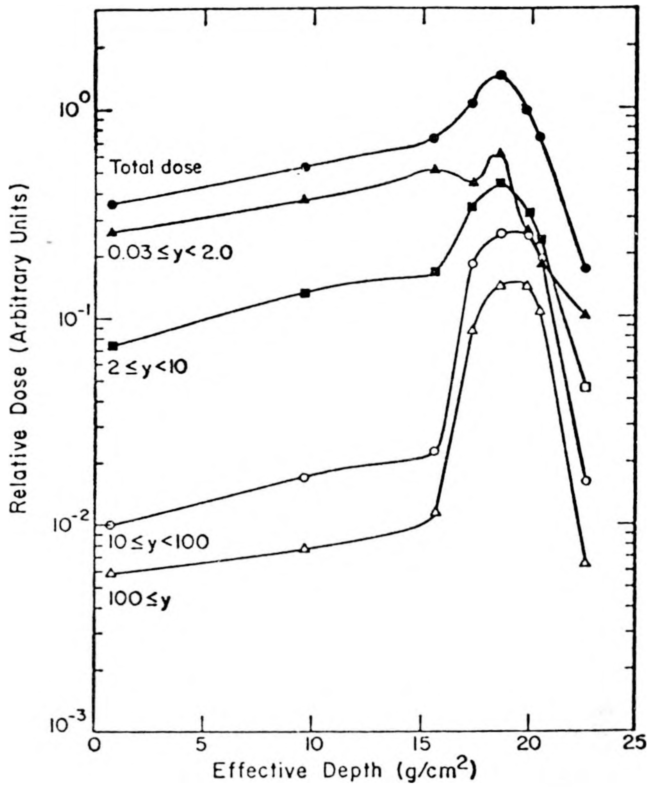


Fig. X-3.
Dose as a function of depth for various intervals of lineal energy.

and X-4 and Table X-I summarize the results of these calculations. Figure X-3 is a series of depth dose curves for π^- in various lineal energy intervals, and shows that high y events contribute significantly to the dose only in the peak region, and are most prominent slightly downstream of the area of peak dose. Figure X-4 is a plot of the calculated RBE vs depth, and also RBE × dose vs depth. Table X-I presents values of calculated RBE and OER at several different depths and survival levels for the theory of Katz *et al.*[3] These results are not inconsistent with the biological results obtained on the biomed channel.

Work is continuing on several projects mentioned in the previous report, including a three-decade logarithmic amplifier and a miniaturized low-noise preamplifier for use with a Rossi proportional counter. Figure X-5 is a photograph of the most recently designed model, and efforts are continuing (with R. Hiebert, E-2) to further reduce the total volume of this system.

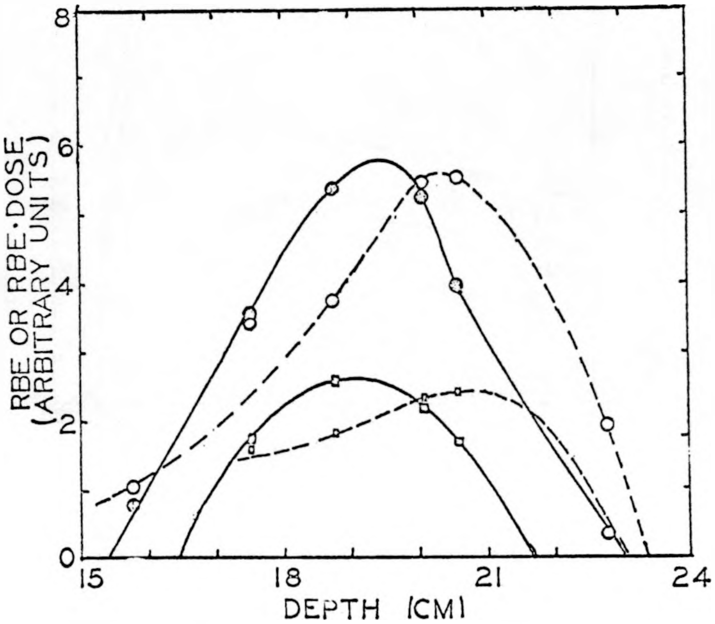


Fig. X-4.
Plot of RBE vs depth (dashed lines) for theories of Kellerer and Rossi (open circles) and Katz **et al**. *open squares); and plot of RBE × Dose vs depth (solid lines) for theories of Kellerer and Rossi (closed circles) and Katz* **et al**. *(closed squares). Note that the ordinates are all of arbitrary scale.*

TABLE X-I

VALUES OF RBE AND OER

Effective Depth	RBE S = 0.89	OER S = 0.89	RBE S = 0.1	OER S = 0.1
9.75 cm	1.3	2.1	1.1	2.4
18.75 cm	3.7	1.3	1.7	1.7
20.55 cm	5.9	1.3	2.1	1.6

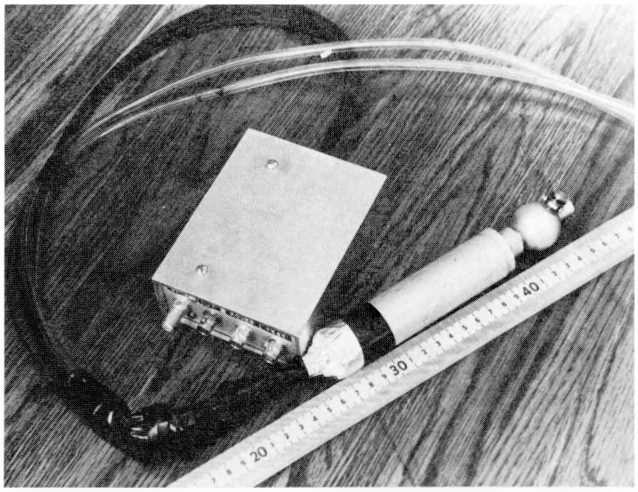


Fig. X-5.
Photo of (left to right) main stage of preamp, first stage of preamp, Rossi chamber.

Practical Application Experiments

Tissue Chemical Analysis with Mu-Mesic X-rays (Exp. 100)

Analysis of the x-ray data for some of the targets studied was completed. The measured yield of Lyman series x-rays from carbon, nitrogen, and oxygen (and fluorine for one sample) was compared with the yield predicted on the basis of the Fermi-Teller Z law, which says that the muon-capture probability for a given element in the sample in which the muon stops is proportional to the product of the Z of the element and the concentration of the element.

It was also assumed that any muon captured by a hydrogen atom is immediately transferred to the element to which the hydrogen is bound. The total number of Lyman series x-rays from an element is equal to the number of muons captured by the element, since all muons eventually reach the n = 1 level. The comparison was done for the two samples, muscle equivalent liquid and tissue equivalent plastic, for which we know the chemical composition at this time. Table X-II shows the comparison between theory and experiment. The statistical errors are generally less than 1%. Analysis of the statistical errors is not complete.

There is good agreement between theory and experiment. Work is continuing on this project to compare predicted and measured yields of x-rays from tissue samples.

TABLE X-II

COMPARISON OF PREDICTED AND MEASURED MUON CAPTURE FRACTIONS (Percent)

	Spokas Tissue Equivalent Plastic		Muscle Equivalent Liquid	
	Z Law	Experiment	Z Law	Experiment
Carbon	89.9	89	14.7	15
Nitrogen	4.0	3.7	5.0	4
Oxygen	4.6	6.3	80.3	81
Fluorine	1.5	1.0		

Technology Transfer

Localized Current Tumor Therapy

Thermal treatment of spontaneous animal tumors is continuing with localized current fields (LCF) at the UNM Medical School and at the Arizona Medical Center in Tucson. Three animals have been treated with a less invasive LCF technique than those used previously in this work. In the more recent approach, the animal is partially surrounded with a saline solution where resistivity has been adjusted to about 800 Ω·cm. Electrodes are placed into the saline "phantom" rather than in the animal, with the current field concentrated in the volume of tissue which bears the malignancy. Skin over the treated volume can be spared by pumping the cooler saline through the metallic electrode into the region of high-current density. In a typical case, the underlying tumor volume can be heated to 44°C while the skin is held to ~ 40°C. This technique, while less effective in high-resolution localization of the heat than other LCF methods, is considerably less invasive. It is still necessary, of course, to place hypodermic-mounted thermistors into the tissue which is under treatment.

Tumors that have been treated recently at UNM Medical School under the cooperative program include:

1. Feline squamous-cell carcinoma of upper eyelid was recurrent one month after surgery. Apparent complete regression after two LCF treatments.
2. Canine mast cell tumor in upper foreleg showed marked regression after one LCF treatment. Withdrawn from treatment due to anesthesia risk.
3. Canine fibrosarcoma of roof of mouth has shown only moderate sensitivity to several LCF treatments. Aggressive LCF treatment continues.
4. Equine sarcoid (a benign tumor) of right foreleg has shown response to first treatment, and will probably require at least one further treatment. (One hundred percent of six previous equine sarcoids on four horses appear to have regressed completely, the first one treated 16 months ago. These tumors do not normally respond well to surgery.)
5. Canine mast cell tumor under chin has received one LCF treatment. At the owner's request, this animal will also undergo x-ray therapy, limiting its informational value to the LCF effort.

Systemic Heating

As a part of the LASL-UNM effort in thermal tumor therapy, an apparatus for whole-body heating of animals has been constructed and placed in H-4 facilities at LASL. Animals with malignancy that is not localized will be candidated for whole-body heating 42°C for 4 to 6 h.

Bioelectric Potentials

A high-impedance millivoltmeter has been constructed for use with silver-silver-chloride electrodes in the measurement of tissue dc potentials. There is evidence that malignant tumors often exhibit a dc potential which is several millivolts more negative than surrounding normal tissue. It is planned to investigate the diagnostic possibilities of these potentials, but it has become clear that considerable engineering effort must first be expended in the design of suitable electrode-skin interface devices. Even if this latter effort is successful, the technique will probably be limited to two or three anatomical locations.

Measurement of Average Differential Breast Skin Temperature

The five temperature-difference integrators (of modified design) are still performing reliably in the testing program at the Medical School in Tucson. At this date, there is insufficient data on malignant cases to determine whether the device is likely to prove valuable in the early diagnosis of breast cancer. Since the investigators in Tucson wish to expand the testing effort in order to answer this question at an early date, arrangements are being made with a private firm to construct devices of the LASL design. These devices will be calibrated and tested at LASL before being used in the field.

References

1. M. A. Paciotti, J. N. Bradbury, J. A. Helland, R. L. Hutson, E. A. Knapp, O. M. Rivera, H. B. Knowles, and G. Pfeuffer, "Tuning of the First Section of the Biomedical Channel at LAMPF," Proc. 1975 Particle Accelerator Conf., (Washington, D.C., 1975), Vol. NS-22, No. 3., pp. 1784-89.

2. A. M. Kellerer and H. H. Rossi, "The Theory of Dual Radiation Action," Rad. Res., **QB**, 85 (1972).

3. R. Katz, B. Ackerson, M. Homayoonfar, and S. C. Sharma, "Inactivation of Cells by Heavy Ion Bombardment," Rad. Res. **47**, 402 (1971).

XI. MANAGEMENT

Budget and Personnel Levels

Through the past nine months of FY-75, accrued operating costs are within 0.3% of the forecast. Authorization for an increase of $200K in operating funds is expected early in May. This money will be used to help defray craft costs associated with the Great Shutdown. Approximately 56% of the capital capital equipment funds are obligated as soon as the Division equipment needs are finalized.

The average number of employees—full-time equivalents (FTEs)—is 333, about 4% more than the forecast.

Safety

Safety Coordination

So that assistance in safety matters is readily available for personnel in the experimental areas, a member of the LAMPF Safety Office has been stationed near the Area Manager's Office, Area A.

Magnets

Warning Lights. A survey was made to identify magnets which require warning lights. Work has started on the installation of warning lights and power-supply modifications for those magnets, as described in the Quarterly Progress Report for the period ending January 31, 1975.

Magnet Terminal Insulation. Magnet terminals are being insulated to provide personnel protection. Terminals are covered with vinyl, and the vinyl is then secured by taping, or by plastic wire-ties. This results in a durable insulation and is convenient to install.

Training

Two division-wide safety meetings were held this quarter. One dealt with manual lifting and possible resulting injuries. A film entitled "Oh, My Aching Back" was shown.

The second meeting concerned cardiopulmonary resuscitation, and a film entitled "Pulse of Life" was shown. Proper techniques were demonstrated on a mannequin. Attendees were given the opportunity to practice after the meeting.

Accidents

Twelve accidents occurred. Nine of these were minor abrasions, lacerations, and sprains which caused no loss of time from work. The remaining three resulted in lost time: two individuals suffered fractures from falls, and the third sustained welding flash burns to the eyes.

Radiation Control

The total radiation exposures for the months January through March 1975 were 14.6 man-rem. The maximum individual exposure was 0.77 rem. Considering the amount of radiation work done during this period, the exposures have been well controlled.

Program Advisory Committee

The LAMPF Program Advisory Committee met on April 3, 4, and 5, 1975 to hear the progress of ongoing experiments and the defense of 22 new proposals, 1 addendum, and 1 revision. All active proposals were reviewed. Subcommittees for each channel or program met to provide detailed consideration of each proposal in its area and to determine relative priorities with respect to the expected LAMPF running schedule for the coming year of operation.

The new PAC meeting will be held sometime in the middle of January 1976. The exact date for it and the deadline for the submission of new proposals have not yet been decided.

The following proposals were approved, approved in part, or approved for parasitic operation in accordance with the recommendations of the PAC:

50 "Radiative Pion Capture in Light Nuclei"
K. M. Crowe, Spokesman
P. Truöel (Univ. of Zurich); R. H. Sherman (LASL); J. Bisterlich, S. Cooper, F. T. Shively (LBL); H. W. Baer (Case Western Reserve Univ.)

181 (Add.)"Angular Distribution Measurements for Pion-Nucleus Single Charge Exchange Reactions"
J. Alster and J. D. Bowman, Spokesmen
J. Alster, M. A. Moinester (Tel Aviv Univ.); M. Cooper (Univ. of Washington); J. D. Bowman, R. Heffner, M. B. Johnson, C. M. Hoffman, J. Potter (LASL)

193 (Rev.)"Measurement of Small Angle Neutrons Elastic Scattering from Protons"
B. D. Dieterle, Spokesman
R. F. Bentley (LASL); H. C. Bryant, R. D. Dieterle, J. Donahue, C. P. Leavitt, D. M. Wolfe, T. Rupp, R. Carlini (UNM)

201 (Rev.)"The $\pi^+d \rightarrow 2p$ Reaction at 100-500 MeV"
R. C. Minehart, Spokesman
R. C. Minehart, Klaus Ziock, James McCarthy, E. A. Wadlinger (Univ. of Virginia)

208 "Measurement of $\sigma(\theta)$ for n−p Elastic Scattering at Forward Angles"
L. C. Northcliffe, Spokesman
G. Glass, J. C. Hiebert, M. Jain, R. A. Kenefick, L. C. Northcliffe (Texas A&M Univ.); B. E. Bonner, J. E. Simmons (LASL)

213 "Muon Transfer Study"
E. B. Shera and R. M. Steffen, Spokesmen
R. M. Steffen (Purdue Univ.); K. Krane (Oregon State Univ.); E. B. Shera, G. Rinker, R. B. Perkins (LASL)

214 "Pionic X-Ray Absolute Yields as a Function of Z"
C. K. Hargrove and M. Leon, Spokesmen
C. K. Hargrove (LASL/National Research Council of Canada); J. J. Reidy (Univ. of Mississippi); J. N. Bradbury, R. L. Hutson, M. E. Schillaci (LASL)

221 "Precision Measurement of the Decay Rate for the Dalitz Decay Mode of the π° Meson"
Cyrus M. Hoffman, Spokesman
J. S. Frank, C. M. Hoffman, R. E. Mischke, R. D. Werbeck (LASL)

222 "Measurement of the Decay Rate for $\pi^\circ \rightarrow e^+e^-$"
R. E. Mischke, Spokesman
J. S. Frank, C. M. Hoffman, R. E. Mischke, R. D. Werbeck (LASL)

223 "Studies of the $(p,n\bar{p})$ Charge-Exchange Reaction"
G. W. Hoffmann and J. E. Spencer, Spokesmen
G. Blampied, R. Liljestrand, J. McIntyre, G. W. Hoffman (Univ. of Texas); J. E. Spencer (LASL)

224 "Inelastic Pion Scattering from ^{148}Sm and ^{152}Sm"
N. Ensslin, D. Madland, and C. Morris, Spokesmen
N. Ensslin (Univ. of Colorado); D. Madland (Univ. of Minnesota); C. Norris (Univ. of Virginia); H. A. Thiessen (LASL)

225 "A Study of Neutrino Electron Elastic Scattering"
H. H. Chen and F. Reines, Spokesmen
H. H. Chen, W. R. Kropp, J. F. Lathrop, R. D. Newman, F. Reines, H. W. Sobel (Univ. of California, Irvine)

227 "(p,n) Reaction Studies on Light Nuclei"
P. J. Riley and J. E. Spencer, Spokesmen
M. Baker, C. Hwang, J. Pratt, D. Slater, J. E. Spencer (LASL); P. Riley (Univ. of Texas)

228 "Real and Imaginary Parts of the Forward Scattering Amplitude in $\pi^\pm$ Nucleus Scattering from 20 to 60 MeV"
H. A. Thiessen, Spokesman
H. A. Thiessen, J. Kallne (LASL); J. Bolger, K. G. Boyer, W. J. Braithwaite, A. Obst, C. F. Moore (Univ. of Texas); C. L. Morris, M. D. Thomason, D. Slater (Univ. of Virginia); N. Ensslin (Univ. of Colorado); G. Burleson, W. Harvey (NMSU)

229 "π^+ vs π^- Inelastic Excitation of Low-lying Collective States in N=28 Nuclei"
W. J. Braithwaite and C. F. Moore, Spokesmen
H. A. Thiessen (LASL); J. Bolger, W. J. Braithwaite, K. Boyer, C. F. Moore, G. W. Hoffman (Univ. of Texas); C. Morris (Univ. of Virginia)

232 "Inelastic Pion Scattering by ^{24}Mg and ^{25}Mg"
D. Madland, C. Morris, and N. Ensslin, Spokesmen
D. Madland (Univ. of Minnesota); C. Morris (Univ. of Virginia); N. Ensslin (Univ. of Colorado); H. A. Thiessen (LASL)

233 "Search for Δ-Configuration in Nuclei"
K. K. Seth and J. E. Spencer, Spokesmen
J. Pratt, J. E. Spencer (LASL); S. Iverson, K. K. Seth (Northwestern Univ.); G. Kyle (Univ. of Minnesota)

234 "A Study of the Inelastic Pion Scattering Reaction at Pion Energies 10-100 MeV"
D. A. Jenkins, Spokesman
F. E. Bertrand, E. E. Gross, C. A. Ludemann (ORNL); C. W. Darden, R. D. Edge, B. M. Preedom (Univ. of South Carolina); M. Blecher, K. Gotow, D. A. Jenkins, W-C. Lam (VPI and State Univ.); R. L. Burman (LASL)

237 "Radiation Damage Studies on Structural Materials for Advanced Reactors"
J. R. Holland and W. V. Green, Spokesmen
W. J. Choyke, L. R. Fleischer, R. E. Gold, J. R. Holland, J. A. Spitznagel (Westinghouse Research Lab.); W. V. Green (LASL)

The proposals listed below have been submitted to the Director of LAMPF during this report period and will be reviewed by the Biomedical Subcommittee of the PAC.

215 "Visualization of Stopping Pion Distribution"
V. Perez-Mendez and J. Bradbury, Spokesmen
J. Bradbury, E. Knapp, J. Helland (LASL); D. Ortendahl, V. Perez-Mendez (LBL)

217 "π^- Production Cross Sections"
M. Paciotti, Spokesman
J. Bradbury, J. Helland, E. Knapp, M. Paciotti (LASL)

218 "Pion Dosimetry with the Nuclear Emulsions and Alanine"
R. Katz, Spokesman
R. Katz (Univ. of Nebraska); H. Amols, J. Bradbury, J. Dicello (LASL)

235 "Radiation Repair of Normal Mammalian Tissues"
E. L. Gillette, Spokesman
E. L. Gillette (Colorado State Univ.); L. M. Holland (LASL); J. W. Watters (Colorado State Univ.)

236 "Biological Effects of Negative Pions"
M. R. Raju, Spokesman
M. R. Raju, J. H. Jett, T. T. Trujillo, E.Bain, J. Frank, L. L. Deaven, R. A. Walters, R. A. Tobey, L. M. Holland, H. Amols, J. Dicello (LASL)

The LEP Subcommittee, meeting at the PAC meeting, became aware that the channel faced a time request oversubscription greater than a factor of two over the time available. Unable to resolve the problem in the time available, an ad hoc LEP Subcommittee was formed with the charter to establish time allocations and priorities at the earliest possible date. The members are Dr. Ernest M. Henley, Chairman, Prof. Hans Frauenfelder, Prof. Arthur Kerman, Prof. David F. Measday, and Dr. Robert T. Siegel. This subcommittee held its first meeting at the Washington APS meeting on April 28, 1975. Recommendations were made for the scheduling of the first three run cycles after the Great Shutdown and relative evaluations of approved experiments were made. It was then decided to defer making additional time allocation and scheduling recommendations until its next meeting. This meeting will be held at St. John's College in Santa Fe, New Mexico on Sunday, June 8, 1975.

LAMPF Users Group, Inc.

User Activities

An HRS Working Group meeting was held in Washington, D.C. on April 27, 1975, with David K. McDaniels (Univ. of Oregon) chairing the meeting. The following agenda items were featured: Status Report on HRS Channel by James Spencer (LASL); Current Status of HRS Dipoles by T. Kozlowski

(BNL); Report and Discussion of Letters from N. S. Wall (Univ. of Maryland) and E. V. Hungerford (Univ. of Houston); and Review of PAC Meeting on Scheduling of Experiments.

The EPICS Working Group met in Los Alamos on February 27, 1975, and was chaired by R. J. Peterson. The meeting began with a summary of the present status of EPICS and the projected schedule by H. A. Thiessen (LASL). Mahlon Wilson (LASL) discussed the schedule as given by the PERT computer program. The PERT schedule for the spectrometer indicates that it should be complete (ready to receive beam) by January 12, 1976. John McMullen (Eng-6) discussed the plans for the emplacement of the spectrometer bending magnets BM-05 and BM-06 on the spectrometer frame.

Thiessen discussed some of the details of the progress with EPICS and outlined methods of carrying out the channel tune-up. According to the projected LAMPF schedule, there should be four months of beam time available between July and December, two months of which should be available for physics experiments in the channel. Proposals for four such experiments were presented by T. Wangler (BNL), C. F. Moore (Univ. of Texas), H. A. Thiessen (LASL), and L. W. Swenson (Oregon State Univ.). There was a discussion of the costs and benefits of carrying out such experiments in the channel while work on the spectrometer was proceeding.

The question was raised of responding to a PAC suggestion that this group should consider making recommendations on the priority of experiments scheduled on EPICS. It was decided to make no response at this time, but to ask members to form ideas on such a list so that some recommendations may be made at the next EPICS Working Group meeting.

Preparations are being made to handle the logistic and communications problems arising from the number of people from various groups who will be on site during the summer and fall for the EPICS tune-up.

The questions of the desirability of rotating the officers and TAP representative was raised. A motion was introduced and passed that the chairman and secretary will serve a single one-year term and the TAP representative a single two-year term. It was decided to hold the next meeting in Los Alamos immediately after the International Conference on High Energy Physics and Nuclear Structure in Santa Fe on June 8-14, 1975. The exact date will be announced later.

Board of Directors

The Board of Directors of the LAMPF Users Group, Inc. met in Los Alamos on March 21, 1975, with Chairman Herbert L. Anderson presiding. After a brief discussion, it was agreed that David A. Lind (Univ. of Colorado) should draft a letter to ERDA stating concern over the role basic research will play in the ERDA organization.

L. Agnew (LASL) will draft a letter to ERDA asking that consideration be given to reinstating the program of seed money for LAMPF users. This money was used by people in the past to come to LAMPF to work on approved experiments when they did not have AEC contracts.

H. Howard (LASL) reported on group health insurance for LAMPF users. After a brief discussion, it was decided that H. Anderson and H. Howard will draft a letter to LASL Director Harold Agnew explaining the concern and need for this benefit to LAMPF users.

The Board appointed Walter K. Hensley (Univ. of Rochester) as Safety Representative for the LAMPF Users Group, Inc.

The Nominating Committee for the upcoming election of officers was appointed and consists of Chairman Mark J. Jakobson (Univ. of Montana), Hans Frauenfelder (Univ. of Illinois), Jon Shoop (Univ. of New Mexico School of Medicine), and Klaus Ziock (Univ. of Virginia).

The Board discussed the format for the Annual Users Meeting. The program will include reports from other facilities, and an attempt will be made to get a speaker from ERDA. The organizing committee consists of H. Anderson (Univ. of Chicago), J. Allred (Univ. of Houston), V. Hughes (Yale Univ.), and L. Agnew.

Technical Advisory Panel (TAP)

The Technical Advisory Panel (TAP) of the LAMPF Users Group, Inc. met in Los Alamos on March 21, 1975, with Chairman Herbert L. Anderson presiding.

A report from the New Facilities Subcommittee was heard. Stanley E. Sobottka (Univ. of Virginia) gave the report on the EPICS channel, stating that the channel is on schedule and will be installed during the Great Shutdown. Alpha tests of the channel will be done during and after the Great Shutdown. The spectrometer will be delayed because of technical support to the channel, but it will be operational by January 1976.

Robert Chrien (BNL) reported on the progress of the HRS project. The field measurements on CBB are complete. A change of philosophy has occurred in that the multipole correction coils will be used between the dipoles instead of the H_t windings as originally planned. It is anticipated that the spectrometer installation will begin August 1, 1975. Data will shortly be available that can allow prediction of the instrument resolution.

There was a discussion with Louis Rosen, Donald C. Hagerman, and Lewis Agnew (all LASL) on progress of the Great Shutdown. the experimental areas are expected to be operational on September 15, 1975. The FY-75 budget is largely responsible for delays in the design work. Rosen stated that in order to get better continuity across group lines, an Accelerator Development Committee and an Experimental Area Development Committee have been formed to establish philosophies and priorities for the development of LAMPF. It is felt that reliability in the 201-MHz section is more important than the 12% duty factor at this time.

The TAP heard a report from V. Hughes (Yale Univ.), F. Beohm (California Institute of Technology), and P. Thompson (LASL) comparing the SIN superconducting channel and the LAMPF Stopped Muon Channel. Work will be started to determine if the Stopped Muon Channel parasite beam using forward decaying μ's can be used as a more intense muon channel with efficiency comparable to SIN's channel.

W. K. McFarlane (Temple Univ.) briefly reported on the work of the LEEP Subcommittee of the TAP. The subcommittee will review future purchases of equipment. Concern was expressed regarding the maintenance of equipment and on-line computers. New maintenance contracts are being negotiated.

Frank Shively (LBL) presented a report on the pair-spectrometer facility, stating that the intended improvements to the LBL pair-spectrometer might make it a generally useful device. If there is widespread interest in such a device, there might be a future request to use LAMPF funds for the improvements.

Peter Nemethy (Yale Univ.) reported on the Neutrino Facility. He said that the neutron background work was completed by three experimental groups: Yale/LASL, BNL, and the Univ. of California, Irvine. These December 1974 experiments determined that neutrino physics can be done at LAMPF and also fixed the final design of shielding. The TAP agreed with Nemethy's report and recommends that steel be provided and crafts be scheduled to complete the neutrino facility in the months following the end of the Great Shutdown.

The TAP briefly discussed the priority of physics experiments done on the Biomedical Channel. In light of the fact that the Biomedical Channel is funded by NCI and DBER of ERDA, the LAMPF policy is that biology and medicine receive priority on that line. The TAP concurred with this policy.

The following recommendations were made to LAMPF Director Louis Rosen by the TAP:

1. The New Facilities Subcommittee of the TAP should meet in mid-June 1975 to review the progress on EPICS and HRS. Benchmarks for EPICS that should be met by mid-June 1975 are:

   (a) The channel is to be entirely installed except for the shielding.

   (b) Assembly and testing of the first spectrometer magnet (BM-05) is to be completed and the magnetic field is to be mapped.

   (c) The magnetic fields of all three quadrupole magnets in the spectrometer are to be mapped.

Benchmarks for the HRS are:

   (a) A complete characterization of the CBB field, including fringe fields (which requires shimming and machining and attachment of nose pieces and field changes).

   (b) Completion of time-of-flight system.

   (c) Completion of HRS air and water supply.

   (d) Completion of the assembly area in Aisle D.

   (e) Completion of Area C shield door.

2. The recent magnetic field data should be distributed to HRS users with some indication of expected resolution if both dipoles exhibit field variations as observed in CBB. The users would be expected to respond with a statement as to whether or not such a resolution expectation is acceptable, and these opinions are to be factored into the final decision on when to mount the magnets. This polling of users would hopefully be completed at the time of the Washington APS meeting.

3. The TAP agrees with and endorses the exchange of approved proposals between LAMPF, CERN, SIN, and TRIUMF.

4. Pursuant to the documented studies, manpower and resources should be expended to develop the parasite beam on the Stopped Muon Channel as an intense muon beam for crystal spectrometer and other experiments.

5. The MP-Division LAMPF Experimental Equipment Pool (LEEP) committee should circulate to the members of the TAP and its LEEP Subcommittee the list of intended equipment purchases and an explanation of the choices made.

6. Steel should be provided and crafts be scheduled by LAMPF to complete the Neutrino Facility in the months following the end of the Great Shutdown.

7. The policy adopted by LAMPF concerning the scheduling of experiments on the Biomedical

Channel is reasonable and consistent with the source of funding for that channel and the practical considerations of mounting physics on that channel.

Liaison Office

The January issue of the LAMPF Users Group Newsletter was mailed to the entire membership.

Letters of invitation and arrangements were made for the following meetings: Board of Directors, Technical Advisory Panel, EPICS, and HRS. Minutes of the Board of Directors and TAP meetings were prepared and sent to members. Letters of instruction, with other pertinent data enclosed, were mailed to the members of the Nomination Committee.

Reminder notices were sent out to all 1974 members who had not returned a membership-renewal form. The names of people who did not renew their memberships were deleted from the membership list on April 1, 1975.

The May issue of the LAMPF Users Group Newsletter is being printed and will be distributed soon.

Visitors Center

During this report period, 28 users were received at LAMPF, and 32 users checked out. Currently there are 46 users at LAMPF. In addition, there are 19 guests on long-term assignments at LAMPF.

A Texas Instruments terminal was received and installed the first week of April. The KBT operator has received instruction in the mechanics of its use for word-processing activities, and is now sufficiently knowledgeable to begin operations. The extensive programming that is necessary to establish the visitor data base has been started, and it is expected that the program will be completed by the end of May. As soon as the programming is debugged, the Visitors Center statistics will be entered into the data base and maintained on the System 2000.

The LAMPF housing office has reserved dwelling units to fill 35 of the 50 requests that have been received so far from visitors expected this summer. In addition, all 20 of the kitchenette apartments, reserved for LAMPF users, have been allocated through the summer months.

A job order has been written to install a display case for the photos of LAMPF personnel and visitors. The display case is expected to be installed by the end of the next report period.

Meetings and Tours

Some of the LAMPF-related meetings that were held at LASL during this report period are:

3/20 – New Facilities Subcommittee of LAMPF Technical Advisory Panel

3/21 – LAMPF Technical Advisory Panel

4/4-6 – LAMPF Program Advisory Committee

Organized tours of the LAMPF facility were conducted for the following organizations:

2/1 – Interested public, sponsored by LASL

2/8 – Naval Regional Medical Center

2/19 – Santa Fe Vocational School

2/20 – Chambers of Commerce Goodwill group

2/25 – Women's Auxiliary of Albuquerque and Bernalillo County Medical Association

2/27 – North American Institute for Electronics

3/7 – Las Animas High School (Colorado) students

3/8 – Interested public, sponsored by LASL

3/10 – Local Chapter, American Cancer Society

3/24 – Merced College (California) students

4/9-10 – Advanced Development Conference attendees

4/18 – New Mexico Youth Awareness Conference attendees

4/23 – Borden Company employees

4/24 – Adams State College (Colorado) students

4/25 – American Association for the Advancement of Science Conference attendees

☆ U.S. GOVERNMENT PRINTING OFFICE: 1975—677-343/47