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Medium-Energy Physics Program

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Compiled by

Eleanor Dunn

Helen Wilson

los alamos scientific laboratory

of the University of California

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CONTENTS

GLOSSARY OF TERMS USED IN THIS REPORT

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

Experimental Area

Primary beam lines in experimental area:

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

Experimental beams:

Beam Area A:

BSA – Beam Stop A
EPICS – Energetic Pion Channel and Spectrometers
LEP – Low-Energy Pion Channel
Neutrino A

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

QUARTERLY REPORT ON THE MEDIUM-ENERGY PHYSICS PROGRAM

FOR THE PERIOD ENDING JULY 31, 1976

I. SUMMARY

Engineering Support

Over 101 000 socket hours were accumulated on the accelerator during this quarter. Five klystrons were rebuilt and 31 switchtubes were reprocessed. Design and development continued on the 1/2-MW, 201-MHz klystron for use as a replacement for the 4616/4664 gridded-tube family. The rf design and cold-test modeling are essentially complete, and final mechanical engineering has started.

Twenty-nine shock tube tests were conducted during the quarter to study shock-related damage to beam-line windows and harps. Emphasis continues to be directed toward the development of a fast-acting detector and valve for beam-line hardware isolation.

The EPA acceleration structures, together with their support structures and vacuum and cooling systems, were shipped to Yugoslavia. Refurbishment of the 100-kW and 1¼-MW amplifiers is nearing completion, and they should be ready for shipment during the next quarter.

Specifications and drawings for the EPICS spectrometer magnet installation were released for bid. Work preparatory to the installation is proceeding on schedule.

Fabrication of the alternating phase-focused, cold-probe cavity is nearly completed. Design work on the drift-tubes has started, and it is anticipated that the completed model will be ready for bead perturbation studies late in the next quarter. A permanent quadrupole magnet program is well under way, and work has started on a 1/2-MW, 450-MHz power source and a six-cell full gradient test cavity. Preliminary work was completed on testing the compatibility of a copper-bright plating to vacuum bakeout.

Approximately one-half of the group effort was directed toward support of the experimental program. Twenty-three experiments were actively supported during the quarter and 23 scintillation units and 9 wire chambers were constructed for experimental use.

Accelerator Support

A successful high-intensity run, and beam availability of more than 80% during production shifts, were major achievements this quarter. A strong maintenance program has insured excellent accelerator reliability.

Although failures of rf units continued to be of concern, there has been a substantial improvement over the last quarter. A detailed reliability report for both quarters is available from the MP-11 group office.

The processing of tubes, development of new equipment, and training of personnel continues at the 201-MHz test stand.

The short life of indicator lamps used throughout the accelerator has been a continuing annoyance to maintenance personnel. Tests indicate that a replacement lamp with a more reasonable lifetime may have been found.

The completion of the design for an 805-MHz solid-state IFA should result in prototype testing during the next quarter.

Extensive modification of all LAMPF standard power supplies has been completed; this should insure greater ease of maintenance and more reliable performance.

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

Accelerator Systems Development

Instrumentation development received major emphasis this quarter. Beam position monitor

(BPM) systems were installed at selected modules. A wire-scanner and phase-scan amplifier with four computer selectable gains was tested and computer codes prepared to measure beam profiles. The prototype low-momentum-component detector was installed and tested. Improvements were made to the Δt and feedforward systems.

Progress was made on understanding the plasma physics aspects of beam halos. Development of the SUPERFISH cylindrical cavity code continued, and comparisons with previous codes, test geometries, and experimental results were extremely good. Analysis of field distributions in the first tank of the 201.25-MHz linac continued; the experimental and numerical results still do not agree over the range studied.

Machine experiments included instrumentation checkout, investigation of steering in the 201.25-MHz linac and TR, tuning of the machine to handle peak currents of 10 mA to 800 MeV, and preliminary investigations of high-peak-current effects.

Data base development continued in a number of areas.

The biomed range shifter received increasing use, and a second-generation packaging proposal was prepared.

EPICS particle separator improvements enabled operation at the design level of 300 kV.

Work began on a hydraulic servoarm system for remote handling.

Injector Systems

Both injectors were operational all of this quarter and have provided the simultaneous H^+ and H^- beams needed for LAMPF operations. The injectors are still being operated with larger beam currents than required for present production runs; appropriate current limiting is being effected in the low-energy beam transport lines. Simultaneous production beams of 100 μA at H^+ and up to 10-μA-av H^- are being provided.

The H^+ ion source was replaced with a higher current model in order to study the operation of the LAMPF accelerator at the peak current required for 1-mA-av operation. Initial tests have been run with beam currents up to 14-mA peak accelerated at low duty factor. The beam quality at 800 MeV during these tests was unacceptable for production runs.

Work was resumed this quarter on studying the matching required at the first tank of the linac for high peak current, fully bunched beams. The experimental results empirically obtained for the required matching parameters for these beams do not agree with results of beam envelope codes. More detailed beam transport calculations using PARMILA are being started. The beam envelope calculations appear to be correct for the 2-mA production beams now being run.

The automatic arcdown recovery circuits have been desensitized and appropriately filtered from transients and now function as expected without spurious trips.

The 1-in-10 pulsing system on the H^+ injector has been expanded to provide additional attenuation of the low current pulses by using simultaneous pulsing on the H^+ chopper plates. This modification permits the 1-in-10 pulsing mode to supply nA peak current pulses to the linac and to provide up to six orders of magnitude attenuation of the H^+ beam in this mode.

The H^- ion source was removed and the extractor parts replaced. These components had been in service for seven months and showed the same hydrogen embrittlement damage previously observed. No other component failures in this source were experienced.

Electronic Instrumentation and Computer Systems

The first prolonged failure of the control computer occurred last quarter. Out of this experience came the criteria for a rudimentary backup system.

The shell for the third operations console was brought out of storage and located in a working area near CCR. Programming for the microprocessor-controlled-function button panel was partially completed. A specification was developed for the new knob/readout panel interface. Design work was started on the keyboard interface. A second CAMAC crate was installed on the control computer to hold the ASCII bus controller module for the console.

The mechanical assembly of the second-generation master timer was partially completed. Progress was made on the electrical checkout and programming for the unit.

The NOVA computer software for the polarized ion source was integrated with the interface hardware and successfully tested with the new console hardware and data terminal.

The emphasis of software developments was on programs to aid operations. The program for recording the integrated beam current in the main beam line was put into operation. Several improvements were made in the magnet setting program. The transmission monitor software was revised to provide a simpler, more unified operator interface and a greater degree of automation. An application of the control vector software to the TR was demonstrated.

A major effort was mounted to design, build, and check out the controls needed to operate the remote-handling system called Monitor.

Work was completed on the control system for the EPICS separator. This system includes a voltage/current crossover regulator and various protective circuits.

The installation and checkout of controls and instrumentation for Line C culminated in the successful transporting of beam to the Line C beam dump.

A host of new speakers and intercom stations were added to the communications system in response to continuing requests for equipment.

The last components for the two new PDP-11/45 computers for LEEP arrived and the systems were put into operation.

A new version of the general data-acquisition package, Q, was released in July. It contained the buffered MBD code requested by users and a more powerful version of QAL for writing event analyzers.

A major collaboration with the LBL was launched with the objective of making Q available under RSX-11M as well as under the current RSX-11D systems at LASL.

A total of $75 000 in capital equipment funds was allocated to LEEP for FY-76T and was immediately invested in items of equipment in short supply.

Three sessions of the Electronics Perspective Seminars were conducted to help the technical staff stay abreast of advancing technology. Over 100 people attended each of the sessions.

Accelerator Operations

The accelerator was in continuous operation throughout the quarter. The machine was operated in three-week cycles: typically with two weeks devoted to research, and the remaining week used for facility development and maintenance.

H^+ beams delivered to Experimental Area A for research increased steadily in intensity, from 20 μA during cycle 2 at the start of this quarter to 75 μA during cycle 6 at the end of the quarter. Machine availability during research shifts averaged 81% for the H^+ beam and 82% for the H^- beam.

The EPICS beam channel was added to the list of active experimental facilities early in the quarter. In HRS, proton beams were tuned to the beam stop and particles were detected in the spectrometer.

Research quality proton beams to Area A totalled 59 300 μA-h during the quarter, as measured at the A-1 target station. An additional 750 μA-h went to Area B. The combined total is three times the cumulative total of all beams delivered to experimental areas prior to this quarter. Fifty-two experiments received beam.

Machine time allotted for facility development was used for the study of beam transport problems in the drift-tube linac and the TR, attempts to accelerate high peak currents, testing of prototype BPMs, and the development of a wire-scanner amplifier with variable gain suitable for the study of beam halos.

In Experimental Areas A and A-East, development efforts were concentrated on achieving beam tunes suitable for operation at 100-μA-average currents, considering limitations imposed by heating effects in vacuum windows, activation of beam line components, and experimental requirements. A start was also made on the development of beam tunes suitable for simultaneous operation of Lines B and C.

Machine operation continued to be reliable and stable despite the increased beam intensity. Another significant improvement in reliability of 201-MHz systems was noted. The first major outage of the control computer occurred during this period. The accelerator was kept in operation at 10-μA-average current instead of the scheduled 50 μA during the three days the computer was out of commission.

Experimental Areas

Emphasis during the past quarter has been placed on maintaining high availability of the secondary beams and research facilities. Substantial direct support of research and experiment setup has been given.

Hardware and shielding changes needed for the new beam cave at SMC-East are nearly complete. Permanent cable packages are planned for SMC, LEP, and P^3 cave-to-counting house routing. A new vacuum valve, an absorber system, and a bigger vacuum pump are all ready for installation at SMC.

The LD_2 target in Area B was repaired and reinstalled. Vacuum system improvements were made in the Area B nuclear chemistry cave.

A number of minor shielding improvements have been made. The redesign of the shield wall near EPICS is complete and the special concrete blocks are on order. Satisfactory operation of the Merrimac shield door has been experienced; new hydraulic trucks and rams have been received.

The Area Manager's Office has been moved into less crowded quarters. A general organization of the outside service yards and storage areas has been carried out.

Support for cryogenic target systems continues at a high level. Early preparations for a tritium target system are under way.

The radioactive water systems are operating reliably. Three new systems are now in use. The radioactive air exhaust system was placed into service.

The Monitor remote handling system was brought up to operational readiness and used in repairs of the A-2 target system during July. Servoarm, the hydraulic nonforce-reflective servomanipulator system, is fast, agile, and accurate. However, it is still a prototype device; a number of improvements are under way. Satisfactory progress is being made on the new two-arm master-slave force-reflective system now on order.

Beam Line Development

Much of the primary beam line development was directed toward achieving reliable operation of Line A at the 100-μA level. Transverse phase-space measurements of the linac beam can now be made routinely in Line A Direct. The results are used to calculate tunes of Line A. The calculated tunes need only a small amount of empirical tuning on-line to produce the production beam. Tunes have been tested with 100-μA beams for several hours of running during development time. Tests with the Line A isolation windows removed indicate that spills in the SY and at the A-4 tunnel will be reduced by a factor of 8-10 when these interim windows are removed for cycle 7.

Methods for achieving compromise tunes of the A-5 exit triplet for the two normal conditions of the A-5 target have been developed. Satisfactory tunes have been developed which keep the spot size at the A-6 window large enough to avoid excessive window temperatures and which avoid large spot-size changes at the A-6 beam stop.

A slit method for measuring the H^- vertical phase-space distribution in Line X has been successfully tried.

Tuning of Line X for Line C input beam requirements has progressed to the point of providing satisfactory pencil beams as well as $\pi/10$ cm-mr beams for initial Line C/HRS tuning. The beam which lies outside the Line C admittance is removed by various strippers upstream of the start of Line C.

Changes have been made to the Line A transmission monitor to improve operator interaction. Line A harp improvements which were evaluated include 0.1-mm silicon carbide monofilament were with a 0.03-mm carbon monofilament core, and a solid alumina card for the large harps. Both improvements will be incorporated in future replacement harps. A new rad-hardened current transformer has been developed for the new A-1 profile monitor.

Tuning and optimization of the SMC-East pion beam has been under way in collaboration with CalTech and Yale user groups. At this time the best stopping pion rate is 2×10^5 $\pi/(\mu$A-s g/cm$^2)$ in a 5-cm by 5-cm target. Results indicate that both the intensity of beam and the background will be adequate for the π-mesic x-ray experiments using bent crystal spectrometers.

Large-Spectrometer Systems

Energetic Pion Channel and Spectrometer

The assembly power testing of the first spectrometer dipole (EA-BM-05) was completed, and construction of the second magnet was begun. A major improvement in the vacuum system resulted when a LN_2 cold trap was installed at the separator box. Beam time was made available for three experiments, with running completed on two, Exps. 130 and 246.

High-Resolution Proton Spectrometer

Beam Line C and the HRS spectrometer were brought to the level of completion necessary to run beam to the beam stop during the last week of July. Tuneup and debugging of the detectors and electronics started during this run and will continue into the next quarter.

Research

This report covers contributions of user groups, other LASL groups, and MP-4 relating to research carried out at LAMPF and received by July 31, 1976. We wish to acknowledge the fine cooperation of the writers, and apologize in advance for whatever mistakes in content and form we have injected.

The collaboration between LBL, LASL, ORNL, BNL, and Texas A&M Univ. working on TOF studies of proton-induced nuclear reactions and working with a thin uranium target in the LAMPF TTA have recently implemented a new TOF system. The new detection system results in greatly improved mass resolution. A new isotope, ^{31}Mg, has been identified by this technique in the fragments from uranium.

The experimental results on direct electron production at LAMPF energies have been accepted for publication in Phys. Rev. Lett. The data show no direct lepton production at LAMPF energies, which, taken in conjunction with the results at high energy, indicate a threshold for this process.

Further experiments on parity violative effects in low-energy proton-nucleus scattering have led to an improved value for hydrogen and the first result for deuterium. The results are consistent with a null effect in both hydrogen and deuterium with a standard deviation of about one part in 10^7. The results are still consistent with the theoretical estimate of Brown, Henley, and Krejs, who predict a value of about one part in 10^7 for hydrogen, but the new upper limits are so stringent as to press hard on recent theoretical suggestions designed to reconcile the large value reported for the circular polarization of the γ ray from the capture of slow neutrons in hydrogen.

New weak-field measurements of muonium hyperfine splitting, $\Delta\nu$, and of the mu-magnetic moment, have been carried out by the Yale group. It is expected that $\Delta\nu$ should be determined to three in 10^7 and μ_μ to one in 10^6 by this work. Strong-field measurements have been made and are being analyzed.

Nuclear Chemistry Research

Nuclear chemistry studies involving protons, other than the thin target work already mentioned, include those related to fission, spectroscopy and isotope production. The work on proton-induced fission of silver, gold, and uranium, employing the mica detector technique, is almost complete. Aside from the intrinsic interest in the proton-induced fission studies, the detector technique is being thoroughly developed before proceeding to the pion-induced-fission phase of the work. The nuclear spectroscopy work is a collaboration between LASL and INEL (Report ANCR-1284). The decay scheme of some 11 different isotopes has been studied since beam has been available in Area B and many new γ lines have been observed. One important aspect of the work has been the clear demonstration of many errors in existing literature. The effort relating to isotope production has continued to develop new production techniques. This work has been biased toward biomedical interests, an example of which is the ^{82}Sr - ^{82}Rb generator. The ^{82}Rb is used in heart infarction studies.

Since the end of the great shutdown in April, much progress has been made in the π and μ nuclear chemistry experiments. In addition to the studies of π-absorption chemical effects already mentioned, Exp. 42, on the lifetimes of muons bound to actinide nuclei, appears to have demonstrated that the quoted lifetime difference as determined by detection of fission fragments compared to μ-decay electrons is now existent.

The π-activation experiment (Exp. 67) which previously established absolute cross sections of $^{12}C(\pi^{\pm},\pi N)^{11}C$ [Phys. Rev. Lett. **34**, 821 (1975)] has turned to the measurement of other reactions, using the above reaction as a reference standard. At the higher fluxes now available from LAMPF, several other reactions are available for study and for future use as π beam flux monitor standards and are of interest to people measuring absolute cross sections for other processes, making cross-checks with other laboratories, helping with beam-composition studies, etc.

Substantial time has been devoted to the pion nuclear-chemistry efforts on LEP and P^3. Preliminary results were obtained for the cross sections for the production of ^{18}F and ^{24}Na from aluminum and ^{24}Na from silicon by π^+ induced reactions. The errors are estimated to be ±10% or less. The ^{24}Na excitation functions for both aluminum and silicon targets appear to have essentially the same shape and show a peak near the free nucleon-pion (3,3) resonance. In contrast, the excitation functions for $^{27}Al \xrightarrow{\pi\pm} {}^{18}F$ reaction involving the removal of nine nucleons appear to be flatter and fall off less rapidly at the lower energies, indicating a greater washing out of the effect of the resonance. The relatively high cross section for this reaction and its small sensitivity to π energy make it a very desirable π-beam-monitor reaction.

A study of the products resulting from π irradiations of medium and heavy-mass nuclei has been run in the LEP channel. Copper and tantalum targets were given timed exposures to a stopping π^- beam, and then removed to a low background environment, where they were counted with a high resolution Ge(Li) γ-ray spectrometer. The yields were thus determined for 21 isotopes. They are in reasonably good agreement with numerical calculations using a cascade code followed by an evaporation code. Some long-lived activities in the tantalum are still being counted.

A survey of π-induced activities at the (3,3) resonance energy is being carried out by irradiating a variety of medium-mass isotopes (14 so far) with π^+. As of this writing, nine spallation product activities have been analyzed, with activation cross sections ranging from 5 to 9 mb.

Of particular note is that five separated isotope targets have been successfully used at thicknesses as low as a sparse 3 mg/cm.

Nuclear Chemistry

For the Nuclear Chemistry Laboratory counting rooms, design work has been completed and fabrication started on the control module and CAMAC interface for the new dual parameter Ge(Li)-Ge(Li) γ-γ coincidence system. One of our three Ge(Li) detectors failed and had to be sent out for refurbishing. A new Canberra 8100 pulse-height analyzer has been received and, by means of a CAMAC interface, will be controlled by and deliver its pulse-height information to the magnetic recording units of the Data-Acquisition System (DAS).

Significant progress in software development for the DAS has resulted in a program to operate the CAMAC scaler-timers and one to control the Canberra analyzer. The hardware problems with the TEC terminals appear to have been resolved with an extra cooling fan.

A special 102-mm-diam branch of the pneumatic "rabbit" system has been activated to transfer targets from the Nuclear Chemistry Cave to the Hot Cell. Development work on the main 76-mm-diam system has continued, with special emphasis placed on getting into operation the Energetic Neutron Station at the A-6 beam stop. The "snake" or "rabbit" stop was completed and the drive mechanism for remotely controlling the stopping location of the "rabbit" was installed.

The second meeting of the experts to review the status of the current version of the VEGAS intranuclear cascade code (ISOBAR) was held on May 15, 1976. It was concluded that three possible inclusions or modifications to the VEGAS program be studied: 1) stopped pion interactions, 2) coherent charge exchange as a nucleon moves through the nucleus, and 3) fission as a mode for the possible breakup of the residual nucleus after the fast cascade. For the absorption of stopped π^- on nuclei, a model is being developed which assumes the pion is absorbed on a pair of nucleons that then proceed to cascade through the nucleus.

Practical Applications of LAMPF

In the LAMPF biomedical program the biomedical pion channel was operated for a number of experiments concerned with radiobiology, dosimetry, therapy beam development, and microdosimetry. Two human patients were treated with negative pions to compare the effects of pions and x rays on metastasized skin modules. Considerable progress was made in developing pion beams with relatively uniform large-volume stopping distributions. There are now considerable data on pion beams spread in depths of up to 10 cm with a dynamic range shifter. Dose model calculations are improving in accuracy.

Several experiments were performed using muonic x rays to determine the elemental concentration of biological samples and core samples from oil-bearing formations. The proton radiography concept has advanced to the stage of a LAMPF experiment proposal.

Management

A major policy change has taken place at LASL that affects visitors to LAMPF. The LASL administration has formed a Housing Office which will be administered by the LASL Personnel Department. This policy change was deemed necessary to alleviate the overall housing problems the Laboratory faces with respect to LASL visitors. In the past, the LAMPF Visitors Center Housing Office has interfaced directly with all visitors to MP-Division, of necessity. However, housing assignments by MP-Division personnel will now be limited to the 20 kitchenette apartments reserved, on a priority basis, for LAMPF users who are setting up, running, or dismantling experiments.

Papers Prepared for Publication: Papers Submitted at Conferences

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M. B. Johnson and M. D. Cooper, "Improved Analysis of Coulomb-Nuclear Interference Experiment for Pions on ^{16}O," presented at the Intern. Topical Conf. on Meson-Nuclear Phys., Carnegie-Mellon Univ., Pittsburgh, PA, May 24-28, 1976.

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II. ENGINEERING SUPPORT

LAMPF Accelerator

Accelerator Support

Seven beryllia waveguide windows which failed in accelerator service have been returned to the vendor for failure analysis and repair. Alumina blanks which could be used for in-house window fabrication have been ordered and received.

Aperture cards for the engineering support drawings are being obtained. It is hoped that the use of these cards, with a card reader, will reduce the handling of the drawing originals. Information from these cards, plus added information from the drawings, is being placed into a file. It is anticipated that when this information is sorted into categories, the search for a particular drawing will be minimized.

Approximately 15% of the total fabrication section manpower effort and over 25% of the hydrogen furnace heats were devoted to accelerator support.

805-MHz RF System

The VA-862A klystrons have accumulated over 798 000 fh with 11 failures, and the L-5120 kystrons have more than 144 000 fh with 10 failures. Two VA-862A klystrons, S/N-207 and -245, and three L-5120 klystrons, S/N-2021, -2023, and -2031, failed in the quarter. The average age of the VA-862As in service is 16 195 fh and the average age of the L-5120s in service is 7270 fh.

Twenty-two of the VA-862A klystrons and two of the L-5120 klystrons remain in the same module where they were installed during accelerator construction.

The klystrons were operated for a total of 101 235 fh in this quarter. Seven klystrons and 31 switchtube triodes were replaced on the accelerator. The LPT-44 triodes have now accumulated more than 923 000 fh, with 31 requiring reprocessing during the quarter. Eleven of the 25 triodes on order have been delivered and acceptance tested.

A gasket has been designed to prevent water, resulting from collector or body leaks on the klystron, from entering the modulator, and a few are being fabricated for testing. The new gasket will require a new pole piece on the klystron and this part has been designed.

Klystron Repair Facility

Three L-5120 klystrons, S/N-2021R1, -2023R1, and -2031R1, and two VA-862A klystrons, S/N-238R1 and -245R1, were rebuilt in the quarter. Two of these klystrons were fully tested to $1^1/_4$ MW; one is being tested, and two are awaiting tests.

An ion pump on the bake-out oven is currently being used in the rebuild process, and the pressure at the pinch-off is now consistently lower than with the turbomolecular bake-out pump previously used. The installation drawings for the rinse tanks have been approved, and the installation will begin soon.

201-MHz Klystron

Design and development work on the 201-MHz klystron is continuing. Cold testing of all five cavities was completed during the quarter. The necessary loop sizes were determined empirically for the input and output cavities, and the tuners for the first four cavities were designed. One prototype cavity tuner has been fabricated and is being assembled in preparation for testing. The large diameter stainless-steel tubing and most of the OFHC copper forgings have been received and are being used by the main shop to fabricate one cavity for the klystron. This klystron will fit on the present modulator, although a new lid and solenoid will be required. The design effort and drafting are nearing completion for the input cavity, which also functions as the attachment point for the electron gun. With the rf design now completed, a considerable amount of mechanical design remains to be accomplished.

Experimental Lines

Area A

The low-momentum detector has been completely assembled and successfully checked out in the SY. Figures II-1 and II-2 show exterior and interior views of the assembly.

Twenty-nine shock tube tests were conducted during the quarter to determine shock related effect on windows and harp wires, investigate methods of sensing the wave front, and testing of fast-acting valves for hardware protection. Shocks of velocity of 1100 m/s were found to damage harp wires. Window fragment velocities were determined to be over 300 m/s.

Sensors including spark plugs, 2-ℓ/s ion pumps, and the SLAC trigger all actuated before the disturbance damaged adjacent wires.

A flapper-type check valve, closed by the inrush of air, was tested. Although its operation was fast, it was not sufficiently rapid to prevent damage to the carbon-filament or silicon-carbide harp wires.

The high-speed valves have been adjusted for higher speed and will be installed in the switchyard.

A blower package has been purchased for use on the SMC, and a standard vacuum, roughing-pump package has been purchased for an Area A spare.

A new design turbomolecular vacuum pump (featuring air bearings and requiring no forepump for line pressure less than 10^{-3} torr) has been installed on a spare port at the A-3 pumping station for evaluation purposes.

Line C

The scattering chamber centered over the pivot point was aligned.

Preliminary positioning of the large detector downstream of magnet CBB was done by the alignment section. Final alignment will be required when the remaining parts of the system have been installed.

Weapons Neutron Research Facility — Line D

All but 4 of the 24 steering magnets, designed and fabricated in-house, have been completed, tested, and delivered to the site for installation.

Eight of the 10 tunnel quadrupole magnets downstream of the waterfall were aligned. Wire scanners and the steering magnets received final alignment. The alignment phase is essentially complete through the end of the tunnel section of the beam line.

The support structure for the three 30° bending magnets is presently being positioned using measurements relative to the beam-line axis and target point. One of the two 30° vertical bending magnets for the WNR experimental area was processed in the tooling dock in ETL. Tooling hole locations and magnet dimensions with respect to the aperture were recorded for future alignment purposes.

After installation, electrical connection, and water hook-up, all ten of the tunnel quadrupole magnets as supplied by the vendor exhibited two significant problems: 1) numerous cold solder connections were found on the interconnecting bus between the coil sections, and 2) the coil clamp design was such that a very high localized load was placed on the conductor insulation where it exited from the coil section, making future ground faults a very real possibility.

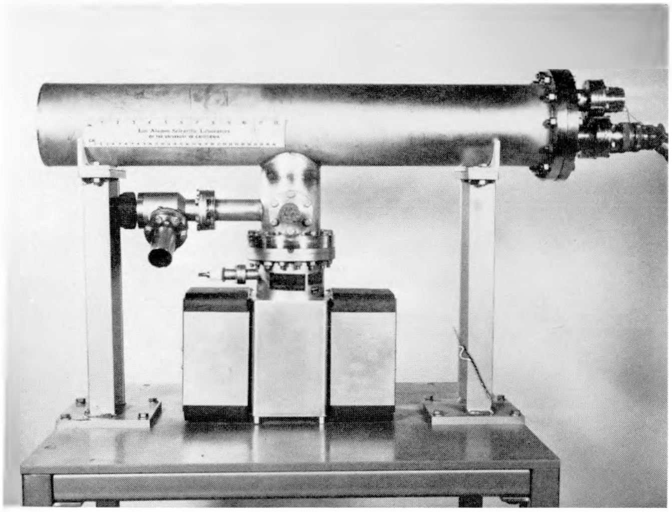


Fig. II-1.
Low-momentum detector — external view.

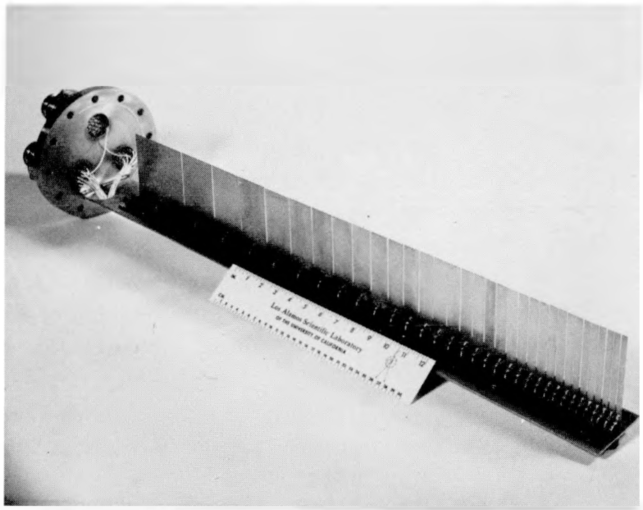


Fig. II-2.
Low-momentum detector —internal assembly with high-voltage shield removed.

To rectify this situation, each interconnecting bus was removed, tinned, and resoldered. The coil clamps were modified, insulated, and reinstalled.

Energetic Pion Channel and Spectrometer

Specifications and drawings for the EPICS spectrometer magnet installation contract have been released by ERDA with a bid opening date scheduled for August 17, 1976.

The field clamps for the first EPICS spectrometer magnet, EA-BM-05, were aligned and bolted to the magnet core.

Two spectrometer magnet coils, EA-BM-05 and -06, and three quadrupole magnets, EA-QM-01, -02, and -03, are being prepared and undergoing preinstallation testing. Coils for the four bending magnets have been tested, as well as one of the two spare coils. The coils were impulse tested to assure that no turn-to-turn shorts existed, and each water circuit was flow tested to check for obstructions or restrictions. All thermal switches were tested for proper operation and temperature range, and were installed.

The three quadrupole magnets are undergoing essentially the same tests with the exception of impulse testing. However, all coil sections are being hipotted to verify that no coil grounds exist. All three quadrupole magnets were processed in the tooling dock. Field clamps were accurately positioned with respect to the bore, marked with the magnet designation, and doweled in position. Reamed tooling holes for in-place alignment were inspected, and adaptor mounting plates were fabricated and installed where required. Quadrupole magnet EA-QM-02 has been completed, painted and delivered to the EPICS area in preparation for installation.

An elevation matrix survey of the new EPICS spectrometer floor indicates certain areas are not within the specified tolerance. Load movement tests conducted with a 31 750-kg dummy load and a prototype air bag reveal problems associated with floor discontinuities. While waxing provided a noticeable improvement, the tests indicate that the floor must be ground to the proper tolerances to permit proper operation of the air bags. Grinding of the floor is now in progress. Rework of the spectrometer frame is now in progress with the modifications ~90% complete. Air bag subassemblies are presently being fabricated.

Biomedical Beam Line

Slit #2 was positioned in the beam line and has been used in conjunction with Slit #1 during operation of the beam line this quarter.

Temporary provisions were made to support a beryllium wedge inside the Slit #2 assembly at the plane of symmetry. Three different beryllium wedge designs were fabricated for use with different beam line tunes. These wedges require manual installation and are a temporary solution until the second-generation wedge configurations are established and a remote wedge changer can be designed and fabricated.

The cowl covering the last magnet in the treatment room was temporarily installed for assembly checking, final fitting, and adjusting of the supporting structure. It was left in the treatment room during the present operating cycle, and installation work will continue when access to the area permits. After the assembly and adjustment have been completed, the cover panels will be removed to permit installation of the quick-acting fasteners and panel rails, and application of the painted finish. The unit will then be ready to prepare the rack panels for cable connectors.

Spare flanges for the biomed triplet helium chamber, with stretched 0.08-mm aluminum windows in place, are complete and ready for installation in the event of any damage to the windows now in service.

Adjustable drive shafts for Slit RT-SL-01 have been fabricated to permit accurate timing of the jaw position potentiometers and to determine the actual jaw location. The lift fixture for Slit RT-SL-01, to permit remote handling, is ~90% complete.

An adjustable base assembly for the cooled-water phantom and its related detector was completed, installed, and put into service.

Electron Prototype Accelerator

Refurbishing of the twelve accelerator tank sections, the graded β tank, and three bridge couplers was completed. These accelerator structure components, along with support structures, vacuum systems, cooling-water systems, and miscellaneous parts were packaged and shipped from LASL on June 25, 1976 to Yugoslavia. This shipment also contained adequate vacuum seals, nuts, bolts, and tools to facilitate reassembly.

The rf power amplifiers which were used on EPA are being rebuilt and tested. The 100-kW klystron amplifier has been satisfactorily tested. The 4KM70LA klystron had to be straightened, having been damaged during the dismantling of the EPA. The 1.25-MW klystron modulator has been tested with one of the developmental L-5120 klystrons and solenoid. This klystron (S/N-2005) was tested up to 1.75 MW and performs well. One more klystron and solenoid will be tested; then the test stand will be available again for processing the rebuilt VA-862A and L-5120 klystrons.

Pion Generator for Medical Investigations (PIGMI)

Two steel and one aluminum, single-cell, copper-plated, 1350-MHz cavities were electron-beam welded into vacuum-tight assemblies. These cavities are now being tested to determine their rf characteristics.

Design is continuing on PIGLET (six-cell, 450-MHz, 5.0-MeV/m powered model) in a manner which will incorporate some final design ideas into a model as quickly as possible. Stainless-steel pipe for the PIGLET cavity and OFHC copper bar stock for drift tubes are on hand. A test cavity for Q measurement studies is being fabricated utilizing bright acid copper-plated stock components. A vendor has been located with the capability of bright copper plating the PIGLET vacuum tank (0.41-m o.d. by 1.22-m long).

Two pieces of metallized ceramic are on order for use in rf vacuum window development.

Machining of the alternating phase-focused (APF), cold-probe cavity is nearing completion. When the drift-tube parameters have been established and the drift tubes constructed, this cavity is scheduled for very extensive bead perturbation studies.

A modest, but continuing, modeling program was conducted on a series of permanent quadrupole magnets. The goal is to design magnets with gradients of sufficient magnitude, and of the required harmonic quality, to be acceptable for use in the drift-tube portion of the PIGMI accelerator. A series of four permanent magnet geometries, with full circular poles magnetized across the diameter, and with pole-radius to bore-radius ratios of 1.00, 1.15, 1.30, and 1.45, have been studied (Fig. II-3). Permanent magnet poles of oriented barium ferrite ceramic and alnico V were supplied in the charged, stabilized (open circuit) condition by the vendor. Ultimately, our investigations will include poles charged on assembly in order to achieve maximum gradients; however, this feature will require special charging equipment and more elaborate magnet geometries.

The following field measurement data is for the series of permanent quadrupole magnets using ceramic poles:

TABLE II-I

PERMANENT QUADRUPOLE MAGNET PARAMETERS

	1.00	**1.15**	**1.30**	**1.45**
Gradient (T/m)	19.5	24.5	29.5	35.1
Bore Radius (mm)	9.64	8.38	7.41	6.65
Quad Strength (T)	0.378	0.444	0.512	0.605
Magnet Length (mm)	15.0	15.0	15.0	15.0
Effective Length (mm)	19.4	18.1	17.3	17.2

Pole Rad. = R_p
Bore Rad. = R_B

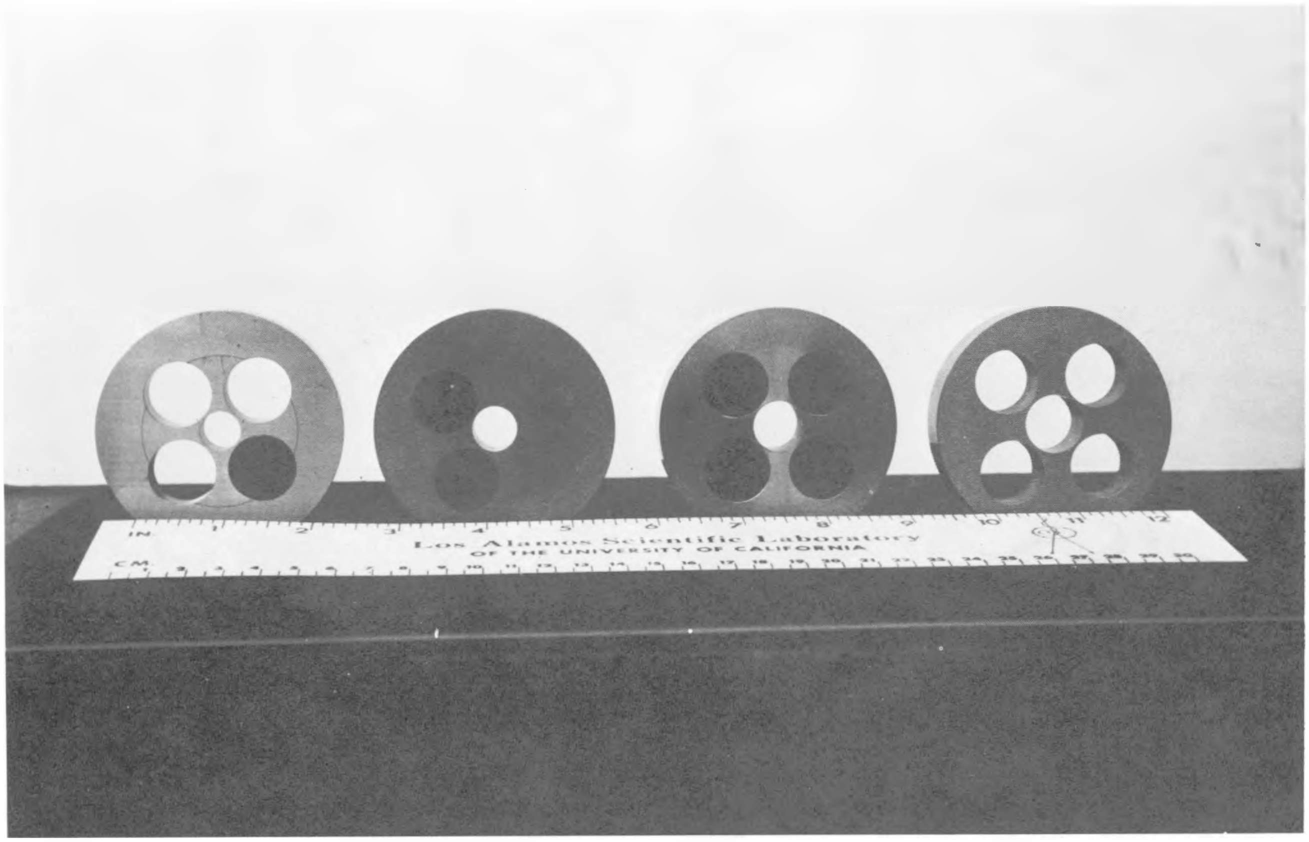


Fig. II-3.
Prototype permanent quadrupole magnets.

Experiment Support

Approximately one-half of the group effort was devoted to the support of LAMPF Users during this reporting period. This support was provided in the form of engineering, drafting, fabrication, and field assistance to Users by technicians and experiment engineers.

The particular experiments (23 total) that received, or are presently receiving, significant support are as follows:

Exp. 2/164 (LEP). This experiment was dismantled and removed from the LEP cave. The DISC counter and cryogenics chamber raising and lowering mechanism, designed and fabricated in-house, was placed in temporary storage at ETL.

Exp. 4 (HRS). Engineering was started on a platform required for the support (~2.4 m above floor elevation) of two vacuum pumps and an instrument rack. Support columns, from the pool of stands and structures being maintained by the group, were selected for support of this platform at the HRS scattering chamber. Fabrication was completed of a special rack to hold four gas bottles required for this experiment.

Exp. 25 (LEP). Fabrication of a detector chamber support rack, made from aluminum channel and angle, was completed.

Exp. 28 (LEP). Engineering and fabrication support is being furnished. This consists mainly of modifying an aluminum scattering chamber to make it suitable for the upcoming experiment and providing a stand to position the chamber at the proper beam height.

Exp. 31 (Neutrino Area). Field engineering in this area continued. Needed were modifications to stands and the water-circulation system and the design of a shielding lid as required to allow for the placement of additional shielding in the Neutrino experimental area.

Exp. 29/54 (LEP). Phase I of this experiment, which has been completed, received engineering and fabrication support for the target-holder system used

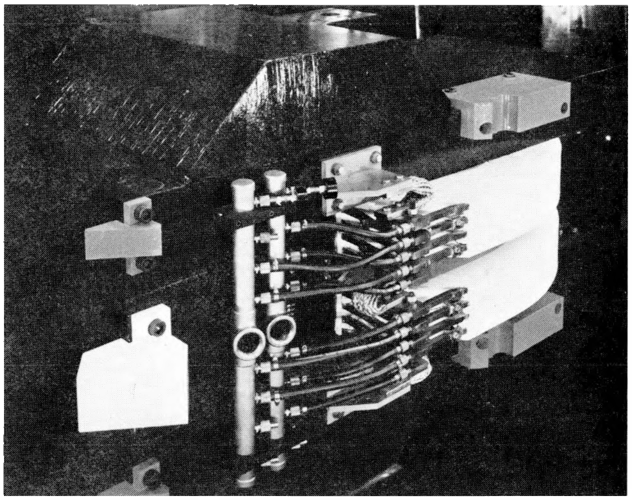


Fig. II-4.
Bicentennial spectrometer magnet.

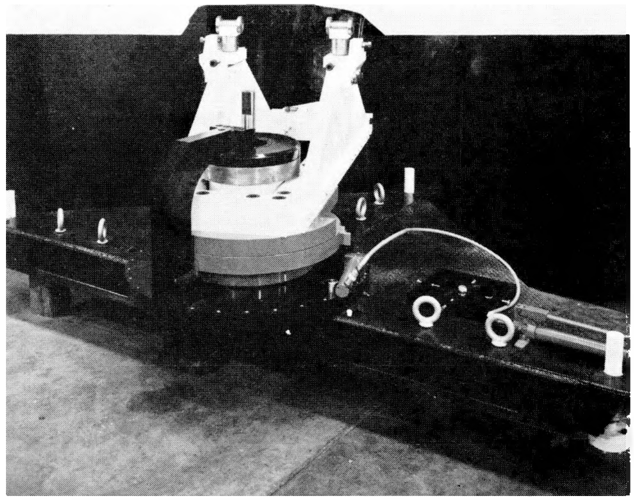


Fig. II-5.
Bicentennial spectrometer stand.

during this phase. Phase II of this experiment, scheduled for next fall, is presently being supported in an engineering, drafting and fabrication effort. The Bicentennial 6800-kG magnet (Fig. II-4), and its spectrometer stand (Fg. II-5), have been reported previously. The assembly of the magnet (iron, coils, water manifold, and coil terminals) is over 90% complete. Remaining to be assembled is a vacuum chamber at the magnet pole face. This vacuum chamber is presently under fabrication, with completion expected within the next four weeks. An extension to this chamber is being designed, and the design of an aluminum structure for supporting detector chambers on the magnet was completed and fabrication started.

Exp. 50 (LEP). Engineering design is under way for the air-pad platform needed to move the twin C magnets. (They exceed the Area A bridge crane lift capacity.) Air pads are on order, and detail drafting of the air-pad structure is now being done in preparation for ordering shop fabrication of the rest of the platform system.

Exp. 65/66 (Area B). Engineering design of a stand for the magnet (being furnished by P-DOR) was completed. Detail drafting and fabrication will follow Users' approval of the design concept. This stand and magnet will be positioned at the pivot point of the spectrometer stand, which is presently mounted in Area B for Exp. 262. Both the magnet stand and the movable spectrometer stand will then be used as a system for Exp. 65/66.

Exp. 90 (P^3-East). This experiment was mounted, using in-house designed and fabricated stands, for support of the target chamber and electronics racks. This apparatus was reported previously; however, it was during the past quarter that the field support for this experiment was furnished throughout its two-week scheduled mounting period. Alignment support, mechanical technician support, and field engineering were furnished.

Ex. 93 (P^3-East). Design was completed and fabrication was started on an adaptor for the support of the Users' target chamber. This adaptor is to allow the support structure presently in use on Exp. 90 to be used for this experiment. Also under fabrication are four detector chamber support stands for attachment to the Kon-Tiki spectrometer platform.

Exp. 130 (EPICS). Field support for this experiment was primarily in the form of handling and gas filling of the large aperture Cerenkov chamber used as part of the experiment. The chamber was removed from the EPICS cave after its use and has been stored at ETL. This chamber, and its mirror system, has been reported earlier as its design and fabrication was being carried out.

Exp. 176 (EPB). Field support was furnished for the mounting of this experiment, essentially in the form of vacuum-systems engineering and beam pipe modifications.

Exp. 179 (Line B). This experiment received alignment assistance and the engineering and fabrication of a new ion and detector chamber for attachment to the existing scattering chamber.

Exp. 181 (LEP). Support of this experiment is presently in the form of engineering and drafting of a

II° spectrometer array (presently ~80% complete). Purchasing of components such as linear bearings, gears, hand wheels, and special structural shapes has been carried out, and these items are now on hand ready for fabrication. The support structure for the leaded glass/photo-tube assembly has been designed and analyzed structurally in preparation for release for fabrication.

Exp. 200 (EPB). Design engineering support, vacuum testing, and fabrication assistance were furnished during the construction of a high-vacuum scattering chamber, which is to be placed in the EPB Line following Exp. 124.

Exp. 221/222 (P^3-East). Engineering was completed for the hodoscope magnet-support structure. The attachment hardware for the chambers to be attached to this magnet is presently under fabrication.

Exp. 262-3-4 (Area B). Field engineering and technician assistance were furnished for the mounting of this experiment. This included the installation of new cable trays and the fabrication and installation of anchor plates to assist in the moving of the air-pad-supported spectrometer stand through its swing angle.

Miscellaneous Engineering Support

Fabrication Activities

The fabrication section processed and completed over 75 jobs ranging from technician support for experiments, fabrication of beam pipes and vacuum chambers and hydrogen brazing of accelerator components, to hydrogen bakeout of klystron cathodes and mod anodes. Rebuilding of the EPA tank sections was completed early in the quarter.

The following experiments were supported by providing technician and various fabrications services: Exps. 156, 65, 29, 90, 179, 54, 200, 93, 121, and 262.

An activity breakdown of the fabrication section effort for the last quarter was as follows:

Activity	Jobs (%)
Support of Experiments	40
Klystron Rebuilding	20
Accelerator Support	15
Other: HRS, EPICS, Injector, PIGMI, Area A, EPA Rebuilding, WNR	25

A total of 35 hydrogen furnace heats were run as itemized below:

Activity	Heats (%)
Klystron Rebuild	45
Accelerator Support	25
EPA Rebuild	18
Other: PIGMI, Experimental Support	12

Vacuum Support

The following vacuum equipment was procured for use by experimenters:

Equipment	Quantity
Turbomolecular Pump Package	1
Forepumps	2
Cold Traps	2
Refrigerator Systems	2
Ion Pump Power Supplies	2

A sizeable supply of LAMPF standard vacuum flanges and tubing has been ordered to support User related activities in the near future.

Light Pipe Shop

Twenty-three units for eight different experiments were completed during the past quarter. In addition to fabrication, 18 units were repaired for 7 experiments. The machine capability of the shop has been greatly expanded with the addition of a new Bridgeport milling machine.

Wire Winding Shop

Nine chambers were fabricated for six experiments, seven carbon-filament harps were wound, and six wire planes were modified or wound for other experiments. To minimize the turn-around time on jobs, a new gluing room is presently being prepared in the basement of the LOB.

III. ACCELERATOR SUPPORT

201-MHz RF Systems

An average of 1979 h was accumulated on each of the 201-MHz rf stands during the quarter. This was 96% of the time available.

The two 7835s that failed during the previous quarter were opened and inspected by RCA. The higher hour tube (14 000 fh) had a vacuum leak at an anode braze joint, severe silver plating on the lower anode ceramic, some arcing to the grid wires and structure, silver plating on the upper anode ceramic, and silver plating and signs of heating in the tube input assembly. The grid wires were not brittle, but some were broken and some buckling was evident. The lower hour tube (4400 fh) also showed signs of considerable arcing to the grid wires and support structure. There was silver plating on the lower anode ceramic. Some grid wires were broken and buckled but were not brittle.

The problems with the two new 7651 cavities have been isolated and solved, and adequate performance levels have been achieved. A fixture to mount the cavities at the test stand is now being constructed, as is a filament supply for the 7651s. Existing bias, screen, and plate supplies can be used at the test stand.

Replacement parts were received and installed in the three new 4616/4664 input cavities. These parts were improperly machined on the original cavities and new parts were supplied by the vendor. The cavities performed satisfactorily in the test stand after the faulty parts were replaced.

The new 4664 output cavity was installed and will be evaluated when Tank 1 becomes available as a load.

A 4616 output cavity was outfitted with a ceramic insulator to replace the failure-prone delrin insulator. This cavity is now running satisfactorily at the test stand and will be cycled into the machine in order to accumulate more hv time on it.

A new design for a hv cable termination for RG-17 is now being tested in Sector C and results will be compared with operational units. It will be some time before results from these tests can be obtained. We continue to experience occasional failures of the present terminations using the Belden hv cable.

The Rexolite vacuum barrier on Tank 3 was inspected at 7000 h and evidence of arcing on the air side of the window was noted. It was necessary to destroy the window in order to remove it. The Rexolite vacuum barrier on Tank 4 has accumulated 8000 h of running time at 9% duty without a failure.

During a routine preventive maintenance period, the filament spring contacts on the 7835 in module 4 were changed.

The over-current trip on the plate supply for the module 1 4616 driver was unreliable. In an attempt to reduce the number of trip-offs, the supply was modified, and an over-current detector and trip were incorporated. The spare supply was also modified.

An IPA Modulator Power Distribution unit was modified to incorporate an additional ac interlock. This modification will be evaluated at the test stand before being added to units in Sector A.

A mechanical misalignment problem was discovered on new Variac sections received for replacements on the 7835 filament supply. This misalignment may account for the early failure of one unit in the machine. The alignment problem was corrected on other units on hand and the manufacturer was contacted about the problem. He requested that we return a new section for evaluation, which we did. Sections received since have been satisfactory. We hope that periodic brush changes in these units will prevent failures during production periods.

Work is continuing on a dc-processing rack for a 4664. A half rack that holds the tube, and has power supplies and water-interlocking, has been assembled. This setup allows dc processing without use of an rf cavity. Work is in progress on control circuits to automate the processing.

Three 4616s and one 7835 were checked and processed at the test stand during the quarter. Another 7835 is being processed, and the 4616 with the patched vacuum leak is being reprocessed and tested. It has had water flowing through the cooling course with the patch for three weeks and has been run at 6% duty for short periods without leakage. The tube was very slow to process after the leak was sealed but shows no evidence of loss of emission.

Work on the stand for 4664 operation continued, with most of the effort being directed toward completion of the 8501 amplifier. A switching unit, which will be used to switch the control system from 7835 to 4664 operation, was designed during the quarter.

A lower dc blocker on the 7835 cavity at the test stand failed after 150 h of operation. The blocker is being sent out for a repair evaluation. Only one other teflon dc blocker has failed in the 201 rf system.

Each of the dc blockers in the machine rf systems has now accumulated ~20 000 h of operation without failure.

805-MHz RF Systems

The total number of klystron crowbars for this quarter was 192 or an average of 2.32 per day. The crowbar rate for all 44 klystrons was 2.05 crowbars per 1000 h, a decrease from the previous quarter. Of the 192 crowbars, 139 were on the six Litton tubes and 53 on the 38 Varian tubes.

Testing of the new indicator lamps continues. Sector D has the new type 376 lamps, and Sector C, the control sector, has the old type 387 lamps. In five months of testing, 89 of the old lamps and 5 of the new lamps have failed. These last five failures occurred during a thunderstorm which resulted in a power outage.

The Δt system was modified to provide CCR with the capability for remote reset of the Δt power supplies. Insulation was added to the Δt control racks to stabilize the internal temperature and reduce drift of the temperature-sensitive elements.

An extensive modification of the tank resonance control system is under way. Modifications are 95% complete in Sector D and 50% in Sector C. The modified system is controlling the tank resonance temperature much better than the old system. The other sectors will be modified as time permits.

The section has taken over the maintenance of the Line C ion pump power supplies. The supplies were arcing internally and were modified to eliminate this defect.

Other activities during the quarter included the following:

1. Assistance was given to MP-4 and MP-9 in the construction of various pc cards and electronic chassis.
2. The modified cooling system for the Sector H capacitor room is being adjusted in an attempt to improve its performance.
3. The power dividers required to free tank power loops for use in the tank-to-tank phase monitoring system have been installed.
4. The modification of the quad magnet power supplies, to alleviate start-up problems by replacing four open relays with enclosed relays, is 20% complete.
5. The Belden 8871 hv cable under test at ETL has 9235 hvh and 7844 h drawing current.
6. The growth test for RG-218 insulation immersed in oil has had some interesting developments. During the first four months (February through May) shrinkage of the insulation was observed, contrary to expectations. During the next two months (June and July) it grew in length. The test is being conducted outdoors. It is now suspected that temperature, as well as immersion in oil, affects the growth pattern of this type of insulation.

Low-Level RF System

In anticipation of the high-intensity run scheduled during the quarter, the 805-MHz IFAs were retuned and retubed, if necessary, to bring them up to full power and minimum phase shift. All tuning holes were plugged and the units were reinstalled. Units suspected of having defects were replaced rather than retuned. It is too soon to tell if this will decrease the failure rate, but, during the high-intensity run, there were few problems attributed to IFAs.

The prototype 201-MHz solid-state IFA has now run 3300 h at the 201-MHz test stand without any major problems.

The design of an 805-MHz solid-state IFA has been completed and a prototype is under construction. The unit uses two transistors and has an overall gain of 13 dB. An internal phase control system holds phase shift across the unit to <4° for a power change from 5 to 25 W. As soon as construction of the prototype has been completed, it will be installed in the klystron test stand for further evaluation.

The 201-MHz 8501 amplifier has been run at peak powers >15 kW with a plate efficiency of better than 50%. This is 50% more power than necessary to drive a 4664 to full output. The installation of 7651 drivers and IPA control circuit switching must be completed before a 4664 can be operated at the test stand.

Phase and Amplitude Control System

Phase subsystem modifications continued during the quarter. These modifications, involving pad changes and new drive components, have been completed on 18 units.

Six phase subsystems have been converted to solid-state diodes. These subsystems have been installed in Sector B, modules 5-10, and stability investigations are being conducted.

The redundant phase monitor system has been completed and is ready for installation through module 24. Installation should occur during the first down period in the next quarter. Parts were ordered and are being received for the remaining phase monitor systems.

The study of feedforward control during high-intensity runs continues.

The H^- buncher to Tank 1 phase monitor is operational.

Power Supplies

The massive modification program on the 84 LAMPF standard power supplies built by Acme Electric and Ling Electronics has been completed. Reliability and maintainability of the units should be greatly enhanced by these modifications.

Installation and checkout of the two power supplies for the Line D (WNR) tunnel quadrupoles is complete.

Two more dual Acme power supplies in the SMC have been rebuilt, making them compatible with the LAMPF standard regulator system. These rebuilt units will be used to replace two unmodified units early in August. This will leave only four units on the power supply platform to be removed and rebuilt.

Ten new bypass shunt systems, like those on EPICS, Biomed, Line D, and the TR, have been installed in Lines A and X. There have been no failures in the first eight weeks of operation.

Eight new 2000-A reversing switches have been received. The new switches are being installed to free older units for rebuild in order to eliminate some poor mechanical design elements.

Beam Diagnostics

Maintenance activities during the quarter included the following:

- Linear actuator driver modules were repaired.
- A wire-scanner actuator with mechanical problems was replaced.
- Wire-scanner amplifiers were repaired and recalibrated.
- The gain of 25 wire-scanner amplifiers was changed for operation with higher beam currents.
- A wire-scanner actuator with a grounded wire was removed and replaced.
- Sample-and-hold boards were repaired.
- Sample-and-hold chassis were tested.
- A bad 5-V regulator card was replaced in the TR high gain sample-and-hold chassis.
- A damaged 100-MeV collector plate was replaced.
- Shims were installed in a wire-scanner actuator in module 5 to correct a problem caused by a loose shaft bearing.
- The EM3 vertical collector plate was replaced due to beam damage.

A vacuum leak in Harp #8 in module 5 was discovered. The leak was caused by improper positioning of the holes in the actuator plate that contain the plastic pins required to hold the aluminum ring in place during installation of the actuator on the beam box. Further investigation resulted in the discovery of another faulty plate; therefore all new actuator plates will be inspected before they are installed.

Several times this quarter, operational tests were run on the beam diagnostics systems linear actuators using the CCR computer. Writing continues on a computer program which will allow much faster performance of these tests. Design continues on a portable microprocessor-controlled test system that will enable some operational tests to be made on the actuators without the use of the CCR computer.

Procurement of spare parts and fabrication of check-out equipment continued.

A review of all beam diagnostics systems drawings was initiated, and the first sections of a manual that will contain general information about the systems were written.

Testing and development activities included the following:

1. The fabrication of the new sample-and-hold system that uses the fast-wire-scanner amplifier is ~60% complete.

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

3. A 5-MeV carbon absorber was temporarily installed between Tanks 2 and 3 of the drift-tube linac. This device was used successfully in the performance of Tank 1 phase scans. The design of a 5-MeV absorber/collector device for permanent installation at the end of Tank 1 for phase scans is in progress.

4. An emittance collector plate made of kovar and glass was installed at the EM2 vertical collector. Evaluation tests scheduled for this quarter were not performed because beam time was unavailable. The tests have been rescheduled for next quarter.

5. The design of a smaller harp board that will provide greater clearances between devices in the same beam box was continued during this quarter. Connectors for the boards were ordered but have not been received. Replacement of all of the large-size fiberglass harp boards with ceramic boards cannot continue until the printing of the conductors on the ceramic boards is completed by E-Division.

6. The design of a new linear actuator with a 5-in. stroke was initiated. This actuator will be used to insert Harp #3 at the end of the drift-tube linac. The 4-in.-stroke actuator presently used does not allow sufficient travel for proper insertion of the harp.

7. Preparations have begun for a test to provide a check on the calculated power dissipation capability of the emittance jaws. Inlet and outlet cooling water temperatures and cooling water flow rate will be monitored during the test.

Vacuum Systems

Only light and routine support was required on the accelerator during this period, with the exception of module 6 where a new water-cooled window spacer was installed in an effort to solve a recurring leak. The spacer appears to have solved the problem.

Vacuum support in the SY continues to be light with no serious problems encountered. A new window valve was built and installed in the LASV05 position.

Moderate support was required in Area A. A few leaks developed after the first run cycles, some window installation work was required, and some target repair was necessary in target cells A2 and A5. A new turbopump was installed and is presently being evaluated at pumping station A3.

Experiment support in Area B continues to demand a good portion of time in the vacuum section with the installation of new experiments and the maintenance of existing ones.

The final installation and checkout of the vacuum system in Area C is in process and has required heavy support in the last few weeks of the quarter.

Experiments continue in the shock tube for the development of fast valves and triggering devices. The vacuum section is providing the necessary vacuum support for this effort.

Mechanical Support

Work on diagnostic hardware has been a continuing and evolutionary process, but design of the current generation of hardware now seems to have stabilized. Spare and replacement hardware is now available or near completion for most of the devices currently in use. Five new 4-in.-stroke actuators and spare parts were ordered for Line D (WNR). All orders have been received except the specially designed components which are expected by late August. A new 5-in. actuator is being designed and an initial order for two assemblies will be placed on completion of drawings.

Two new 201-MHz tuning slugs are being built by LASL personnel. One unit is 80% complete, the other 50%.

Previous work commitments on the HRS cooling-water system were completed this quarter.

Preliminary design of the EPICS cable bridge is complete. Final design is subject to acceptance and funding by MP-10.

Support of Exp. 99 was substantial and consisted of design and fabrication of experimental support devices, and complete redesign and installation of the magnet cooling system.

Reliability Study

Table III-I is a list of rf units which had the greatest number of failures.

TABLE III-I

MAJOR RF UNIT FAILURE-RATE HISTORY

Unit No.	Name	Section	No. of Failures
1147	Modulator switch tube	805-rf	30
1111	IFA	Low-Level rf	21
2001	Quad magnet power supply	805-rf	16
125	IPA-2	201-rf	13
6711	Ion pump power supply	805-rf	12
1146	Klystron modulator	805-rf	11

IV. ACCELERATOR SYSTEMS DEVELOPMENT

Beam Dynamics

201-MHz-Linac Field Distribution

Analysis of the Tank 1 field distribution data continued. The fitting procedure explained last quarter was unsuccessful in the global sense, and other mechanisms for explaining the difference between experimental results and the numerical calculations were sought. The data suggest that the field distribution under high-power conditions may differ from that measured under bead-pull conditions. One mechanism for this might be an oil-can effect on the rf end-walls. Simulation of this effect using the SUPERFISH cavity code lends support to the hypothesis. Dial indicator devices were designed and fabricated to mount at two spots on the upstream head to measure any movement under various operating conditions. If this effect proves real, an interpolation along a "tilt" dimension, as well as on the other variables already involved, will be necessary in the data analysis. This complicates matters, but appears feasible.

Accelerator Structure Field Distribution — SUPERFISH

The SUPERFISH code received major attention during the quarter, and is now in an essentially operational condition. The procedures for describing the cavity geometry have been streamlined and made convenient to use. Secondary quantity calculations have been added. The code has been tested against the results of other codes and experimental measurements, and has agreed extremely well. Studies of geometries needed for the PIGMI project are in progress. Now a proven code, this development stands as one of the most significant contributions to accelerator structure and magnetic field calculation in recent years.

201.25-MHz-Linac and Transition Region Steering

A procedure was devised for steering both beams to desired output position and angle coordinates at the end of Tank 4 (100 MeV) using a minimum amount of steering. Five steering magnets located in Tanks 3 and 4 are used in each plane. The equations are solved in least-squares manner. The procedure works quite well in numerical simulations. However, experimental data for the vertical plane show that both beams leave Tank 4 above the desired axis when they have been injected on-axis at 750 keV, and the procedure fails to give a reliable solution for this situation. The reason for the offset is not known at this time. Data for the horizontal plane have not been gathered because the horizontal oscillation of the beam makes it difficult to achieve the required accuracy.

The control-vector method for independent control of the position, angle, and relative path-length difference of the two beams in the TR was tested. The program is capable of setting the parameters, but noise and instabilities in the magnet current instrumentation make operation extremely slow (due to the need for a great deal of averaging) and make determination of the coefficients difficult. The next step in this development will be to determine how to improve the hardware.

Beam-Halo Analysis

Testing of a wire-scanner amplifier with four computer-switched gain ranges began, with encouraging results. The supporting computer codes switch gain as required during a profile scan. Afterward the data are rearranged with the proper multipliers into a smooth profile. Additional subroutines provide line printer and plotting capabilities. The data are stored on magnetic tape for further analysis. The same codes and instrumentation can be used to measure bunch phase-width properties in studies of longitudinal dynamics, in conjunction with the phase-scan absorber/collector systems. These scans produce an integrated density distribution as the bunch passes through the left edge of the bucket. A precise, computer-controlled zero-offset will be provided to the amplifier for measurement of the upper half of the distribution. This approach would also be appropriate for transverse measurements where a jaw or intercepting plate is run into the beam. (See also remarks under instrumentation development below.)

A beginning was made on the problem of reconstructing emittance data from a series of wire-scan profiles.

Work continued from the theoretical side in trying to understand the basic origin and time/space development of halos. It was concluded that self-collision effects are too small to lead to particle losses. But in a computer simulation with a smaller number of particles, collision effects overwhelm the collective effects that need to be studied. Plasma physicists are familiar with this problem and have techniques for smoothing the space charge forces of a limited number of macroparticles representing the real beam of many more particles. These measures alleviate the numerical problems, but a very large number of particles (of order 10^6) would still have to be run in order to achieve accuracy to the level required by beam-spill criteria at the 10^{-3} to the 10^{-4} level.

Another numerical method used in plasma physics is the solution of Vlasov equation by expanding the distribution function in phase space in orthogonal functions, and determining the time behavior of the coefficients. We plan to pursue this approach even if substantial progress is obtained in the analytic work because of the relative ease of generalizing to more complicated situations. It appears that there might be some advantage in computer time over the many-particle method, but probably no more than a factor of 5. The method does appear suited to the problem of achieving accuracy in the tails of the distribution.

On the analytic side, it seems that there are no presently available plasma physics results that can be directly applied to the linac problem because the applications are so different. However, by starting from the basic principles, some insight can be gained. Considering the space charge effects from the point of view of plasma physics, the size of the beam bunch is at most a few Debye lengths in diameter. Also, the beam is composed of particles all of the same charge and is therefore nonneutral even on a large distance scale. This regime of plasma parameter values has not been well investigated by plasma physicists. It is true, however, that such a beam is well represented by a Vlasov equation model, as there are a large number of particles within a Debye sphere and the plasma frequency is of the same order as the oscillation frequency due to the external focusing forces. The next step will be to look at electrostatic collective effects in a small nonneutral plasma with (mainly) linear external focusing forces, in two dimensions, because such a simpler model can be more completely solved and because such results are useful in verifying two-dimensional computer simulations.

Design work began on a method to measure (the linear part of) the space charge forces. This method will involve looking at the variation of the beam profile structure with peak beam current (actually density of beam.)

Horizontal Oscillation Control

An attempt was made to control the 12-Hz horizontal oscillation of the H^+ beam using a pair of electrodes located between TDQL01 and TDQL02. A signal was fed back from a fast BPM located between Tanks 2 and 3 to a high-voltage op amp which in turn drives the electrodes. The bandwidth of the control loop was ~30 kHz which allowed oscillation control to be achieved within a 200-μs beam pulse. The results are shown in Fig. IV-1, where the top trace displays the uncontrolled oscillation amplitude at BPM 2/3 to be ~2.5 mm peak-to-peak. The bottom trace shows this amplitude to be reduced to ~1 mm peak-to-peak by feedback control. The data accumulation time in both cases was ~20 s, and the beam conditions were 5-mA peak H^+ at 7.5 pps. Peak voltages of ~60 V were required on the 1-m-long electrodes gapped at ~2 cm.

The above technique worked well for single point control, namely BPM 2/3. However, the production of a node at this point does not eliminate the oscillation in other parts of the machine. To achieve this, two-point control is required, and this will be tried using a twin pair of electrodes to be installed in the beam pipe inside TDQL02. The design for this beam pipe is complete and utilizes two pairs each of 30-cm-long horizontal and vertical control electrodes separated by 75 cm. The electrodes are segmented circles in cross section and gapped at 6 cm. They should be ready for test during the next quarter.

Long-Term Stability Development

Data Management

Certain disk files on the control computer contain data which are updated only rarely but which are

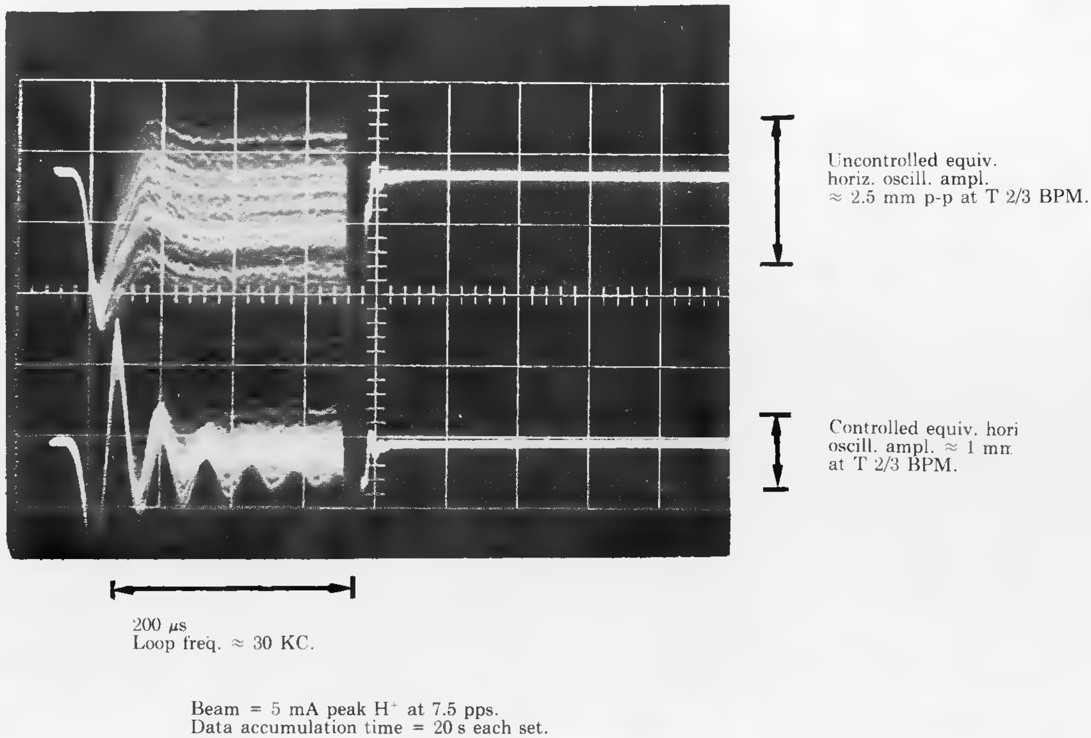


Fig. IV-1.
Horizontal oscillation control at a BPM between Tanks 2 and 3, using electrostatic chopper electrodes in the H^+ transport line ahead of the linac. Top trace: Uncontrolled oscillation amplitude ~2.5 mm p-p at BPM. Bottom trace: Controlled oscillation amplitude ~1 mm p-p toward end of pulse-time scale 50 μs/division. Closed-loop ringing frequence ~30 kHz. H^+ beam running at 5-mA peak and 7.5 pps; data accumulation time 20 s for each trace.

vital to the proper operation of the machine. A system has been put in operation which monitors the integrity of such blocks of data by testing checksums periodically and upon demand. Data now being monitored include accelerator parameters (energies, powers, quadrupole strengths and alignments, etc.), Δt parameters, wire-scanner parameters, phase-scan calibration data, and LAMPF model parameters for beam transport calculations using the program TRACE. This information is also stored on a magnetic tape as backup, and in the event that the information on disk is lost, it may be restored from the tape.

Operations-Support Development

Operations/Maintenance Equipment Reporting Data Base

A retrieval program was written for the maintenance group, with versatile ordering, date, and equipment selection capabilities.

Rack inventories were corrected and distributed for all 805 equipment. Units were physically renumbered to correspond to earlier changes made in the catalog of equipment.

Further work was done on methods for entering data into the summary data base which was designed to store information for long-range studies of accelerator performance. Some of the original assumptions about modes of accelerator operation have been changed and are documented in a report in progress. The PLI program which transfers data into the summary data base was rewritten to conform to the changes in philosophy. All information from operations/maintenance cards has been entered from January 1 through July 3 (end of operating cycle 4). No downtime from shift reports has as yet been entered.

Experimental Schedule Data Base

Redefinition and data loading were completed.

Experimental Area Management Work Orders

A new, single-level data base was completed to keep track of these work orders. Other information needs for experimental area management were satisfied by writing specialized retrieval programs to get data already stored in the Experimental Schedule and Visitor Center/LAMPF Users Group, Inc. data bases.

Bibliographic Data Base

Compilation continued. A concordance of all authors represented and a subject dictionary were prepared and placed in the MP-Division library.

General CCF-Related Problems

During the past quarter, an unusually high number of damaged data-bases occurred. These will continue to be a problem in the present saturated and unreliable computer environment. A request to C-Division to purchase modifications to S2k to improve recovery time was made, and possible ways to protect the data bases are being considered.

A tour of the machine rooms at CCF was arranged for MP personnel working on data bases.

Assistance was given as needed on file management for both LTSS and KRONOS for summer employees and other personnel. Data-base training was provided for LAMPF personnel.

Diagnostic Equipment Development

Beam Position Monitors

A selected number of BPM systems of both types (see last progress report) have been installed at the front end of the machine. Both systems have been calibrated to give a 1-V output for a 2-mA beam 1 cm off-axis, and their performance and long-term stability are then evaluated. Typical data taken to check gain and linearity are shown in Fig. IV-2. The beam is first centered using the wire scanners; then the BPM is biased to produce a null at this point. Next, the beam is steered to produce a deflection for checking gain and linearity. Complete performance data for both systems will be obtained during several operating cycles so that the long-range stability can be determined. It is expected that selection of the final system will be made next quarter. In the meantime, both systems can be used by operations to aid in beam tuning.

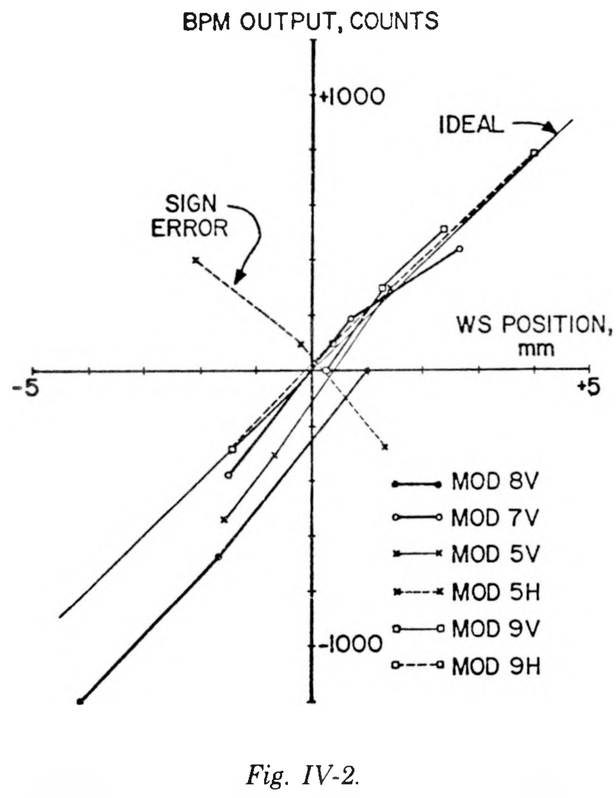


Fig. IV-2.
Preliminary experimental data from BPM system.

ΔT Hardware

New rf preamps were ordered for the Δt system. The amplifiers have 70 dB of dynamic range with a constant level output signal of 10 dBm. Transmission phase transfer over a 20-dB range is 3° max, and over the total 70-dB range, 10° max. The amplifiers are insensitive to power supply variations and rf input power level variations.

Digitally controlled voltage sources were procured, installed, checked out, and made operational for control of the Δt centering phase shifters. These sources increased the speed of the Δt measurement significantly.

The Δt cabinets had more thermal insulation added in an attempt to improve temperature control. The cabinets are insulated so well that a heat leak had to be provided, for some of the instrumentation generated heat in order to maintain a 43.5°C temperature. Controlling temperature at 43.5°C has apparently caused more problems than it has solved, so a proposal for rack cooling is now being prepared.

Palladium Leak Controller

A palladium leak gas pressure controller was designed, prototyped, and tested with good results. This unit will be installed in the H^+ injector as soon as possible.

Beam Profile Measurement Instrumentation

A significant step forward was taken this quarter in instrumentation for measuring beam profiles. The necessary rack wiring was completed in modules 5-13 and 40-48 for the multirange wire-scanner amplifier designed by MP-1. This unit embodies several options, the most important being the ability to switch gain in four steps of one decade each, upon receipt of signals from a two-bit gain-select code. A single portable unit of this type has been assembled and preliminary measurements of beam profiles made at the above modules using a 10-mA beam. Software has been written to sense signal level automatically and to switch gain at specific thresholds. Noise problems from rf interference and grounding and shielding difficulties are apparent on the most sensitive ranges, but it appears feasible to eliminate them.

A circuit was designed and prototyped using a 12-bit D/A converter to generate an offset voltage for the multigain wire-scanner amplifiers. These amplifiers could then be used to increase the resolution of the integrated phase-scan signals. The phase scan bin at 40 MeV has been wired to use this system.

Feedforward System

Noise from the current monitor used for the 805-MHz feedforward signal was reduced by a factor of ~5 by utilizing the second coil on the transformer in the amplifier feedback circuit. The use of beam gate on this amplifier resulted in premature termination of the feedforward signal when the slow risetime feature was being used in the injector. This latter circuit holds the beam on for 12-15 μs after beam gate ends. An interim correction was made using a much longer gate pulse. The feedforward system was used in tuning work to bring the machine up to 10-mA peak beam current using short pulses at a low duty factor.

Coaxial Ionization Chamber

An investigation was initiated into the feasibility of using some type of coaxial ionization chamber to look at spill in the 201.25-MHz linac.

Emittance Hardware

During the repair of a melted collector at the 100-MeV phase-scan station the damage to the 95-MeV absorber and the EM11 tungsten jaws was assessed. Negligible damage was found on the 95-MeV absorber. It was clear that melting in the beam spot had occurred at EM11; however, no structural damage had occurred.

Low-Momentum-Component Detector

The prototype detector designed to measure low-momentum components in the H^- beam has been installed on Line X in the SY. The detector (Fig. IV-3) consists of an array of 32 secondary-emission foils which is shielded by common high-voltage planes and housed in a vacuum chamber. This detector (Fig. IV-4) was installed on the north side of Line X, 2 m downstream of the first bending magnet in the SY. Components of the beam having less than the design momentum are deflected through larger angles and pass through a thin window into the air.

Fig. IV-3.
Detector assembly for the low-momentum-component detector (LMCD).

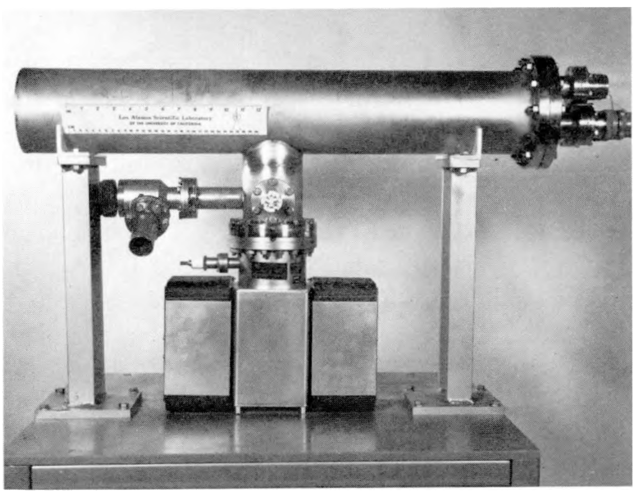


Fig. IV-4.
Assembled LMCD and vacuum system.

These beam components subsequently pass through the thin wall of the detector chamber and through the secondary-emission foils. Each foil in the array is positioned to lie on the trajectory of particles having the discrete energies corresponding to modules 4-36 having final energies of 100 to 597 MeV.

The secondary-emission current, a function of the incident proton energy, charges a coaxial signal cable attached to each foil. The voltage developed on the cables is multiplexed and digitized for display in the control room. Initial tests indicate good integrity of the system from the detector to the operator's display. The system was further tested with H^- beam during normal production, and signals corresponding to low-momentum components between 200 and 400 MeV were observed. These initial observations indicate that, in its present configuration, the detector system is sensitive to average currents of 1 nA.

Microprocessor Development

The new pushbutton-LED front panel board was checked out and accepted.

A 611 storage scope was interfaced to the Fermi crate and is now ready for use as part of the bead-pull apparatus.

The quad linear actuator interface boards for the Fermi crate have been laid out and received from E-Division.

Two dense memory boards (8K-RAM) and (4KROM/4K RAM) have been designed and have been submitted for layout. These boards are necessary to allow operation of the bead-pull setup until the storage in the main computer is available to the microprocessor-controller.

The TI ASR-733 terminal is now being used with the Fermi crate.

A 1702A PROM Programmer which uses five commercial cards and two interface cards has been assembled and is awaiting checkout.

Parts were obtained to build a fiber optic light link. A clock-interface for the Fermi crate was checked out and modified.

The circuit boards for the debug box have been received from E-Division and are in the process of checkout. One of these boards is a general-purpose connector board which allows cables and internal connections to be made without soldering.

A relatively powerful teletype system monitor program has been written for the Fermi crate. This monitor is capable of loading memory from, and dumping memory to, tape (either punch paper or TI cassette). Memory change, zero, move, and compare options are also available. Preliminary copies of this software have been given to R-1 and L-10.

Modifications have been made to the 6600 cross-assembler output routine to allow tapes to be made which are in the correct format to be used with the Teletype system monitor.

Four $1\frac{1}{2}$-h sessions on the Fermi crate were given to members of MP-11, MP-12, R-1, and Temple Univ. users group.

A number of improvements and corrections have been incorporated in the cross assembler for microprocessor code. A disassembler program for microprocessor code from FNAL has been adapted to run on a CDC6600 computer under NOS. The disassembler accepts machine code as input and produces a source-like listing with mnemonic operation codes and symbolic addresses. The assembler and disassembler are in use in adapting and developing software for the bead-pull control crate.

Bead-Pull Apparatus

The frequency counter interface board for the new bead-pull apparatus was given its initial checkout. Actual application of the board awaits the first PIGMI bead-pull.

Central Computer Control System Code Development

As mentioned above, codes for steering in the 201.25-MHz linac and the TR received attention.

A new 201 harp program has been implemented. Its basic operation is similar to the old program; however, this program can read and display which beam gate is being used to control the sample holds. The new code uses a given number of motor pulses to position it, as opposed to the setpoint seek of the old program. Minor errors in the plot package of this program were also corrected.

Software maintenance is also being carried out on the emittance code. Data files have been consolidated. A modification was made to the program which allows the selection of H^+ or H^- beam gate for the sample holds. A second modification which increased the speed of the data collection-plotting routine was also made.

As mentioned above, programs have been written and put in operation to test checksums on blocks of data in disk files periodically or upon demand. These include programs to add or delete data blocks on the list of data blocks to be monitored, programs to document the date and contents of the initial data entry or data update operations, and subroutines to return the latest date that the blocks of a specified file were entered or updated or the earliest date that the checksum was found bad, if ever.

The 201-MHz linac parameter display program was corrected to show the Tank 4 steering magnet setpoints in proper sequence.

Collaborative Programs

Biomed Range Shifter

The range shifter has been used in several dosimetry experiments this quarter. It has been found that dose flatness of ±2% over strokes up to 10 cm can be readily achieved using refined histograms, and the experimental results have been useful in selecting the best theoretical approach to histogram prediction. In normal operation, a new histogram can be stored in the microprocessor memory in a couple of hours with no beam line adjustments in the form of wedges being necessary to achieve whatever dose distribution is desired. The servosystem can be run over a significant speed range without affecting the dose distribution appreciably. The integrated depth-time traces of the command and response functions have been compared to determine the effect of slew-limiting and overshoot, and it has been found that they differ by no more than 3% over the time scales tested. The final improvement to the existing system is the addition of a shaft encoder as shown in Fig. IV-5 to allow the depth of the range shifting fluid to be read back directly into the MPU memory or, by rearrangement, the master control computer. This will allow the drift characteristics of the device to be closely watched and opens up new avenues of command and control techniques.

Modifications were made to the range-shifter driver to allow the sending of beginning-of-cycle signals to the Biomed Control Computer.

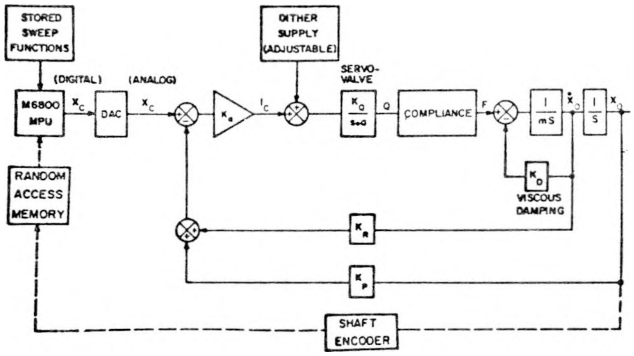


Fig. IV-5.
Biomed range-shifter control system block diagram.

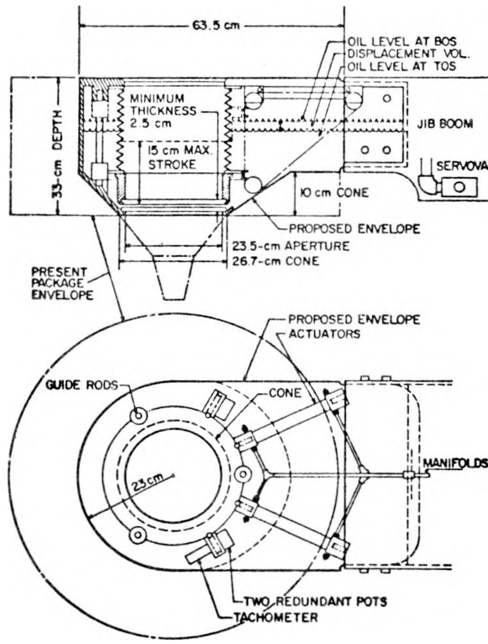


Fig. IV-6.
Proposed repackaging for the biomed range shifter to improved clinical shape characteristics.

Second Generation Range Shifter and Collimator Proposals

Preliminary design of an improved range-shifter package to provide a more clinically acceptable shape has been completed and is shown in Fig. IV-6. The specifications of this unit will be essentially identical to the existing one with the exception of a 1.5-cm greater stroke capability and the facility for attaching the collimator conveniently. The collimator will have a one-degree-of-freedom travel relative to the range-shifter housing which, in addition to the swing of the jib boom, will allow convenience of positioning the collimator under unsymmetrical or off-center beams. Reorientation of the cable cylinders to the horizontal plane allows the base of the unit to be conically shaped, providing greater convenience for hands-on positioning. The redesigned unit will replace only the range shifter in the present system; the jib boom, hydraulics, and power supply will remain unchanged. The entire unit can be preassembled to replace the existing range shifter during a short down-period.

EPICS Beam Separator

Significant improvements to the beam separator control electronics were made this quarter allowing the unit to operate at its design level of 300 kV. These improvements were the development of a crossover system to allow conditioning of the system to occur while controlling on current, and to switch over automatically to precise voltage control (0.05% regulation) when the conditioning current falls below a selectable threshold. With the improved electronics installed, long runs were made with the unit at 275 kV and shorter tests were conducted to as high as 340 kV. Refinement of the electronics is continuing as problems continue to appear.

A large liquid nitrogen cold trap and valve combination were installed just above the flux box. The cold trap is within 2 m of the center of the electrode gap in the box. This should help trap much of the heavy organics that were not being taken out by the turbopump and will improve channel vacuum quality considerably. It should also gradually reduce the conditioning time required to bring the separator to high voltage.

Since the unit went into operation two quarters ago, it has not been opened to inspect the electrodes. The procedure required to open the separator components for inspection and cleaning is shown in Fig. IV-7. It is planned to go through this procedure during a selected shutdown period next quarter.

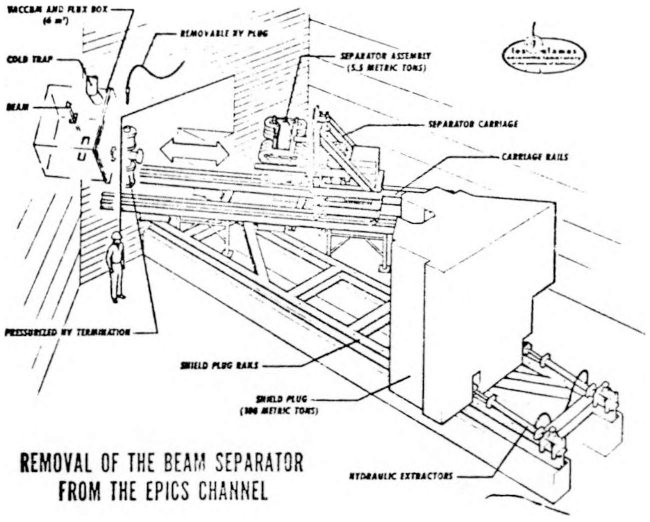


Fig. IV-7.
Pictorial demonstration of procedure used to open the EPICS separator for inspection and cleaning.

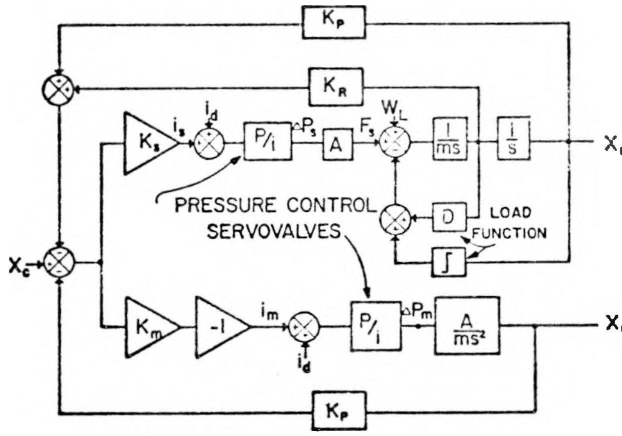


Fig. IV-8.
Block diagram of the control system for each degree of freedom of the master-slave servomanipulator.

Hydraulic Servoarm

Preliminary design work has been started and some purchase orders placed on the new force-reflective servoarm operational model. This model will be used to test the basic concepts to be used in the full servoarm development program. It will be capable of two-degree-of-freedom control and will utilize either a mechanical-hydraulic slave to respond to the master commands or an analog computer. The latter approach allows more flexibility in choosing certain system parameters but sacrifices realistic response in others.

The basic control concept is shown in Fig. IV-8. Position signals fed back from both the master and slave actuators to a common summing point are compared to the command signal. The unbalance error signal is split between the two forward loops with a sign change in one to generate commands to the servovalves. These are pressure control valves which, due to internal feedback, produce pressure differentials across the load ports in response to the command signals. Thus the working pressure is applied to the load and a reaction pressure is applied to the master manipulator arm giving a physical feel to the job being done. The model will test the realism and usefulness of this feel and allow better electronic development.

V. INJECTOR SYSTEMS

H^+ Injector

The H^+ injector has been used this quarter to provide the high-intensity proton beams required for LAMPF operations. This injector was operated at peak currents from 12 to 25 mA and used an ion source with ~1/2 the original design current of 50 mA. The jaws at the EM2 emittance station are still being used to provide the current-limiting required to produce the low peak current beams for production runs.

The H^+ ion source was replaced with a higher current (36-mA peak) source. When injector operation is completely checked out at this current level with production beams, the original 50-mA ion source will be put back into operation. These tests are being conducted to determine proper operation of the accelerating column and fast stabilization circuits for high peak current, high duty factor operation.

The use of argon venting of the accelerating column when changing ion sources definitely improves the recovery of high power operation of the accelerating column after letting it up to atmosphere. Ion source components are now vacuum baked before installation, and high voltage conditioning times have been reduced. The study of vacuum contaminants in the accelerating tube appears to be necessary before reliable, high duty factor operation can be achieved at the design current for LAMPF.

Periodic retubing of the high-voltage generator has been instituted and should reduce the on-line downtime.

The motor-generator-set (MG Set) maintenance has been postponed because of lack of maintenance time. Complete operational spare units and parts are now on order.

Two beam line pumps were replaced after a vacuum accident occurred. Normally, these pumps have a lifetime of several years.

H^- Injector

The H^- injector has provided the H^- beams for LAMPF operations. The beam chopper has been used extensively, and over 1-μA-average of 40-ns chopped beam has been provided.

After seven months of service the fault rate on the extractor power supply showed an increase. The H^- ion source was removed and extractor components were replaced. Characteristic spalling and deformation caused by hydrogen embrittlement were observed on the extraction electrode. The back surface of the anode aperture plate showed a thin contoured deposit, presumably molybdenum, which had diffused through the aperture (Fig. V-1). The plate was cleaned and restored to normal operation.

The spare canal power supply was installed in the H^- equipment dome and functioned properly after correct interfacing to control circuits was made. The original canal power supply is being overhauled to eliminate the excessive overcurrent-trip problem.

The control problems associated with these high-voltage power supplies in the equipment dome were apparently solved by making appropriate changes in the relay control chains.

The cooling-water hoses on the C-W generators have been replaced with a new type of high temperature, high pressure, insulating line which is expected to prevent the flooding problems previously experienced. This type of line will be installed on all injectors if initial operation is successful.

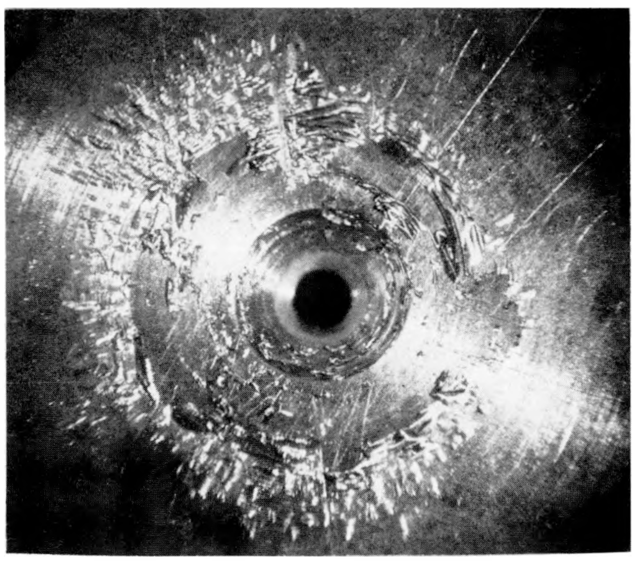


Fig. V-1.
Anode aperture plate showing deposition of molybdenum films; the anode aperture is 0.6-mm-diam.

Both dome ion pumps were rebuilt this quarter. Their lifetimes were as expected with the gas flows used.

Preliminary work has been done on a microprocessor unit which will be installed in the equipment dome. Fiber optics will be installed and a supplemental data channel will be set up to evaluate the use of this type of system as a high-voltage interface. Application of such channels is planned for use with special interfacing to the polarized ion source.

Polarized Ion Injector

The design of all of the major components for the ion source has been completed (see Table V-I). The NOVA computer systems program and the ICR control console for the polarized ion source have also been completed and checked out. The wiring for the injector dome, C-W power supply, and the MG Set has been completed and is ready for final checkout. The MG Set has been run but there is a

TABLE V-I

STATUS OF POLARIZED ION SOURCE COMPONENTS

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

x = Previously completed
* = Completed this quarter

problem with the voltage regulator which has not yet been resolved.

Modifications were made to the argon charge-exchange cell (which is presently installed on the P-9 polarized source) to reduce plasma oscillation. These modifications resulted in a 30% increase in polarized beam current to give a beam intensity of 600 nA. Further improvement may be possible, but development will be deferred until this cell is installed in the LAMPF source next November.

The assembly of the 750-kV accelerating column has begun and the initial bonding tests are now complete. The titanium electrodes have been received from the vendor. The assembly is expected to be completed next quarter.

Injector Development

Studies were resumed of the high-peak-current beams that will be needed to obtain 1-mA operation at LAMPF. During the Great Shutdown, water-cooled apertures were installed in the injector beam transport lines and were sized to permit the desired operation at 17-mA peak current. It has been found that this collimation will, in fact, only permit transport of 2/3 of the required peak current, and suitable modifications are now being made. The failure of the design calculations to predict accurately the beam dynamics is attributed to a basic inadequacy of using beam envelope calculations for these high-peak-current beams. More realistic calculations using PARMILA with suitable space charge interaction and bunching effects have been initiated. Before the Great Shutdown, beams with the required peak current (25 mA) were prepared and documented, but no extensive tests with the linac were carried out at that time. The present program is directed at obtaining agreement between observed behavior of real beams and theoretical models.

Detailed studies of the matching required at the entrance of Tank 1 have been carried out using simplified beam dynamics transport codes. The results are in good agreement with observed capture in the linac at low currents (2 mA), but deviate at higher peak currents. More accurate simulations are required to predict the necessary quadrupole matching conditions. Empirical bootstrapping techniques will be used initially to determine these conditions.

Work was also started this quarter to study the problems entailed in operating the accelerator with the peak-beam currents required for 1-mA-average operation.

Extensive beam tests were carried out with several peak currents captured and accelerated to 800 MeV. These tests were conducted over a range of peak currents from 2 to 14 mA with most of the work done at 10-mA-peak accelerated beam. At 14-mA-peak, there was clearly observable beam loss along the linac so no attempt was made to increase the duty factor. At 10-mA-peak there was still sufficient beam loss to limit operation to 7.5 Hz at 500-μs pulse width before spill monitors tripped the beam off. Transverse emittance scans obtained in the injector and in the TR are shown in Figs. V-2-5 for this beam. The RMS emittance of this beam damped from 0.57π cm-mrad in the injector to 0.23π cm-mrad in the TR to 0.09π cm-mrad in the SY* in the horizontal plane. Similar behavior was observed in the vertical plane, although the vertical phase space showed a larger halo structure in the TR.

Work has continued on development of a new arc-pulse modulator. Several prototype transistor switches have been fabricated. Design of input drivers, control circuits, and suitable capacitor storage banks has begun. It is anticipated that many of the *ad hoc* modifications now installed on the SCR modulator in the H^+ injector (risetime control, 1-in-10 pulsing, etc.) can be incorporated as an integral part of these new modulators. More important, of course, is the improved reliability and stability that is anticipated in their operation.

Some support was provided for the P-11 high-current H^- ion source program in building test stand hardware and in carrying out some of the initial tests on the surface ionization source. The testing program on the Osher charge-exchange source has now been postponed indefinitely in order to carry out the surface ionization program.

*The switchyard measurement is not conclusive since there were significant (30%) low-momentum components in the beam.

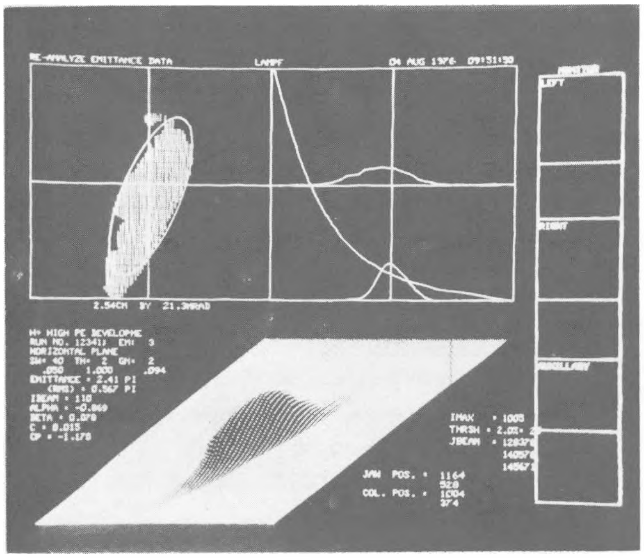


Fig. V-2.
Horizontal emittance scan in the injector transport line for a 10-mA accelerated H^+ beam. The RMS emittance is 0.57π cm-mrad while the total emittance is 2.41π cm-mrad at 750 keV.

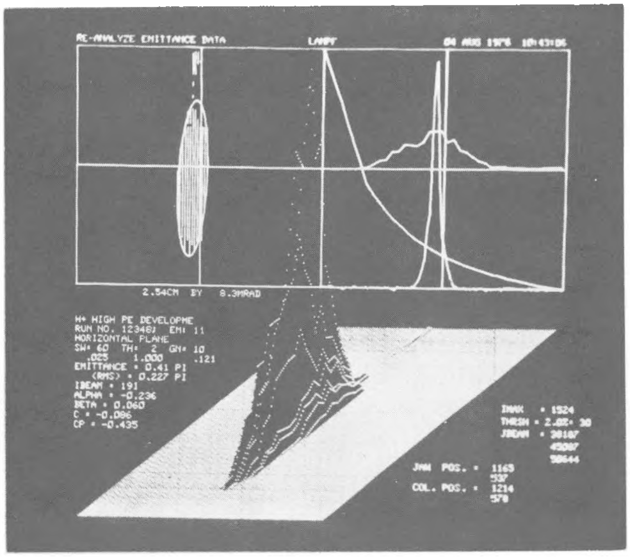


Fig. V-4.
Horizontal emittance scan in the TR for a 10-mA accelerated H^+ beam. The RMS emittance is 0.23π cm-mrad and the total emittance is 0.41π cm-mrad at 100 MeV.

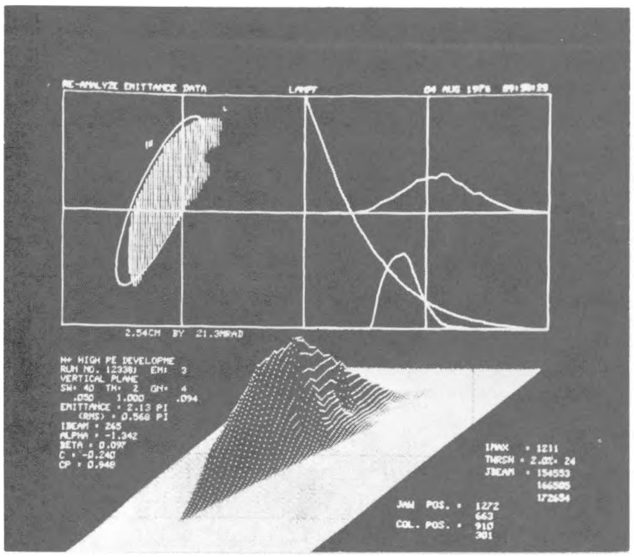


Fig. V-3.
Vertical emittance scan in the injector transport line for a 10-mA accelerated H^+ beam. The RMS emittance is 0.57π cm-mrad, while the total emittance is 2.13π cm-mrad at 750 keV.

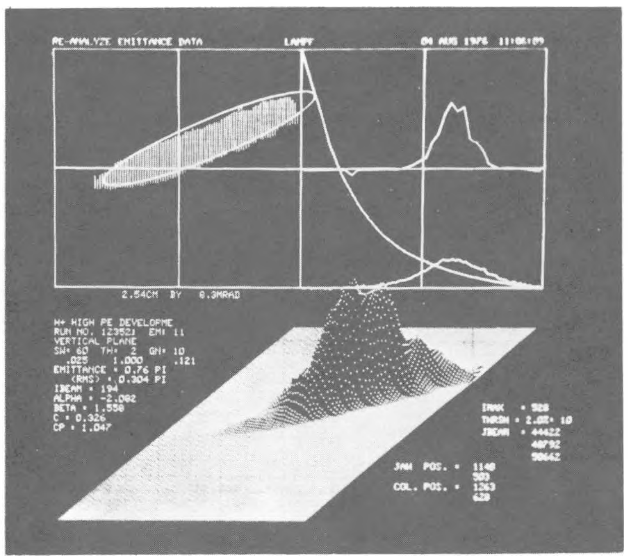


Fig. V-5.
Vertical emittance scan in the TR for a 10-mA accelerated H^+ beam. The RMS emittance is 0.30π cm-mrad while the total emittance is 0.76π cm-mrad at 100 MeV.

VI. ELECTRONIC INSTRUMENTATION AND COMPUTER SYSTEMS

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

Computer Control System

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

Control Computer

The first prolonged failure of the control computer occurred last quarter. It followed a lightning strike on the power line. Actually, two components failed simultaneously. The first was located and corrected within an hour. The second required several days to isolate. The diagnostic efforts were thwarted because the failure manifested itself in many ways and a constant failure mode was difficult to identify. Once the problem was recognized as part of the memory protection logic, the defective component was located in a matter of hours. A post-mortem review of the repair effort was held and a procedure was developed for handling any future problems of this magnitude in a more effective way.

The KSR-35 teletype, which has served for almost seven years as the main keyboard device on the control computer, was replaced by a Texas Instruments Model 733 KSR unit. This new unit is faster and noiseless.

Control Consoles

The third accelerator control console is scheduled to be installed in CCR in October following the removal of the terminal computer. Several meetings were held to coordinate the activities associated with this development.

The shell of the console was brought out of storage and located in a working area near CCR. The new console is designed to permit the use of microprocessor-controlled console devices. The first device of this type to be designed is a button panel module, similar to those currently in use on the existing consoles. The software for this device is ~50% complete.

A new Knob/Readout panel is being developed for the console. It, too, will be microprocessor-based for greater flexibility than is possible with the present hardwired, random-logic units. Several operators and programmers were consulted in the process of developing a set of design specifications. A preliminary design review was held and work on a prototype is under way.

The checkout of the LASL-designed IEEE ASCII bus analyzer was completed. The analyzer's modes of operation are talker, listener, and controller, allowing it to simulate any device on the bus. The analyzer includes a 1024 × 12 RAM for message storage and retrieval. The unit is portable and physically easy to carry for on-site work. This analyzer will be very useful in diagnosing software and hardware problems in an IEEE bus interface system.

The design of a keyboard that can be used on the IEEE bus was initiated.

A second CAMAC crate was installed on the control computer. This crate was needed to support the bus controller and the CAMAC modules associated with the status display system for the experimental area.

Master Timer

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

The mechanical assembly of the second-generation master timer was started and will be completed next quarter. Twenty-three plug-in timing modules for the system are under construction in E-Division. Checkout of some of the units was started. The master timer will be controlled by an 8080A microprocessor. The programming for the microprocessor was partially completed.

While the new master timer is being built, the old master timer is still functioning. An intermittent timing signal which caused a considerable amount of inconvenience last quarter was finally isolated to a pc card and corrected. The troubleshooting of the master timer is difficult because the unit is seldom off-line.

Microprocessor Developments

Microprocessors will be used in several applications along the accelerator in future quarters. Several projects were completed in support of this development.

A new hexadecimal debug package was completed for the Control Logic-8080 microprocessor development machine. This package will allow easier use of the development machine when applied to such tasks as ASCII bus and data-link checkout. All programming and hardware checkout will now be based on the hexadecimal number system in order to be compatible with the Intel-supplied assembler and PL/M compiler. The second Control Logic development machine was modified to be completely compatible with the first unit.

The CPU/Memory board utilizing Intel's 8080A reported on last quarter and designed for use in a CAMAC module was debugged and checked out. The complete fabrication of more boards is in progress. Since pc boards are being used, assembly of these boards can be accomplished very rapidly. The testing of these boards will begin early next quarter.

A software diagnostic routine to test and debug the CPU/Memory board was written, debugged, and is in use. This program exercises and tests the on-board RAM memory, the entire instruction set of the 8080A microprocessor, the address bus, data bus and control bus connectors, and the supporting logic. This diagnostic routine can be used to test the entire board or, by substituting integrated circuits, any new or suspected part.

Accelerator Interface System

The NOVA computer software for the polarized ion source was integrated with the interface hardware described last quarter. The control system was fully checked out using new console hardware and the partially wired remote data terminal (LAMPF-DACT) soon to be placed in the ion source dome. This work was done in preparation for commissioning of the source later in the year.

A thermal protection unit was installed on the NOVA computer, and its front panel display lights were converted to LED indicators to reduce lamp failures.

Microcontrolled Data Links (MCDL) are being developed to reduce the overhead associated with handling the satellite control computers. Diagnostic programs for the MCDL were completed and, with their use, the prototype MCDL was further debugged. The MCDL system software was also finished and tested in a laboratory CAMAC system. On-line testing of the data links will begin shortly in CCR between the control computer and one of the satellite computers.

A modification to allow CCR operators to restart and completely reload downline the satellite control computers was designed and tested. Six restart boards were fabricated. Four were installed, one will be installed next quarter, and one will be retained as a spare.

A PMOS multiplexer was designed to replace the existing multiplexer in the analog data system. This card has been laid out in drafting and two prototype boards will be built next quarter and evaluated. The feasibility of using a CMOS multiplexer will be studied further.

Computer System Software

A modest effort was directed toward the maintenance and improvement of the SEL 840 system software. This effort included the diagnosis and correction of faults and the addition of new features or capabilities to the system. Some of the improvements made during the quarter are noted below.

A program was written to check the binary cards received from the CCF. As a result, two bugs were uncovered and corrected in the SEL 840 software with a concomitant improvement in the reliability of reading cards.

The Assembler was modified to provide macros to implement the complete set of operating system calls, to improve the error messages, and to provide automatic conversion of channel designators into hardware addresses. This last feature permits a marked improvement in the degree of symbolism in a program without incurring an execution time penalty for channel table reference. Thus, program listings will improve as items of documentation.

A program was written to verify and exercise the disks while the computer is on-line to the accelerator. This program should permit earlier detection of disk corruption and hardware failures.

The programming for a system modification to use the hardware save-and-restore-registers feature was completed. This feature, which promises a 5% to 7% saving in 840 CPU cycles in normal operation, was installed in the computer during the great shutdown, but software to take advantage of it had to await the completion of more urgent work. Installation and checkout will be paced by the availability of dedicated computer time during maintenance and development periods.

In order to provide a larger measure of compatibility with the magnetic tapes used by other computers both at Los Alamos and elsewhere, a facility for writing binary-coded decimal tapes was installed.

A number of the diagnostic programs, which provide system status or information about particular tasks and serve as debugging tools, were modified to run at remote consoles as well as in CCR.

Accelerator Applications Programs

The major part of the software support for accelerator operations is directed towards programs which provide new facilities for accelerator control and monitoring, improve existing capabilities, or support new accelerator and beam-line hardware.

The magnet-setting program, which is a complex set of interacting tasks and data files, is one of the most important features of the control system. The heavy use it receives and its central role generate a continuing modest stream of changes and improvements. During the quarter, TR magnets were added to the magnet data base, the plotting module was modified to plot the fields of bipolar magnets, and a field error indication was added to the display.

The Run-Permit diagnostic software was improved by the addition of a program to print the contents of the data file.

The definition of new area designators for the location and naming of beam-line devices forced an enlargement of some of the directory tables for the master channel tables.

The beam spill monitor display was updated to correspond with changes made in device designators.

The program which displays the status of the liquid deuterium target was revised to provide more information to the operators and to permit operator control of the personnel safety bypass in Area B.

The RICE test program is currently being revised to account for new analog multiplexers in modules 62, 64, and 65.

The program for recording the integrated beam current in the main beam lines was completed and put into operation. This program utilizes the data acquired in the remote beam-line minicomputers from the beam-line toroid current monitors. The minicomputers accumulate the total charge passing through each toroid over time intervals which are under the control of the SEL 840. Thus, a more accurate record is obtained than under the old sampling scheme used previously.

A considerable body of software has developed, and is continuing to develop, around the toroid current monitors and voltage-to-frequency converters. In addition to the recording function cited above, they are used in the beam-line protection system, which is critical to safe operation at beam currents above 10 μA. The transmission monitor software, which was in use at the beginning of the quarter, was revised to provide a simpler, more unified operator interface and a greater degree of automation. The interactions with the beam current recorder include not only the sharing of the toroid data, but provisions to allow changes in amplifier gains, background reading, and calibration to be performed without producing erroneous records or endangering the protection scheme. The second version of this software is now in use. Work continues on it, however, in collaboration with MP-13, to minimize the possibility that an operator error, hardware failure, or system overload can weaken the protection it provides to Line A.

Work was begun on the accelerator status monitor software. This system will provide a TV display of accelerator and beam status which can be transmitted to areas remote from the CCR. It is designed particularly to serve the needs of experimenters for information on the accelerator's operational status and beam parameters, but it is expected to be useful to other personnel who are closely concerned with the accelerator's operation.

A program was provided to give the operators the capability of storing messages in the computer and retrieving them. This facility, though simple, is expected to improve the reliability of communication between shifts.

Work was begun on a program to provide a more highly automated and more efficient scheme for testing beam diagnostic devices. This program is expected to permit the checkout of these devices, which must be done during maintenance and development periods, to be done more quickly, easily, and reliably.

The development of the control vector technique for controlling accelerator parameters continued during the quarter. Measurement of magnet constants and calculation of control vector parameters for the direct control of phase, angle, and position of the H^+ and H^- beams at injection into the waveguide portion of the linac by varying the settings of TR magnets was done. Some refinements were made in the techniques used for setting variables in the control vector. In particular, options were added to take multiple readings of data in order to reduce the sensitivity to noise and to permit limited automatic changes in pulse motor to data channel calibration factors. Some tests with live beams were conducted with limited success. It appears that the magnet "constants" are not really constant and that control vector parameters must be known to greater precision than they are now known.

Experimental Area Controls and Instrumentation

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

Switchyard

Two major tasks were completed in the continuing process of upgrading the controls and instrumentation in the SY.

The dynamic bypass shunts on 11 SY magnets were replaced to provide more stable performance and ease of maintenance. The racks containing the old shunt system were removed and new racks of shunt gear were installed. The computer controls were connected and the system was put into operation. Four new alarm panels for the shunts were wired into the system. New drawings to document the system were submitted to drafting.

Quadrupole magnets LX-QM-03 and -04 were placed on separate power supplies. Formerly, a single power supply served both magnets with one being controlled through a shunt. The modification provides the flexibility needed to satisfy the beam optics criteria.

A beam gate distribution unit was designed, fabricated, tested, and installed in the SY. This unit distributes the H^+ and H^- beam gates to various computers and devices in the experimental area based on operator-supplied criteria.

Area A

A major effort was mounted this quarter to design and build the remote controls needed to operate the remote handling package called Monitor. Functions that were put under remote control include all of the HAP hydraulic boom movements, hydraulic pumps, pan, tilt, zoom, focus, and iris on an array of TV monitor cameras, lighting intensity controls for the TV cameras, and positioning of the stem TV camera pod. Figure VI-1 shows the final system. The remote controls are attached to the pedestal in the foreground; the control racks are on the left, and the Monitor boom is in the background. The Monitor was operated through these remote controls to effect repairs in a high radiation environment in Area A.

Hastings gauges were installed in Areas A-3 and A-4 to replace the Varian vacuum controllers which have proved unreliable on the beam lines.

An indication that the A-3 beam plug is in its mid-position was designed and connected to the control computer. The appropriate drawings were updated.

Wire schedules were prepared for the AMO trunk line package and issued to the electricians. Racks for the AMO were installed and junction box layouts completed.

The first stage of software to provide the Area Manager with a logging and alarm terminal for Area A utility systems was completed. Periodic reports of utility system status are generated by the SEL 840 and printed on a remote 30-character/record printer in the Area Manager's office. The computer also scans the channels giving the utility status for alarm conditions and prints a special

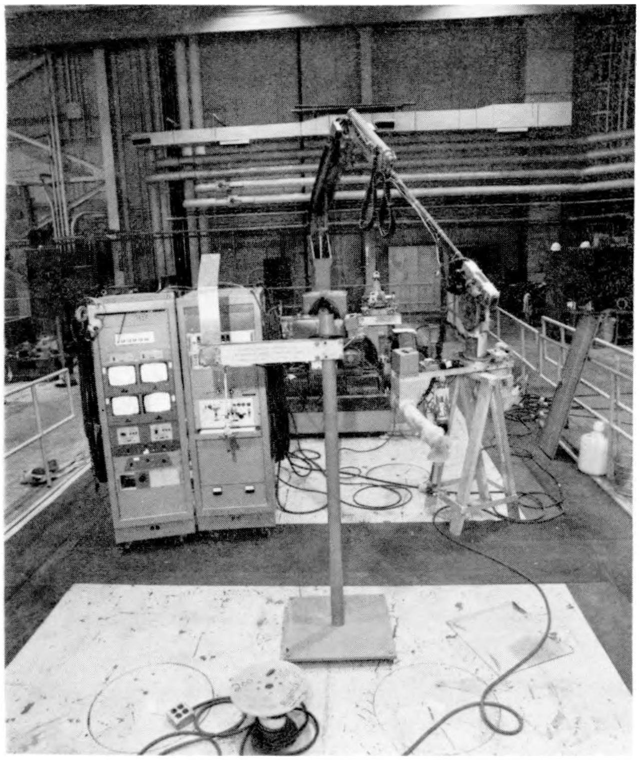


Fig. VI-1.
Monitor is one of the remote-handling devices at LAMPF. The remote controls are on the pedestal in the foreground; the control racks are on the left, and the Monitor boom is in the background.

report in case of trouble. Reports can also be requested at any time via keyboard command from the terminal. The first stage includes the Area A water system. Other systems are expected to be added in the future.

The harp control software was modified to operate the Low-Momentum Detector to permit preliminary checkout of this device. The display was modified to compute median and spot size only.

Thin Target Area

Seven new binary signals to indicate the position of the thin target were connected to the control computer and verified. CAMAC controls for two new pulse motors were installed. The checkout of the drive and readout channels will take place next quarter when the CAMAC modules arrive.

EPICS

Several improvements were made in the controls and instrumentation for the EPICS area. The wire schedule for the interlock system for all EA (EPICS Area) magnets was completed. Ten cables for the interlock circuitry were fabricated. The interlock wiring, including flow switches, was installed on magnet EA-BM-05 and connected to the control chassis. The computer controls to the power supply (EA-MP-04) which feeds magnets EA-BM-05 and -06 were installed and tested. The ground fault detector chassis for the focus magnets was installed in the EPICS regulator rack and checked. In the counting house, wiring was installed for the MWPC power supplies and the channel listings were updated.

Work was completed on the control system for the EPICS separator. The frequency servo loop was replaced with a stable, fixed-frequency oscillator. A new soft-spark detector was built and installed. A voltage/current crossover regulator was designed, fabricated, and put into operation. During the system checkout, it was necessary to research and improve the grounding system. The only element of the control system that may be lacking is some sort of servoing on the condition of the vacuum. If the new cold trap is effective, this servo input may not be required for the automatic run-up capability.

Design and writing of the new EPICS magnet control program was completed and checkout is in progress.

The NOVA magnet mapping system was enhanced to permit more on-line analysis of the data acquired, especially from DVM readings. BCD and binary magnetic tape capabilities were added to the BASIC language interpreter to permit control of data storage at the BASIC level. This system is intended to be used to map the EPICS spectrometer magnets BM-05 and -06.

Stopped Muon Channel (SMC)

Work continued in support of the conversion of magnet power regulators. The magnet interlocks were revalidated after the interlock chassis was reinstalled in new racks. Drawings were prepared to document this change. The wiring to distributed 24-V dc was completed. The power supply for the logic chassis was installed and rack-to-rack wiring was started. The display panel for the SMC was built and will be installed when the power supply changeover is finished.

Low-Energy Pion Channel (LEP)

A new vacuum valve was installed at the end of the LEP beam line. Cables to control the valve were pulled and connected. The addition was documented.

P^3 Line

The controls for the A-2 collimator in the P^3 line were tested. The only problem to be resolved is an interaction between the mechanical motion of the collimator and the limit switches. An alarm circuit was wired to the hydrogen target. CAMAC controls for the ISIC systems were installed and checked.

Beam Stop Area

The wiring defined in the wire schedules for the ISOP area was completed by the electricians. The following systems were partially or completely checked out: 1) ISOP cart drive, 2) TV lights and controls, 3) ISOP water system, 4) remote readout for water controls, 5) stringer motor drive, and 6) stringer limit switches. A multichannel system to control the speed and position of the ISOP stringers was built and installed but not tested. The stringer speed control was modified to ramp up and down in a predictable fashion. A substantial amount of documentation is yet to be done.

Lines B and EPB

The turbopump located in the nuclear chemistry cave was modified and remote controls were installed to operate this pump from Equipment Room B.

The counting house for Line B was completed and the controls and electronics for Exp. 179 were moved to this permanent location. Some additional work will be required when the target motor is changed from a pulse motor to an ac motor.

Line C and HRS

The installation and checkout of controls and instrumentation for Line C culminated in the successful transporting of beam to the Line C beam dump. All 66 magnet windings in Line C performed satisfactorily. The main problem uncovered in these tests was the lack of adequate current capability in the 24-V dc control power system. To correct this deficiency, power supplies capable of supplying 550 A at 24-V dc were acquired for installation as soon as the beam line is available.

The focus of the work in Area C was shifted to the HRS frame which is scheduled to receive beam early next quarter.

CAMAC controls for the ISIC systems were installed and checked. The programs for data acquisition and display from these devices were completed and put into use. These programs will run on any PDP-11/45 equipped with a Kinetic Systems 3911A CAMAC interface, and they have been used successfully at P^3 East as well as on Line C.

Software was also provided to display the values of two secondary emission monitors required for Line C tuning.

Modifications were made to the scintillation beam scanner programs to improve their speed and reliability.

Communications

The communications system continued to grow in response to requests for more stations and speakers. A new distribution box was added to Area A South to support more stations in Area A. Six speakers and one intercom station were installed in the Merrimac hot cell area and staff machine shop. Two stations and a speaker were installed in the A-4 target area. Two stations were installed on the middle and upper levels of the HRS. The Injector area received three new stations. The communications system in the Biomed treatment area was reinstalled and connected. A speaker was placed in the Area B counting house. The communications systems for three trailers were disconnected and reconnected after the trailers were moved. Cables for new stations were pulled to two health physics locations. Selected speakers were modified to accommodate the speaker cutout and volume feature. Two and a half days were spent troubleshooting a fault that disabled the Area A-South speaker system.

The effort to improve the volume on the CCR line progressed but with no audible results as yet. The amplifiers to convert the impedance of the on-line monitors were fabricated and are ready for installation. The two-way amplifier, which was to allow the CCR line to be split into two systems, was received and installed but did not produce the desired results. The problem is being reconsidered with the aid of a consultant.

Experimental Data-Acquisition System

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

Experimental Area Computers

The last components of the two new PDP-11/45s arrived and were installed. Slow delivery by the vendor of the disk systems caused a delay of several months in making these systems operational. The vendor has not yet supplied the new disk drives which were ordered but has supplied used drives on a no-cost loan until new drives can be delivered.

Plans were made and background material prepared for a summer study to review the current status of LAMPF computing support of experiments and to recommend courses of action and priorities for the future. Participants in the study, which was scheduled for August, were weighted toward persons who have participated in experiments at LAMPF and have had responsibility for the computing requirements of their experiments.

Computer Maintenance

During the past quarter, there were about 270 service calls for computer maintenance from the two maintenance teams — DEC and Group E-5. The E-5 team implemented their preventive maintenance schedule by assigning a technician almost full time to the task.

An over-write problem on Tektronix 4010 CRT terminals was solved by adding a modification to the terminal. Details of the modification were provided to the computer maintenance personnel so that they can install the modification as required.

All of the KSC-90/IBM-729 magnetic tape unit controllers were made operational with PDP-11/45 computer systems in the Experimental Area. Field changes and modifications discovered in the course of this effort were transmitted to the Kinetic System Corporation to ensure that future units would be received in operating order.

PDP-11 System Software

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

A tape utility task was written to run on the LAMPF Terminal Computer. This program satisfies a need to translate tapes from one format to another in order to be readable on the various tape systems in use at LAMPF. It also permits the contents of a tape in any of the defined formats to be printed.

A program was written to transfer an RSX-11D source file to magnetic tape in card-image format. Such a tape can be sent to C-Division to have standard cards punched.

A program was provided to list the tasks installed in an RSX-11D system.

Data-Acquisition Software

Development of the general data-acquisition package, Q which runs on the PDP-11s, continued.

A version of the MBD (programmable CAMAC interface) software which buffers event data in its own memory was completed. Timing tests indicate $\sim 5\ \mu s$ per word transferred in this mode of operation. The ultimate speed of which the MBD is capable under control of the best possible program is estimated to be $\sim 3.5\ \mu s$ per word.

The QAL translator, which translates a user event specification in MBD and PDP-11 code, was improved by the addition of commands which permit user-supplied MBD code to be inserted into the event specification to handle the special situations which often arise in experimental setups. Options were provided for saving and restoring the PDP-11's floating point registers upon entry to or exit from an event analyzer. The user interface to the translator was changed to provide a greater degree of control over the files used and created. Optional interfaces to the analyzer were provided to make it compatible with all current versions of the FORTRAN compiler and with assembly language programs.

The program QDUMP, which prints the contents of a magnetic tape generated by Q, was made less vulnerable to errors and bad data from the tape.

Much work went into improving the ease of use, reliability, and efficiency of various components of the package and to responding to matters which have arisen in the course of early usage.

All of the above improvements were contained in a new release of the software which was made available to users in July.

A development which was not completed in time for the July release is a major revision of the histogram plotting package. It represents a considerable improvement in the flexibility and readability of plots. It is expected to be ready for use early in the next quarter. A photograph of some sample plots is shown in Fig. VI-2.

A major collaboration with LBL was launched with the objective of making Q available under RSX-11M as well as under the current RSX-11D systems at LAMPF. The objective is to have complete compatibility between the two systems rather than to permit separate LASL and LBL versions to come into existence. In order to accomplish this objective, very close communication is being maintained between the two software development groups via telephone and an exchange of visits. A benefit of the collaboration which may outweigh the substantial one of having Q available under these two operating systems is the detailed critical review much of the code is receiving by two independent groups. The result should be improved design with excellent reliability.

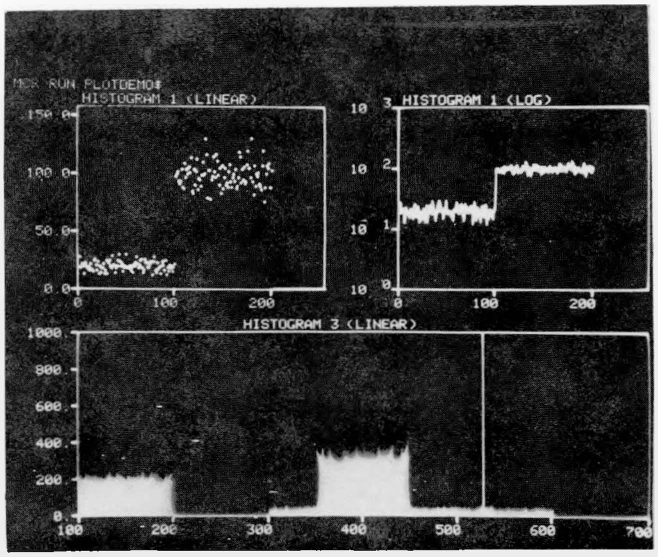


Fig. VI-2.
Sample graphs produced with the new histogram-plotting software.

Interface Hardware

A dual-ADC to PDP-11 interface for a nuclear chemistry experiment is under development. The unit will incorporate an LSI-11 microcomputer to provide independent and parallel data handling. The CAMAC module through which the data will be read into the computer was completed and tested. Mechanical items for the ADC interface were procured or fabricated. The front panel for the unit is shown in Fig. VI-3. Pin listings of the wiring were carried to 50% completion. Wire wrapping of the unit and electrical checkout will proceed next quarter. A preliminary report on the interface and readout module was written.

The Master Clock used by the nuclear chemists for experiment timing has proven to be unreliable. A WWVB receiver/decoder was ordered and a unit will be designed to interface with the CAMAC Clock Readout module developed last January. This new unit will need to convert the day:hour:minute:second NBS data into the day:fractional-day data desired by the users. A microprocessor will be used to perform the fraction-day calculations and handle the formatting of the output data to the existing slave display units.

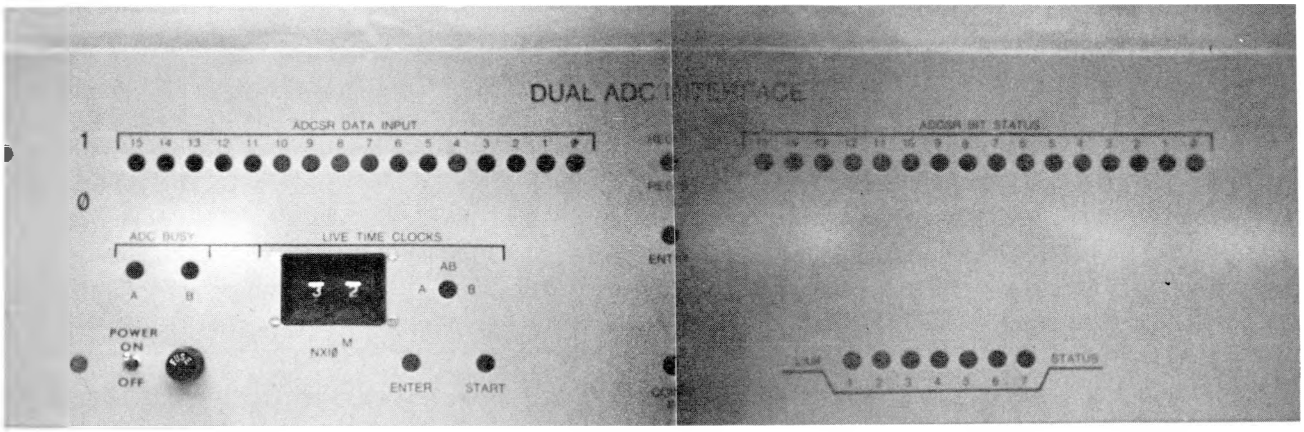


Fig. VI-3.
Front panel of a dual-ADC unit which utilizes an LSI-11 microcomputer to provide independent and parallel data handling.

LEEP

A total of \$75 000 in capital equipment funds was allocated to LEEP for FY-76T. These funds were immediately invested in items of equipment currently in short supply. One of the items is a new product, a one-wide NIM module, containing 12 fast amplifiers with a fixed gain of 10. This module sells for \$70 per channel vs \$130-350 per channel for competing products. Ten of these modules were purchased on the basis of a positive evaluation of two units purchased several months ago.

The maintenance operation for LEEP equipment continued to go smoothly. About 75% of the work last year was performed by technicians assigned to LEEP. The overflow, amounting to some \$17 000 in services, was handled by E-Division. Oscilloscopes are the most troublesome item. They fail frequently, are in short supply, and are most difficult to repair. Another vendor's equipment is being evaluated for comparison.

The digital panel printers ordered last quarter were received. These printers were purchased to provide a hard copy of data from LEEP multichannel analyzers. A delay in modification of the analyzers for their use has resulted because of connector problems. The connector supplied with the analyzer option board is not a LASL stock item and the mating connector had to be special ordered. These connectors should be received early next quarter. One unit was modified and tested with satisfactory results.

A delivery problem on connectors for the fixed-delay boxes delayed their fabrication. These connectors have been on order for four months and, in spite of frequent inquiries, they have not been shipped.

Miscellaneous I&C Problems

Solutions were developed for several problems which were peripheral to the main focus of the effort on instrumentation and controls.

Liquid Hydrogen Refrigerator Temperature Control System

Bids covering the four automatic sequence controllers for Experimental Area LH_2 refrigerator systems were returned late in the quarter. The controllers will provide automatic startup, run, and shutdown of the refrigerators in order to reduce manpower and provide more reliable surveillance and logging of operations. The bids will be reviewed next quarter.

Fast-Acting Vacuum Valves

The efforts of the Vacuum Task Force were supported with the development of instrumentation which facilitated a series of measurements on a shock tube that clarified the physics of broken vacuum windows. This knowledge prompted the design of a protection system based on spark plug sensors and an extremely fast-acting vacuum valve. An initial design was completed for the trigger system which involves four channels of spark plug input, a first-fired detector, and a high peak energy solenoid drive circuit. Construction of the trigger circuit will be complete within three weeks. The final version of the circuit will be determined by an evolutionary process.

Several ways of driving the valve closed were studied. One promising scheme is based on an explosive bolt employing an exploding bridgewire. Explosive components and firing circuits were ordered for testing.

Fast-Wire-Scanner Amplifiers (FWSA)

In order to study certain beam properties and to study the feasibility of replacing the older wire-scanner amplifiers by improved equipment, a self-powered, mobile electronics package was designed around the FWSA and built for evaluation.

Cryogenic Pressure Servo

A cryogenic pressure servo was designed, fabricated, and tested. Several problems remain but performance is approaching the ideal. The servo will monitor and control pressure, provide over-and-under pressure alarm signals, drive remote Sonalerts, and provide a digital output of the actual pressure. A printed circuit will be fabricated in the near future.

Sharing LAMPF Technology

Two members of the staff attended meetings of the NIM-CAMAC Working Group for computer interface standards. A draft document covering multiple CAMAC Controller/Distributed Intelligence Systems was generated and will be carried to the European CAMAC Working Group for further developments and collaboration. The standard provides for multiple auxiliary crate controllers (which may involve autonomous microprocessors) to share the CAMAC crate dataway such that distributed processing can be accommodated within a CAMAC system.

Continuing Education

The problem of keeping the technical staff abreast of the latest technology was attacked in several ways.

Three sessions of the Electronics Perspectives Seminar were held, one in each month of the quarter. In May, a tutorial was presented on the topic of fast, bipolar, bit-sliced microprocessor applications. The tutorial was given in two 90-minute segments. "Oscilloscope Basics" was the title of the seminar in June. It was presented in two 90-minute sessions by a representative of a major supplier of oscilloscopes. In the July seminar, a senior technologist conducted a digital workshop in three 2-h meetings. For this seminar, a logic demonstrator was designed and built. It accepts inputs through a set of front panel switches. LED lamps provide a visual display of inputs and outputs for all basic logic functions, including gates, counters, and address. Over 100 people attended each seminar and received a set of lecture notes and reference material.

Two members of the staff attended the National Computer Conference in New York City in order to gather information on advances in display systems in general, and color graphics in particular.

Three members of the staff attended formal courses in microprocessor system design, microprogramming techniques, and the use of Field Programmable Logic Arrays.

Three members of the staff completed a Digital Equipment Corporation video tape course on the PDP-11 series of computers.

VII. ACCELERATOR OPERATIONS

General

The accelerator was in continuous operation throughout the quarter. The machine was operated in 3-week cycles, typically with two weeks devoted to research, and the remaining week used for facility development and maintenance.

H^+ beams delivered to Experimental Area A for research increased steadily in intensity, from 20 μA during cycle 2 at the start of this quarter to 75 μA during cycle 6 at the end of the quarter. Machine availability during research shifts averaged 81% for the H^+ beam and 82% for the H^- beam.

The EPICS beam channel was added to the list of active experimental facilities early in the quarter. In HRS, proton beams were tuned to the beam stop and particles were detected in the spectrometer.

Experimental Program

Research quality proton beams to Area A totalled 59 300 μA-h during the quarter, as measured at the A-1 target station. An additional 750 μA-h went to Area B. The combined total is three times the cumulative total of all beams delivered to experimental areas prior to this quarter.

Fifty-two experiments received beam as shown in Table VII-I. This tabulation does not include parasite use of beam during production runs or the beam used in facility development or tuneup activities.

TABLE VII-I

QUARTERLY REPORT OF BEAM PROVIDED FOR EXPERIMENTS

Experiment No.	Channel	Shifts (8 h)	μA-h	Experiment No.	Channel	Shifts (8 h)	μA-h
2	LEP	42.5	8000	156	EPICS	26.00	6700
7	SMC	18.0	8000	164	LEP	12.00	3100
12	SMC	23.5	3500	174	RADIP	0.30	170
29/54	LEP	38.5	19900	176	EPB	25.50	----
31	Neutrino	84.0	21200	179	AB Neutron	34.50	131
35	LEP	42.5	17000	193	AB Neutron	78.00	300
37	SMC	56.0	19300	195	Biomed	16.30	3100
44	Biomed	12.0	3500	214	Biomed	3.80	400
60	SMC	27.0	10500	219	EPB	61.00	----
67	LEP	9.0	2400	236	Biomed	8.50	2400
67	P^3	7.5	2400	243	AB Nucchem	3.00	60
80	P^3	59.0	12400	246	EPICS	81.00	37000
86	TTA	72.0	25500	254	Neutrino	99.50	12700
90	P^3	21.0	7600	263	AB Neutron	14.00	52
99	P^3	45.5	20000	265	EPICS	28.00	8900
100	SMC	14.0	5100	269	AB Nucchem	5.00	164
103	P^3	0.7	280	270	Biomed	34.00	7400
105	AB Nucchem	1.0	37	271	Biomed	33.50	8100
119	P^3	4.0	1880	272	Biomed	4.00	560
121	LEP	28.0	8900	273	Biomed	12.50	3800
123	P^3	14.5	3800	274	Biomed	15.00	4300
124	AB Neutron	7.0	----	275	Biomed	31.00	6800
130	EPICS	30.5	5700	277	SMC	6.00	1700
142	SMC	19.5	3900	278	EPB	9.00	----
148	Neutrino	51.5	15300	279	AB Neutron	15.00	70
151	Biomed	1.0	360	282	AB Nucchem	0.15	----

Facility Development

Machine time allotted for facility development was used for the study of beam transport problems in the drift-tube linac and the TR, attempts to accelerate high peak currents, testing of prototype beam position monitors, and the development of a wire-scanner amplifier with variable gain suitable for the study of beam halos.

Software control vectors were developed to provide independent single-knob control of H^+ beam position and angle in the TR main-line. Attempts to provide similar controls of H^- position, angle, and phase in the side track did not succeed, probably because of magnetic field nonlinearities which are not understood.

Attempts to tune 10 mA peak currents to 800 MeV, although apparently successful in that cavity fields were kept within tolerances presently thought adequate, were invariably accompanied by unacceptable beam-loss levels as a result of low-momentum components.

In Experimental Areas A and A-East, development efforts were concentrated on achieving beam tunes suitable for operation at 100-μA-average currents, considering limitations imposed by heating effects in vacuum windows, activation of beam line components, and experimental requirements. A start was also made on the development of beam tunes suitable for simultaneous operation of Lines B and C.

Operating Experience and Downtime Accounting

Machine operation continued to be reliable and stable despite the increased beam intensity. Another significant improvement in reliability of 201-MHz systems was noted. A summary of the machine downtime is given in Table VII-II.

The first major outage of the control computer occurred during this period. The accelerator was kept in operation at 10-μA-average current instead of the scheduled 50 μA during the three days the computer was out of commission. The problem was traced to transistor damage apparently caused by line voltage surges associated with lightning.

TABLE VII-II
QUARTERLY SUMMARY OF MACHINE DOWNTIME

Category	Downtime (h)	Percent of Total
201-MHz amplifiers and transmission lines	27	10
805-MHz amplifier systems	64	24
Vacuum	20	7
Magnets and magnet power supplies	8	3
Interlocks	25	9
Injectors (H^+ = 13, H^- = 13)	13	5
Water	14	5
Computer control and data acquisition	60	22
Reference source	4	2
Beam stops, plugs, targets, strippers, scrapers	6	2
Beam diagnostics	6	2
Timing distribution systems	2	1
Miscellaneous (utilities, etc.)	20	7
TOTAL	386	

VIII. EXPERIMENTAL AREAS

Secondary Beam Line

The major work of the secondary beam line section during the past quarter has been to assist experimenters in their setups and experimental runs, and to update and improve the secondary beam lines, their caves and counting houses.

Major activities were:

1. Beam plugs for SMC-East have been designed and built, and will be installed before cycle 7 to be integrated into the personnel safety system for that cave. The bulk shielding setup for Exp. 101 to be run in that cave is nearly complete.

2. A major cleanup in the SMC beam channel has been carried out, and services to the experimental caves have been updated. The SMC counting house is to be remodeled shortly, and a permanent trunk-line cable package is to be installed from the counting house to the caves for experimenter use.

3. Services have been updated in the LEP cave including a permanent trunk-line package. A similar trunk-line package is scheduled for installation in P^3; remodeling of the P^3-West counting house is planned.

4. An air-activated vacuum valve has been ordered for SMC, and a hand-operated absorber system has been designed and built for installation into the vacuum of SMC for use in low-momentum muon beam studies.

5. A large vacuum pump package (rough pump/blower system) has been received and will shortly be installed in SMC. The vacuum pump package for P^3 is being rebuilt.

6. Extensive support has been given in setting up Exp. 90 in P^3. Support has been given to Exps. 121, 35, and 29/54 in LEP. Experiment engineer support is being given to Exp. 25.

7. The test channel has received heavy use over the past quarter from approved experiments, and users doing general development work.

8. The rebuilt LD_2 target in Line B has been reinstalled and is working quite satisfactorily. As a result, Exp. 193/279 finished its run. Assistance was rendered in setting up Exp. 262/263/264 in Area B.

9. In EPB, Exp. 279 was set up and run. Then the EPB beam cave was completely dismantled; shielding walls on the north and east sides of the cave were moved outside the building. This massive rebuild was done in preparation for the run of Exp. 124.

10. Remote controls and a remotely operated air-activated vacuum valve for the turbopump in the nuclear chemistry cave of Line B were installed and are now operational.

11. A temporary beam stop was placed in Line B for part of cycle 6 to allow Line C tuning to be carried out while setup and rebuilding in Area B continued.

Shielding

Fabrication and installation of the steel boxes to cover the service trenches and cableways at the top of the shield completed the shielding mass for the main beam line through Experimental Area A. Minor modifications will be made and several have already been designed. A more compact concrete face has been designed for the EPICS area to allow greater travel of the spectrometer. Special blocks for this face have been ordered for delivery in August.

Design work included a shield mass to cover the vacuum pump at the top of the EPICS beam line. The large-diameter pump-line penetration is allowing radiation leakage at the top of the shield. To reduce the general background, the pump package will be enclosed in concrete shielding.

A concrete and steel shield was fabricated and installed around the exterior end of the A-2 target shield and drive mechanism. Higher than normal radiation levels existed here because of the routing of the target cooling water leads through the mechanism.

Considerable effort was dedicated to filling cracks between shield blocks. Most of these were around the Merrimac shield doors, at the side walls and around the top key blocks. Polyethylene tees, 2.5- and 10-cm thick, were installed. They were effective in reducing the radiation leakage through the cracks.

A major task during this quarter was the continuing improvement of the massive shield door moving systems. The hydraulic lifting and moving trucks, a major maintenance concern, were extensively modified to provide dependable service. Ten trucks were completely overhauled and 28 new trucks were assembled and checked out. Two additional sets of large hydraulic rams for pushing and pulling the doors were assembled.

The large shield doors at A-1, A-2, A-5, and A-6 target stations were opened and closed during this quarter. These operations, to gain access to beam line hardware requiring maintenance repairs, provided good tests of the systems for moving the massive shield assemblies.

Since the hydraulic trucks cannot be left in the shield doorways because of the radiation levels, dummy trucks have been fabricated from cast iron to form removable shield plugs for the truck slots. Some 50 of these dummy trucks have been assembled by AMO technicians and 16 of them installed under doors 2B, 2C, and 2D. The rest will be installed as other doors are opened.

Facility Operations

The AMO was moved into a trailer complex obtained as surplus from another laboratory division. The new quarters are located south of Area A. Adequate space is available for the AMO staff, a safety office, health physics office, cryogenics office, water systems office, remote handling offices, and a lunch room. Operations will be hampered until the intercom system is installed in the new building.

An updated version of the layout of the experimental areas has been prepared (Fig. VIII-1).

Organization of the service yards near the experimental buildings has continued toward full scale operations. Paving of yards and parking areas on both north and south sides of Area A along with previously applied slope treatment has greatly reduced the dust problems. Some isolated drainage problems still are to be corrected, and additional dust control will be applied at the east end of the area.

A large shielding yard has been established to the east of the main beam stop. Steel slabs, scraps, and iron counterweights are now stored there for future

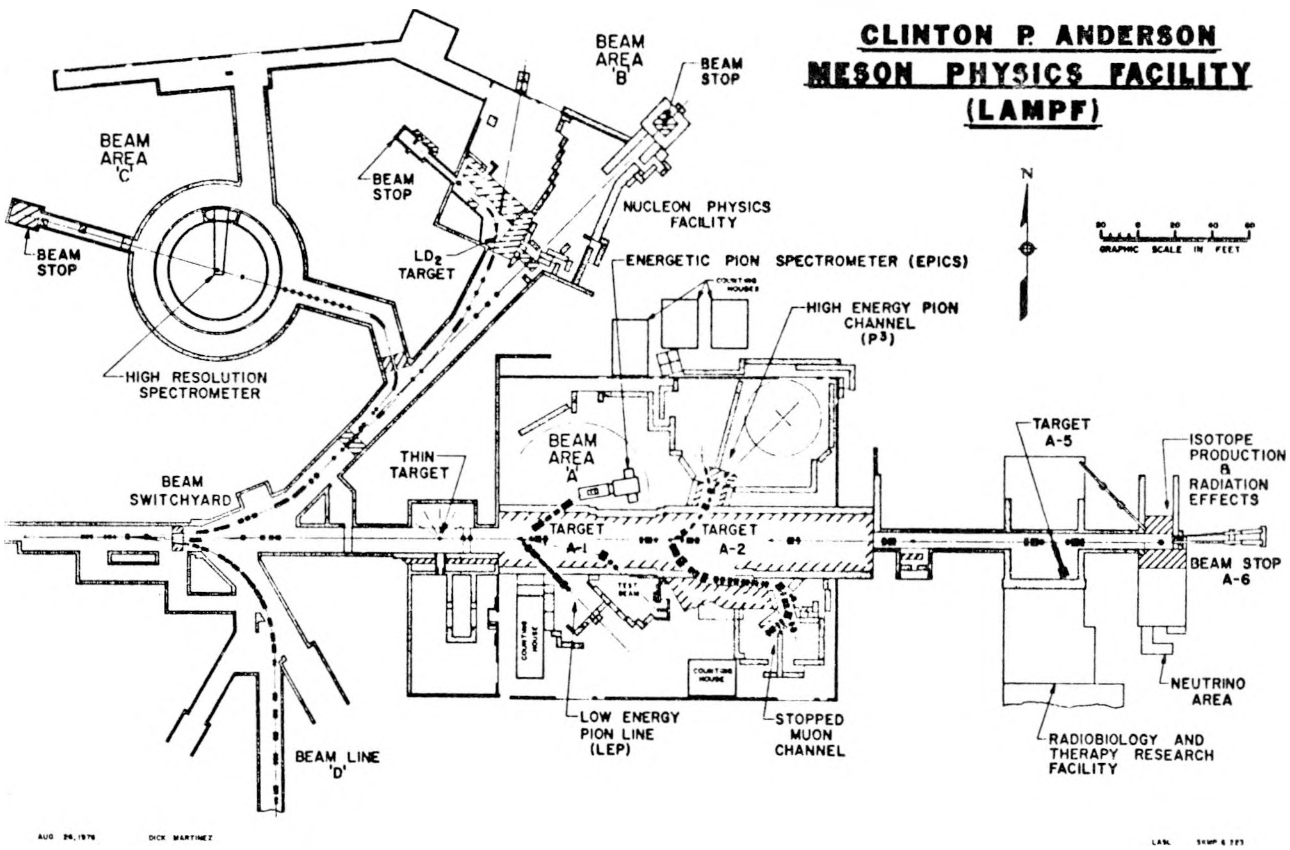


Fig. VIII-1.
Layout of experimental areas as of July 1976.

shielding needs. A cutting area has been erected there to handle all the steel cutting needs.

Low-level radioactive solid-waste storage has been consolidated north of Area B. Large components and shield blocks with residual radioactivity have been placed in a secure enclosure. Miscellaneous hardware pieces are stored in a locked trailer adjacent to the enclosure.

The staff shop in Experimental Area A has been expanded with the addition of a horizontal milling machine with a vertical head attachment, and a 14-in. lathe with a 54-in. bed. Some rearrangement of the shop area has improved the working space. The adjacent tool crib has been expanded to provide a larger inventory of tools and parts for experimental area use.

The AMO technicians utilizing the staff shop have fabricated 14 large gas bottle racks and have installed these racks throughout the area — mostly near experimental setups where needed gas supplies can be properly maintained and serviced. The AMO has continued and expanded its support of experiments in setup, operation, and takedown. Considerable support has been provided in the cryogenic systems, not only in experimental targets but also in the production targets. The assembly and operation of these targets has required about 12 man-months of support during this quarter.

Cryogenics

The LD_2 target in Area B developed several leaks due to various causes, and considerable work was required to repair them. The central shielding plug was rebuilt with new transfer lines, and the target loop required new electrical feedthroughs and windows. An alternate target system was built by the Univ. of New Mexico research team using a cryostat borrowed from LBL. MP-Division designs were used.

A tritium target system has been built and tested for Exp. 90. The cryostat was made to work properly, but other operational difficulties have made necessary the construction of a second generation cryostat, currently in progress.

Refrigerated targets were built and operated for Exps. 176/219, 99, 262/263/264, and 193. Similar targets are being constructed for Exps. 124 and 222.

Experimental Area Cooling-Water Systems

The five radioactive water systems (X02-X08) operated continuously during this period. As of July 31, 1976, the water specific resistivity for each of these systems was as follows:

X02	~ 4.5 MΩ-cm
X03	~ 9.0 MΩ-cm
X04-6	~12.3 MΩ-cm
X05	~ 1.2 MΩ-cm
X07-8	~14.5 MΩ-cm

Three new water-cooling systems are now operational. Included are systems for the EPICS spectrometer magnets, the HRS spectrometer magnets, and the magnets in Area A experimental caves.

Installation has begun on the system to collect and print out water systems data in the Area Manager's Office.

Installation has also begun on the high/low flow alarms from the Area A and A-East valve cave flowmeters.

Radioactive Exhaust System

The exhaust fan is now continuously drawing air from several areas and discharging it to the 100-ft stack. Those areas include the SY, A-6 beam stop, A-5 target cell, Area B beam stop, Area B building, and Area C beam stop. A damper has been designed and built for the SY duct. Dampers are installed in the Area B and Area C ducts, in addition to the radiochemistry fume hoods.

Remote-Handling Equipment

The Monitor remote-handling system was prepared for operational use in mid-July. New control panels were delivered and assembled. The hydraulic Servoarm was mounted as the right arm on the shoulder assembly at the end of the Monitor boom. The left arm is the PAR rate-controlled manipulator. The second pan, tilt, and zoom camera unit has been mounted on the shoulder assembly; a unidirectional microphone has been installed on the camera.

Monitor, in conjunction with manually operated tools, was used in a remote handled repair job at target cell A-2. One piece of water-cooled shielding was removed from above the A-2 target box, and the vacuum hatch was opened. This allowed release and withdrawal of the A-2 target mechanism, which had been stalled. The A-2 mechanism was altered to prevent recurrence of the fault and reinserted.

Further consideration of TV camera position and lighting must be given for more effective use of the Monitor system. The services of a TV consulting firm that specializes in remote handling will be sought.

Servoarm, the hydraulic nonforce-reflective master-slave servomanipulator system supplied by the Remotion Co., has proven to be a fast, agile, and accurate manipulator. However, it is still a prototype device with many improvements needed before it can be upgraded to a force-reflecting system. Among the improvements under way are movable hydraulic seals, a stress analysis of all of the arm components, and installation of pressure relief valves and safety devices to protect both the mechanism and operating personnel.

Preliminary design work has been started and some purchase orders placed on a Servoarm operational model. This model will be used to test the basic concepts to be used in a development program for a full force-reflective Servoarm system. The model will be capable of two-degrees-of-freedom control and will utilize either a mechanical-hydraulic slave to respond to the master commands or an analog computer. The latter approach allows more flexibility in choosing certain system parameters but sacrifices realistic response in others. The basic control concept has been laid out. Position signals fed back from both the master and slave actuators to a common summing point are compared to the command signal. The unbalance error signal is split between the two forward loops with a sign change in one to generate commands to the servovalves. These are pressure control valves which, due to internal feedback, produce pressure differentials across the load ports in response to the command signals. Thus the working pressure is applied to the load, and a reaction pressure is applied to the master manipulator arm giving a physical feel to the job being done. The model will test the realism and usefulness of this feel and allow better electronic development.

Satisfactory progress is reported by the T.O.S. Co. in the construction of the two-arm force-reflective master-slave system (Telearms) which is scheduled for delivery in early 1977. Delivery of the boom system which will support Telearms is expected shortly.

Effort is continuing on the design and fabrication of remote handling tools. A prototype retractable eyebolt has been completed. Procedure manuals for the assembly and disassembly of target cells and the main beam stop have been drafted.

The prototype cryostat, with its new ^{3}He condensing coil, has been tested several times. Temperatures of 0.35-0.5 K were obtained in the ^{3}He system. The refrigeration load measurements have been hampered by the liquid level indicators used at the present time which could not discern level differences of 3 mm-10 mm. Design studies for better liquid level indicators will commence presently.

The design for modifying this cryostat to receive a target insert is now in progress.

IX. BEAM LINE DEVELOPMENT

Beam Line A

Switchyard

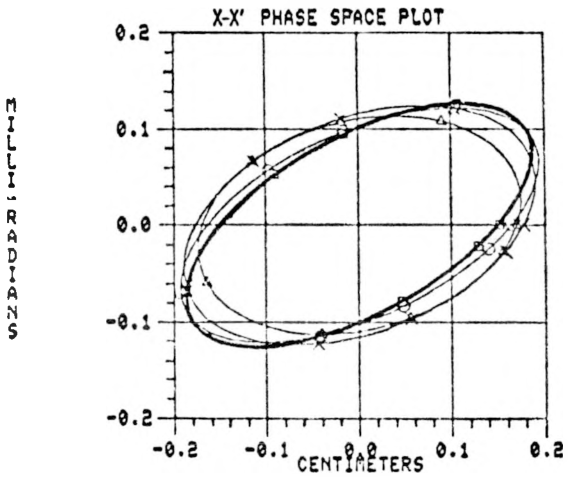
During this quarter we have had production runs of 20-, 35-, 50-, 60-, and 75-μA beam current in Areas A and A-East. Transport tunes were developed for these currents with the immediate goal of progressing to 100 μA with acceptable spills in the SY and in the hands-on-maintenance A-4 region. Near the end of the quarter, a 2-h run at 120 μA demonstrated the capability of the transport system. A week later we transported 100 μA for several hours with spills reduced by a factor of ~10 from previous operations. These reduced spills were made possible by removing vacuum isolation windows in A-4 and in the downstream end of the switchyard. These windows were originally installed as interim protection for the Area A harps in the event of a sudden vacuum failure. The SY window will be replaced with a fast closing (<100 ms) valve for cycle 7 with spark-plug vacuum triggers located in the SY and Lines C, B, and EPB.

Present spill levels are believed to be adequate for extended operation at 100 μA but a decrease in the beam halo must be made for operations at higher levels. Insertion of thin targets on the order of 10^{-3} radiation lengths of uranium at the SY TTA produces spills in A-4 which are intolerable. Additional development will be pursued to accommodate these targets. An alternative is the use of thinner targets which is also required by the EPICS-imposed constraints on the A-1 spot size.

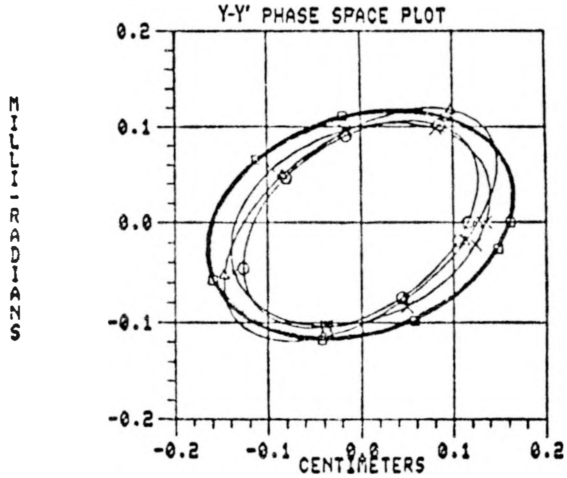
Linac Phase-Space Measurements

Measurements of the phase-space parameters of the beam exiting from the linac became routine during the quarter. The parameters are extracted from profiles of the beam at four locations in the SY within 20 m of the end of the linac. Several results are of interest:

Measurements made in cycles 2, 3, and 4 at peak currents between 1.5 and 1.8 mA are shown in Fig. IX-1 together with the predicted phase-space ellipse from a 1971 Monte Carlo calculation in which particles were traced through the linac. The calculated ellipses shown are those which would contain ~40% of



SYMBOL	SPOT	DIV	CORR	EMIT	I_p	
CIRCLE	.1940	.1220	.5350	.0200	1.8 mA	Cycle 2
X	.1900	.1240	.3650	.0219	1.5 mA	Cycle 3
TRIANGLE	.1740	.1130	.2290	.0191	1.6 mA	Cycle 4
SQUARE	.1880	.1260	.5980	.0150	14.0 mA	Monte Carlo



SYMBOL	SPOT	DIV	CORR	EMIT	I_p	
CIRCLE	.1270	.1060	.4170	.0122	1.8 mA	Cycle 2
X	.1400	.1040	.2700	.0140	1.5 mA	Cycle 3
TRIANGLE	.1480	.1190	.5180	.0151	1.6 mA	Cycle 4
SQUARE	.1660	.1180	.2340	.0150	14.0 mA	Monte Carlo

Fig. IX-1.

Linac H^- emittance from SY measurements at 800 MeV, and from 1971 Monte Carlo calculation (heavy line). Measured emittance contours, assumed elliptical, are derived from central 68% of beam profile width and correspond to rms emittance for Gaussian-like distributions.

the beam if the 4-dimensional ellipsoid in transverse phase space is filled uniformly near the exit of the ion source (40% in 2-dimension projects to 68% in 1-dimension and thus corresponds to the rms size for Gaussian-like distributions). The calculated ellipses are for a peak current of 14 mA at the exit of the linac and do not take into account misalignment, tuning errors, etc. The measured horizontal ellipses tend to be larger than the calculated ellipse, but horizontal oscillations of the beam are known to exist and could account for this difference. The measured vertical ellipses are smaller than the calculated ellipse and may be reflecting the apertures required to reduce the peak current. In general one concludes that there is reasonable agreement between measurements and predictions and that the linac beam is reasonably reproducible as reflected in the similarity of the three measured ellipses.

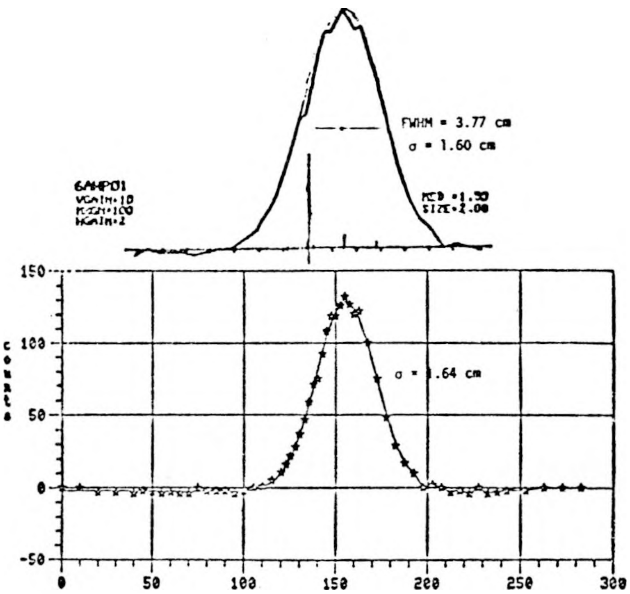


Fig. IX-2.
On-line harp beam profile (top) with ruler-measured FWHM, and off-line analysis of profile (bottom) as Gaussian-plus constant background.

A-6 Compromise Tune

Insertion of the 8-cm high-density-graphite biomedical production target increases the A-5 exit emittance and reduces the beam momentum by 45 MeV/c. Beam studies have been made toward minimizing the effect of A-5 target position on the A-6 users, by minimizing the A-6 spot size change with A-5 target position. In addition, the A-6 vacuum window and beam stop have current density limits which impose spot size requirements. The emphasis of this effort has been concentrated on measuring the beam phase space at A-5 with sufficient accuracy to calculate the downstream transport. The first task was to determine the repeatability of the information from the harp data with off-line as well as on-line analysis. The off-line analysis fitted a Gaussian plus background to harp data stored on tape. Program output is shown in Fig. IX-2. There was <5% difference between this fitted profile width and the width determined from FWHM estimated from the on-line harp display. The variation from profile to profile for the same magnet setting was 2% or less. Thus a conservative estimate of 10% was placed on the FWHM width obtained on-line.

The next task was to determine the A-5 exit emittance with target-in and target-out. The method used was to make profile measurements on the two harps downstream from the target over a range of settings of 5A-QT-4,5,6. The calculated transport matrix elements are combined with the measured profile widths to estimate the emittance.

Then a setting for 5A-QT-4,5,6 was calculated which would minimize the A-6 spot-size change with A-5 target-in to target-out change. To check the results, foil irradiations were made by CNC-11 at the beam stop for both A-5 target-in and -out at three different magnet settings around the calculated values. One of the settings produced a near circular spot size between target-in and -out. This setting was the one predicted to be the best compromise tune by calculation from the emittance measurements.

The actual spot size at the 6A-HP-01 harp and the beam stop is dependent upon the phase-space parameters at A-5. The compromise between target-in and target-out is dominated by the effect of the momentum change between target-in and target-out. At this time it appears to be that a ratio between 5A-QT-04,-05 field values of 0.9 produces the best compromise tune. More data must be taken to confirm this belief for the larger spot sizes needed at 100 μA and above.

H^- Beam Studies

A narrow horizontal slit has been used to probe the H^- phase space by stripping all beam outside the slit opening and subsequently separating the stripped beam from the unstripped beam with a bending magnet. After passing through a bending magnet, the horizontal distribution of the unstripped beam is related to the momentum distribution as well as transverse phase space at the slit. After drifting a distance from the narrow slit, the width of the beam in the direction of the narrow dimension of the slit is a representation of the divergence at the slit. Figure IX-3 shows two distributions obtained with a 0.5-mm slit on July 11. Figure IX-3(a) is a plot of the horizontal distribution vs slit vertical coordinate and shows that the beam is composed of two distinct components. Whether the beams differ in momenta, or only in transverse phase-space properties, has not been determined at this time. Figure IX-3(b) shows a typical transverse phase space (y vs y') distribution.

Muon Channel

South Leg Low-Momentum Beam

The region of useful operation of the south leg of the channel has been extended from 55 MeV/c down to 47 MeV/c. The loss in total intensity was 20% for which the experiment currently using the beam was more than compensated by an increase of 20% in signal-to-noise. Positron contamination remained below 5%. Total flux was $\sim 100\ \mu^+/\mu$A-s.

East Leg High-Intensity Pion Beam

In collaboration with the Caltech and Yale groups under Felix Boehm and Daniel Lu, ~30 shifts of beam time were spent investigating the east leg. The π-stopping rate was found to vary only slowly with momentum from 120 to 250 MeV/c. The final best-case stopping rate was 1-2 $\times 10^5\ \pi$ (μA-s-gm/cm^2) in a 5- by 5-cm target. The uncertainty in the measurement is due to the uncertainty in the method used for determining the proton beam intensity during the low-intensity pulse. Total beam spot size is 5 by 15 cm. A troublesome discovery is that the beam intensity is two to three times higher in front of the two quadrupoles which constitute the east leg than at the intended focus. Calculations are under way to investigate this further.

The results of this effort indicate that both the intensity of the beam and the backgrounds will be adequate for the π-mesic x-ray experiments using bent crystal spectrometers.

The PDP-11/45 Used for Exp. 142

The PDP-11/45 currently intended for Exp. 142 and, ultimately, as a replacement for the μ-channel 11/20 is now fully operational under either DOS or RSX.

Line X Tuning Development

Approximately five shifts of H^- beam line development time were spent in this quarter on

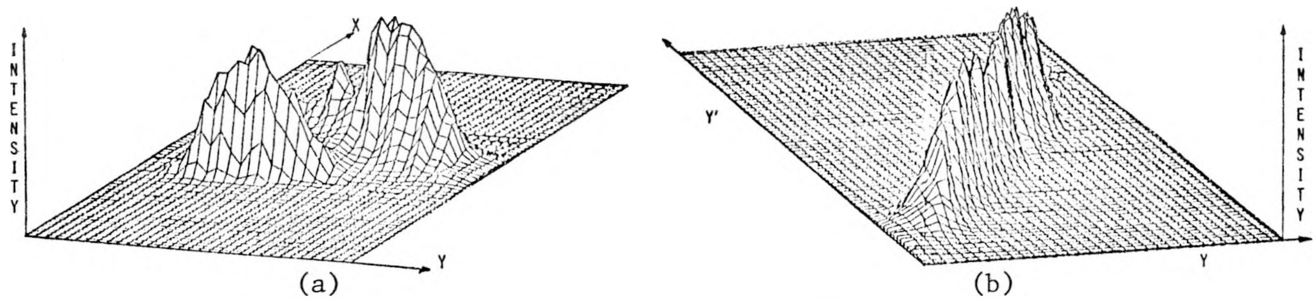


Fig. IX-3.
Emittance of H^- during cycle 5 as measured at LX-ST-1Y by slit-scan method. The stripper is a narrow horizontal slit and can be moved vertically across the beam to give true slices of y phase space.

Line X tuning to meet Line C input beam requirements, imposed principally by the Line C admittance. The requirements are specified as x and y spot sizes and divergences at the Line C stripper source, LX-ST-05. (The x-spot size requirement may be relaxed since the stripper foil may itself form the required spot size in the x-dimension). In order to maximize the beam available to Line B as well as Line C, the beam at LX-ST-05 should be tuned as a phase-space waist. The phase-space areas outside of the Line C admittance are to be trimmed off using upstream Line X strippers. Finally, the beam should be achromatic after the 45° Line X bend.

Line X has a four-quad output section for phase-space matching, to minimize the amount of beam stripped off upstream to meet the Line C admittance. The four quads are close together, with no profile instruments between them, and run with short focal lengths. This arrangement is difficult to tune.

In addition, the phase-space measurement per se is difficult under the best of conditions. The technique employed currently uses profiles from three wire scanners, as shown in Fig. IX-4, located in the 17-m quadrupole-free space starting near LX-ST-05. The analysis approximates true isodensity contours in transverse phase space with ellipses fitted to the three profile percentile widths, as shown in the figure, with the ellipses labelled by percentiles on the profiles.

The phase-space measurement and analysis technique was used in a succession of beam runs with

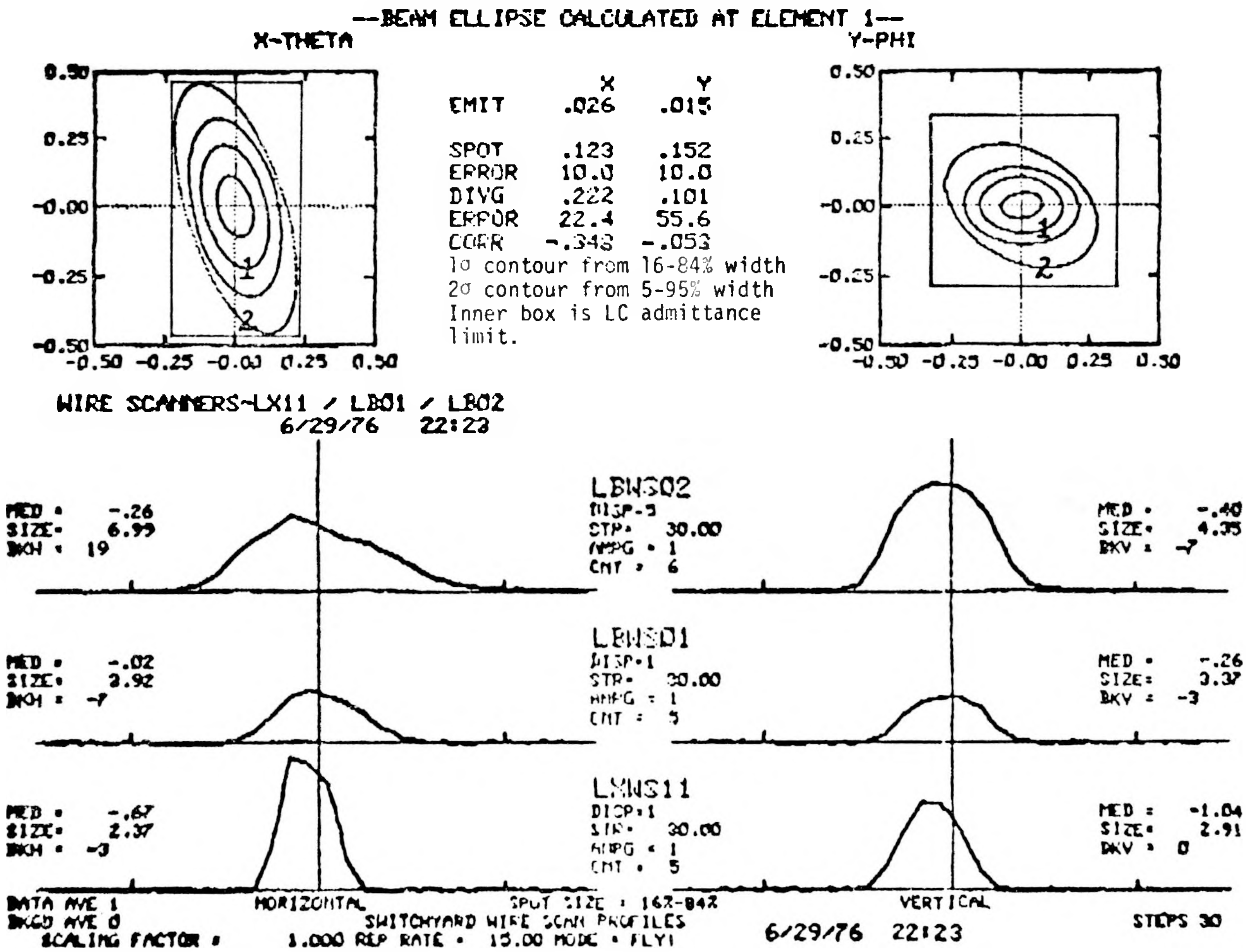


Fig. IX-4.
Output beam profiles and phase space from Line X when tuned for simultaneous B and C use.

various quadrupole tunes, finally converging to the tune shown in the figure, which is suitable for initial Line C operations. The analysis, although only approximate, shows that >90% of the beam is within the Line C acceptance limits. Only a small amount of beam was stripped off upstream. Among the remaining developments in this area are studies of efficient ways of measuring the outlying phase space and observing the effects of the strippers.

Instrumentation and Controls

Harps

A new harp wire was evaluated this quarter and the results to date indicate suitability as a replacement for the carbon monofilament now in use. The new wire is 4 mil (0.1 mm) silicon carbide monofilament with a 1.3 mil (0.03 mm) carbon monofilament core. The wires can be prestressed so that thermal expansion due to beam heating will not cause the wires to sag. The new configuration will be one wire per bundle rather than the four wires per bundle now in use.

Three harps were replaced during this quarter, twice at location 5A-HP-04 and once at 5A-HP-02. A number of wires were broken on each harp and a coating of some foreign material was observed on most of the wires. An electron microprobe determined that the major elements in the coating were tin and sulfur. Although tin was used in the plating process for the carbon wires, it is unlikely that the large wire area with cratering was caused by this source. The sulfur component could be caused by hydraulic oil that leaked into the vacuum just prior to the occurrence of problems with the harps.

Hardware improvements under development for the harps are:

- higher purity alumina substrates for the small (10-cm bore) profile monitor harps,
- nickel-printed circuitry is under consideration to permit spot-welding wires rather than soft-soldering them,
- replacement edge-connectors, all ceramic, to improve the mating of these plug-ins,
- commercially-obtained ceramic feedthrough insulators to replace the present m.i. assembly fabricated in-house.

Beam Line Protection

Development of a new set of programs for current monitor readout and transmission protection was coordinated. The programs have improved operator interaction. For example, the calibration procedure leads the operator through the correct sequence on the CCI. Storage scope displays are available for documenting system status, e.g., present parameters in the transmission monitor tables. A half-shift of development time was spent diagnosing some hardware and program deficiencies.

Magnet Systems

A set of tests were run (with MP-1) in a temperature-controlled oven to study thermal effects on the present and prototype metering shunt amplifier cards. The factors studied were offset, common-mode rejection, and gain stability. Although the present design exhibits some CMR slew, the prototype exhibited essentially the same error in offset slew with temperature change. Further development on that manufacturer's component was discontinued.

Magnet Measurement

Preparations for mapping the first EPICS spectrometer magnet were extensive. A dowel-pin was fitted to the Zozobra test magnet to develop the computer-driven pin-find program. A milling machine was modified and fitted with stepping-motor drive to carry the cantilevered 3-m mapper tube (see Fig. IX-5). The MP-10 coil cart assembly was fitted to this mapper, and preliminary maps have been taken.

During this period, the mapping of the Bicentennial magnet for Exp. 29/54 was finished. The Ames C magnet for Exp. 93 was remapped, after the coils were repaired, with no pole shims. Eighteen field maps of the hodoscope magnet were made for Exp. 221/222. In order to calibrate the hodoscope measurements, the coil integrator gains were remeasured since the 0.6-m gap of this magnet precluded the usual technique of normalizing to an NMR standard. Also the Zozobra test magnet was mapped at two currents to check the calibration of the two coils measuring the B_y-field components. The 30D40 Magnet (C-configuration for Exp. 90) with steel plates added to the side opposite the yoke was also mapped.

Fig. IX-5.
Magnet mapper cantilevered and mounted on milling machine with 3-axis travel for EPICS spectrometer measurement.

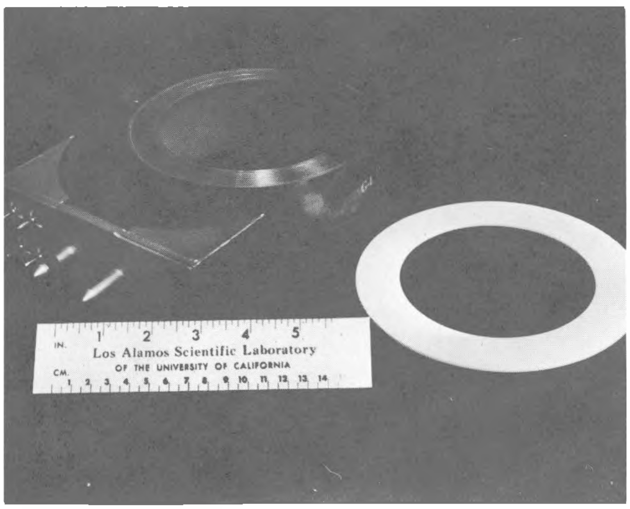


Fig. IX-6.
Components for radiation-hardened beam current transformer: mounting, Hy-Mu80 core, alumina ring.

Hardware Development

Magnet assembly has been delayed by the moves required to accommodate PIGMI equipment in the former magnet laboratory. However, a new entirely inorganic current transformer has been assembled for the new A-1 profile monitor (Figs. IX-6 and IX-7). On bench test, this transformer exhibited a droop of ~3% on a typical LAMPF pulse.

High-Level Dosimetry

A third film type has been procured for addition to the high-level dosimetry package previously described.[1] In addition to the silver-phosphate glass rods, which read satisfactorily up to 10^5 rads, it was felt desirable to have read-out capability between 10^5 and 10^7 rads, where the Kodak Megarad film becomes effective. A polystyrene film[2] has therefore been added for this intermediate coverage, and its only disadvantage appears to be greater light sensitivity than the other materials exhibit. The pure aluminum foil holder for the dosimetry package makes the light sensitivity a negligible consideration.

Calibration work on these dosimeters is continuing, using the P-6 gamma calibration facility.

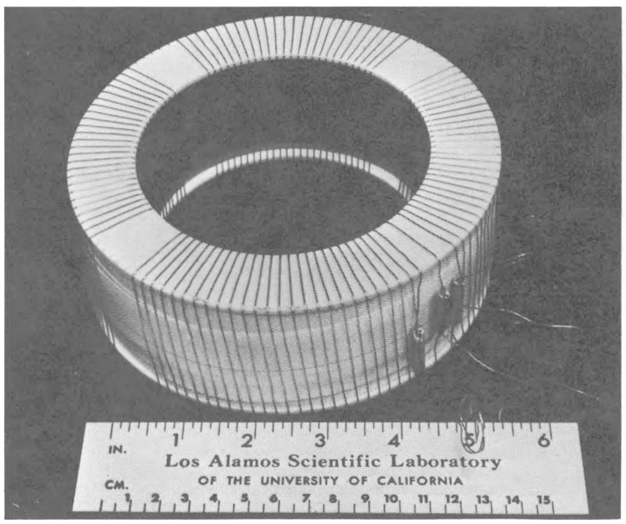


Fig. IX-7.
Beam current transformer, 10-cm bore, 100 turns. Completely inorganic, with calibration winding.

Primary Beam Line Vacuum System Improvements

A 10-cm commercial fast-closing valve which closes in 25 ms has been selected and ordered for use in isolating Line A from the rest of the primary beam lines in case of a vacuum accident. This valve will not be delivered until October 1976. In order to operate at 100 μA average current, the isolation windows in Line A must be removed to avoid undue activation of the downstream SY and the A-4 tunnel. An improved version of the LAMPF-designed 10-cm gas-operated fast valve shows promise of closing in <100 ms, which is sufficient to protect the Line A harps from accidents occurring in Lines B, EPB, C, and D. This valve will be installed in August 1976 as an interim measure until the commercial valve is delivered.

Shock tube tests of several possible fast-valve triggers were conducted to measure response time and reliability. Spark plugs operating at ~2 kV with a 0.5-mm gap were found to be very satisfactory and will be used. Controls and firing circuits to operate the interim fast valve are being built and tested prior to installation in August.

Shock tube tests using a helium gas driver at atmospheric pressure were conducted and showed that this harp-breaking disturbance propagated about three times faster than a disturbance driven by air. Helium-driven shocks can arise from accidents with helium targets which are installed in beam line vacuum systems. One upcoming HRS experiment has such a target installed in the Line C/HRS scattering chamber.

A thermocouple gauge has been instrumented so that the Line A vacuum can be read out reliably in CCR. Thermocouple gauges with meter-relay-type trip points have been installed to shut off the beam if the Line A vacuum exceeds 2×10^{-2} torr.

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1. Progress Report ending April 30, 1976.

2. W. P. Bishop, K. C. Humpherys, and P. T. Randtke, "Poly(halo)styrene Thin-Film Dosimeters for High Doses," Rev. Sci. Instrum., **44**, 443-51 (1973).

X. LARGE-SPECTROMETER SYSTEMS

Energetic Pion Channel and Spectrometer

The assembly of the first spectrometer dipole magnet (EA-BM-05) was completed. The power and water tests were passed and the magnet is now set up for measuring, using the power supply that will later be used to power both EA-BM-05 and EA-BM-06 in series. The spectrometer frame has been modified and is ready for installation. The frame will be installed after completion of grinding of the floor, which is currently scheduled to begin in early August.

A major improvement was made in the channel vacuum system by installing a liquid nitrogen trap at the separator vacuum box. Prior to this installation of this trap, a vacuum problem was observed which showed up as a factor of 3 increase in the pressure and frequent arcing of the separator whenever the proton beam was above 50 μA. After installation of the trap, with beam currents as high as 100 μA, no observable increase in the pressure occurs and the separator performance is similar to the beam-off condition.

The second run of the EPICS channel tuneup (Exp. 130, Phase I) was completed early in the quarter. Final results of this work are tabulated in Table X-I.

The major conclusions of the channel tuneup are that the beam intensity is approximately as predicted, that no significant discrepancies between the measured and calculated beam phase-space parameters have been observed, and that the separator removes unwanted particles as calculated. There remains the problem that the separator voltage cannot easily be maintained above 230 kV. It is expected that the new power supply which is scheduled for delivery in the Fall of 1976 will cure this problem.

Two additional experiments received beam time during this quarter. Exp. 246 (elastic and inelastic scattering of pions at 50 MeV by the Carnegie-Mellon group) was run in its entirety. More than 450 h of production time were obtained with no significant downtime resulting from the EPICS channel. Exp. 265, γ rays from light nuclei, received ~180 h running time and was able to obtain significant results. The remainder of the running time of Exp. 265 is scheduled for the next quarter.

TABLE X-I

SUMMARY OF RESULTS OF EXPERIMENT 130, PHASE I (EPICS CHANNEL TUNEUP)

Energy and Polarity	Fractional Composition				Fraction/ Nuclear Event Pions	Total Pions	Measured Count Rate Extrapolated to 1 mA	Expected Count Rate at 1 mA	Pions per Ion Chamber Count
	π	μ	e	P					
50.0 π^+	0.599	0.289	0.041	0.008	0.054	0.653	1.0×10^7	0.93×10^7	2.78×10^7
67.5 π^+	0.634	0.193	0.034	0.007	0.122	0.756	2.4	2.1	3.62
151.0 π^+	0.754	----	----	0.023	----	0.754	12.3	13.5	6.15
200.0 π^+	0.791	----	----	0.043	----	0.791	18.9	23.5	5.69
255.0 π^+	0.741	----	----	0.069	----	0.741	20.8	32.0	5.35
290.0 π^+	0.189	----	----	0.801	----	0.189	15.3	26.9	----
67.5 π^-	0.563	0.173	0.153	----	0.083	0.646	0.68	0.58	3.15
151.0 π^-	0.697	----	----	----	----	0.697	2.6	3.3	5.61
200.0 π^-	0.823[a]	----	----	----	----	0.823	3.7	3.6	6.84
255.0 π^-	0.811	----	----	----	----	0.811	3.6	3.5	6.79
290.0 π^-	0.836	----	----	----	----	0.836	3.1	2.7	6.94

[a]At this energy pions and electrons overlap in time of flight. Several percent electrons included.

High-Resolution Spectrometer

The major accomplishment in the past quarter was the completion of enough of Beam Line C and the spectrometer to allow us to run beam to the beam stop and begin debugging of the detectors. The beam line was in final form. The scattering chamber was installed with a temporary curtain, and a 0.4-mm aluminum vacuum window was used instead of the transition piece to the spectrometer. The spectrometer and detector system was installed, but no attempt was made to get more than roughing pump vacuum. The Brookhaven chambers were installed, but only half of the wires could be read out because the readout system was not complete. The PDP-11 computer was working, but a hardware bug caused frequent crashes.

Under these somewhat primitive conditions, it was possible to steer the beam to the beam stop. With all magnets set for calculated currents, it was observed that there was vertical dispersion of 17 cm/% on the target with the correct sign. The beam spot was too wide to clear the target frame cleanly, but was less than 5 cm high, which means that the momentum spread delivered by the accelerator is considerably better than advertised. The room background was rather high and it seemed possible to operate our large scintillators only when the beam current was 10 na or less. No information was obtained about the resolution in this first short run.

XI. RESEARCH

Research Highlights for the First Half of 1976

The accomplishments of the last six months are correlated with the new levels of accelerator performance achieved during this period. The schedule published on March 19 of this year called for the accelerator to go from 10- to 80-μA-av beam current in the first seven cycles of three weeks each. We have adhered to that schedule remarkably well. The average beam current in cycle 6 (the most recent one) was 75 μA, compared to 65 scheduled; the availability was 86% compared to 65% proposed in March. A week of extra time was given to experimenters in cycle 5 out of scheduled contingency time. In cycle 7, we are running 100 μA.

This record has made LAMPF the outstanding medium-energy physics facility during this period from the standpoint of accelerator performance and beam delivered to experimental areas.

On the experimental side, the HRS is installed and first beam has been seen at the focal plane. The EPICS channel is complete and is being used for preliminary experiments, e.g., 50-MeV π^+ scattering from light nuclei. The EPICS spectrometer is being assembled. The neutrino facility has been upgraded, as described below. The Bicentennial LEP spectrometer has been readied for service. Design of the π^0 spectrometer is nearly complete, and the main components are on order.

LAMPF Exp. 241 on direct or prompt positron production is concluded. The result is that for 256-MeV and 800-MeV protons on hydrogen, no direct leptons are seen. The value on the 800-MeV invariant cross section is $E(d^3\sigma)/(dp^3) = (-14 \pm 12) \times 10^{-32}$ cm^2/ [Sr(GeV/c)^2], which is several orders below an extrapolation from high-energy data. This suggests a threshold energy for the phenomenon. Searches in the GeV region are now under way at ANL by the Columbia Univ. group.

A number of runs of the experiment (at the LASL tandem Van de Graaff) to detect parity violation in pp-scattering was made. One objective was to improve the performance of the tandem Lamb-Shift polarized ion source, which, in part, is a prototype for LAMPF. This was quite successful. The output current was increased from 200 nA to 500 nA. This development is very important to LAMPF. Current modulation was reduced by an inverse feedback system; residual transverse polarization was reduced by a feedback system. More digital channels were added to make a total of seven which were read once a second during the experiment. This makes possible off-line regression analysis of the total cross section on the important beam variables. The preliminary results on hydrogen for the last run are:

$$A_H = (\Delta\sigma/\sigma)_H = (0.05 \pm 1.4) \times 10^{-7}$$

(15-MeV protons on hydrogen)

For the first time a significant result in deuterium was obtained, made possible by the improvement in transverse polarization control, namely:

$$A_D = (\Delta\sigma/\sigma)_D = -(0.3 \pm 0.9) \times 10^{-7}$$

(15-MeV protons on deuterium)

These results, consistent with Cabbibo-like theory predictions, of one part in 10^{-7}, make the published npdγ data of Lobashov *et al.* appear somewhat doubtful, although not completely ruled out.

Further improvements of the 15-MeV data seem quite possible.

The E2 nuclear resonance effect in pionic atoms occurs when the energy difference between atomic levels is nearly equal to the difference between the ground state and an excited state of the nucleus. The coulomb field is then effective in producing configuration-mixing in the overall state, which may be observed as a change in attenuation of the pionic x-ray line from an isotope (Z,A) relative to (Z,A ÷ 1). The effect, predicted by M. Leon in cadmium and first seen last winter by a LASL-Munich-Univ. of Mississippi team, has now been observed at LAMPF also in palladium and ruthenium.

The new results have been used in connection with some calculations to confirm an interesting conjecture made by Ericson *et al.* some years ago. The Ericsons and Krell remarked that the zero energy P-wave π-nucleus potential should change sign as Z increases beyond ~36, because the *nuclear* P-wave interaction has contributions from the *π-nucleon* S-waves (repulsive) and P-waves (attractive); as the nuclear radius increases with Z, for some value the S-wave contribution overtakes the P-wave, and the resultant potential should change sign. Using a phenomenological potential which had this behavior, the pionic level shifts and widths were calculated and compared to the observations. The new results confirm that in palladium (Z = 46) the π-nucleus potential has become repulsive.

Nuclear Reactions Involving Protons

Collaborative studies have been made at the TTA of proton-induced fragmentation of uranium. Improved mass resolution of the TOF ΔE, E spectrometer has made possible the discovery of a new isotope, ^{31}Mg, which lies rather far from the stability line but is stable against neutron emission.

Nuclear chemistry studies involving protons, other than the thin target work, include those related to fission, spectroscopy, and isotope production. The work on proton-induced fission of silver, gold, and uranium using the mica detector technique is almost complete. Aside from the intrinsic interest in the proton-induced fission studies, the detector technique is being thoroughly developed before proceeding to the π-induced-fission phase of the work. The nuclear spectroscopy work is a collaboration between LASL and INEL (Report ANCR-1284). Since beam has been available in Area B, the decay schemes of some 11 different isotopes have been studied and many new γ lines have been observed. One important result is the clear demonstration of many errors in existing literature. The effort relating to isotope production has continued to develop new production techniques. This work has been biased toward biomedical interests, an example of which is the ^{82}Sr-^{82}Rb generator. The ^{82}Rb is used in heart infarction studies.

Pion total cross sections were measured for a variety of energies between 24 and 238 MeV using 19 nuclear species as target material. The bulk of the data is still being analyzed. The data are of high precision except in the cases of the lowest pion energies. The data on $\sigma_{tot}(^{48}Ca) - \sigma_{tot}(^{40}Ca)$ have been fitted to predictions with an optical potential using $(r_n - r_p)$ as a parameter. The best fit values, namely:

$$(r_n - r_p)(^{48}Ca - {}^{40}Ca) \cong 0.05 \pm 0.02 \text{ F}$$

are in good agreement with the latest values from alpha particle and proton scattering experiments.

The experiment to test the nature of the muon conservation law (Exp. 31) depends on measuring the rate of beam-associated neutral events in a large water Cerenkov counter protected from charged particles by an anticoincidence scintillator array, for H_2O and D_2O, such events being defined as a Cerenkov pulse within the beam pulse and without a scintillation pulse veto. The detector is surrounded by steel walls, floor, and roof. The amount of steel in the front wall, i.e., in front of the main proton beam stop, has been varied, and the neutron background measured as a function of wall thickness.

Beam-associated backgrounds have been measured with 4 m of iron in the front wall. Measurements of background at 5 m are now under way. Preliminary results of cosmic-ray-induced background measurements are available. Present indications are that the front-wall thickness required to have a beam-associated neutral background $<10\%$ of the expected neutrino event rate is between 6 and 7 m. It is planned to add 1.1 m of additional iron during the fall quarter. If 100 μA of beam can be made available at reduced duty factor, say 1% or less, it may be possible to begin taking data on the neutrino-induced events.

The LASL, Univ. of Mainz, Florida State Univ., Purdue Univ. collaboration is continuing its study of nuclear charge distributions for the transition elements. A paper entitled "Systematics of Nuclear Charge Distribution in Fe, Co, Ni, Cu, and Zn Deduced from Muonic X-Ray Measurements" is scheduled for publication in Phys. Rev. **14C**. An abstract of the work appears below.

The π activation experiment (Exp. 67) had previously established absolute cross sections of $^{12}C(\pi^{\pm},\pi N)^{11}C$ [Phys. Rev. Lett. **34**, 821 (1975)]. The deviations of the π^-/π^+ cross-section ratio from the impulse approximation predictions have been successfully interpreted as resulting from charge exchange of the recoil nucleon as it leaves the nucleus [M. M. Sternheim and R. R. Silbar, Phys. Rev. Lett. **34**, 824 (1975)]. Since then, data for knockout ratios in ^{14}N, ^{16}O, and ^{19}F (Exp. 102) have also been found to agree with this nucleon charge exchange model. There are also indications from the ANL/LASL Exp. 121, which measures deexcitation γ rays from the residual nuclei from $\pi^{\pm}$ bombardment of nickel isotopes, that there is a similar reduction in knockout ratios due to nucleon charge exchange. For such medium-weight nuclei, however, recent work by Silbar, Ginnochio, and Sternheim suggests there might be large discontinuities in these ratios coming from nuclear structure effects. Silbar will briefly describe developments in this area.

Using these $^{12}C(\pi^{\pm},\pi N)^{11}C$ cross sections measured earlier as a reference standard and with the higher fluxes now available at LAMPF, several other reactions are being studied for use as π beam flux monitor standards. Preliminary results were obtained for the cross sections for the production of ^{18}F and ^{24}Na from aluminum, and of ^{24}Na from silicon, by π^{+}-induced reactions. The errors are estimated to be $\pm 10\%$ or less. The ^{24}Na excitation functions for both aluminum and silicon targets appear to have essentially the same shape and show a peak near the free nucleon-pion (3,3) resonance. In contrast, the excitation functions for $^{27}Al \overset{\pi}{\rightleftharpoons} {}^{18}F$ reaction, involving the removal of nine nucleons, appear to be flatter and to fall off less rapidly at the lower energies, indicating a greater washing out of the effect of the resonance. The relatively high cross section for this reaction and its small sensitivity to π energy makes it a very desirable π-beam-monitor reaction.

A study of the products resulting from π irradiations of medium- and heavy-mass nuclei has been run in the LEP channel. Copper and tantalum targets were given timed exposures to a stopping π^{-} beam, and then removed to a low-background environment, where they were counted with a high resolution Ge(Li) γ-ray spectrometer. The yields were thus determined for 21 isotopes. They are in reasonably good agreement with numerical calculations using a cascade code followed by an evaporation code. Some long-lived activities in the tantalum are still being counted.

A survey of π-induced reactions at the (3,3) resonance energy is being carried out by irradiating a variety of medium-mass isotopes (14 so far) with π^{+}. As of this writing, nine spallation product activities have been measured, with activation cross sections ranging from 5 to 9 mb. Of particular note is that five separated isotope targets have been successfully used at thicknesses as low as 3 mg/cm^2.

Using the high-intensity and high-purity μ^{+} beam from the SMC at LAMPF in 1974, we measured the hfs interval ($\Delta\nu$) in the ground state of muonium ($\mu^{+}e^{-}$) to high precision in a weak-field experiment (Exp. 37). Two different microwave magnetic resonance techniques were used to observe the transitions $(F,M_F) = (1,\pm 1) \leftrightarrow (0,0)$ at very weak magnetic field (<2 mG). Both of these techniques — "old" muonium and separated oscillating fields — are line-narrowing techniques and have higher statistical power than the conventional resonance technique. Data were taken in argon and krypton at pressures from 1.7 to 5.3 atm. Analysis of the data has been completed and the value reported for $\Delta\nu$ is:

$$\Delta\nu = 4\ 463\ 302.2(1.5)\text{kHz}\ (0.3\ \text{ppm})\ .$$

The above value agrees within one standard deviation with the value of $\Delta\nu$ reported by the Chicago group, which has an accuracy of 0.4 ppm. From our value for $\Delta\nu$ we obtain values for the μ magnetic moment and mass:

$$\mu_\mu/\mu_p = 3.183\ 329\ 9(25)\ (0.8\ \text{ppm})$$

$$m_\mu/m_e = 206.769\ 27(17)\ (0.8\ \text{ppm})\ .$$

The accuracy of μ_μ/μ_p and of m_μ/m_e is limited by the accuracy of the calculation of an α^3 radiative correction term in the theoretical expression for $\Delta\nu$.

A second experiment, Exp. 37A, is now under way to measure the transitions $(M_J,M_\mu) = (^1/_2,{}^1/_2) \leftrightarrow (^1/_2,-^1/_2)$ and $(-^1/_2,-^1/_2) \leftrightarrow (-^1/_2,{}^1/_2)$, designated ν_{12} and ν_{34}, respectively, at a strong magnetic field of 13.6 kG from which both $\Delta\nu$ and the μ magnetic moment μ_μ (or actually the ratio of the μ magnetic moment to the proton magnetic moment, μ_μ/μ_p) can be determined. The goal is a precision of $\simeq$1 ppm in μ_μ/μ_p and $\simeq$0.1 ppm in $\Delta\nu$.

Recent improvements in the LAMPF SMC, most importantly the evacuation of the channel plus a better tuning condition for the initial channel magnets, have increased by a factor of 6 the ratio of stopped muons to primary protons for our thin gas target, as compared to 1974. With a primary proton current of 100-μA time av, and using a μ^{+} beam with a mean momentum of 50 MeV/c, the μ^{+} stopping rate is 1.3×10^4/s time av in a krypton gas target of 1.7 atm, 19 cm in length, or an instantaneous stopping rate of 2.6×10^5/s during the on-time of the accelerator.

The experiment is a precision microwave-magnetic-resonance measurement using a strong magnetic field. A major piece of equipment in the experiment is a high-precision eighth order solenoid, designed and constructed at Yale Univ., which provides a magnetic field stable to 1 ppm and homogeneous to 4 ppm over the region 19-cm diam by 19-cm length occupied by the microwave cavity. The magnet is powered from a well-regulated 1-MW power supply and is stabilized with reference to an NMR signal. The microwave system provides outputs in the range of 1.9 GHz to 2.5 GHz of ~50 W, which are stabilized in frequency to 0.01 ppm and in power level to ≃1%. For our target, the purity, temperature, and pressure of the krypton gas are of critical importance. Scintillation and PWC counters are used. We are able to use the μ stopping rate resulting from the 100-μA beam without difficulty. The experiment is largely under computer control of the PDP-11/20 computer in the SMC counting house.

Excellent resonance curves have been obtained with krypton pressures of 2 and 6 atm, which are our planned operating pressures. These data are now being analyzed, and a careful consideration of all systematic errors is being made before the main data-taking begins in the fall of 1976.

The Rice-Houston group have taken extensive data in the EPB line, using 800-MeV protons on light targets, and their two-arm spectrometer system to measure a variety of processes in light elements, including:

00)	pp elastic scattering
0)	pd elastic scattering
i)	pp → π^- + d π inelastic
ii)	pp → π + x
iii)	pd → π + x
iv)	p ^{6}Li → dπ^+ ^{5}He
	→ dπ^- ^{6}Li

The data for the several reactions are in various stages of analysis, none complete, but at this stage show a number of interesting features. In particular, the angular distribution for reaction (ii) has been compared by detailed balance to the inverse reaction measured at CERN for closely corresponding π energy, with good agreement. In reaction (ii), under different kinematical conditions, the Δ is seen and also a strong np final state interaction. Under reaction (ii) also, the following processes are included and have been seen in preliminary surveys:

$$pp \rightarrow pp\pi^0,\ pn\pi^+,\ p\Delta^+,\ n\Delta^{++},\ d\pi^+,\ d^*\pi^+ \ .$$

Under reaction (iii) the following are possible for π production and have been seen in preliminary inspection of the data tapes:

$$pd \rightarrow pd\pi^0;\ nd\pi^+;\ (pp)n\pi^0;\ (nn)p\pi^+;\ pp\Delta^0;\ nn\Delta^{++};\ pn\Delta^+;\ (ppp)\pi^-;\ (nnn)\pi^+\pi^+;\ ppn\ .$$

The data are being analyzed off-line, and cross sections for these reactions will be deduced.

The Rice-Houston experiment on the scattering of $\pi^\pm$ on ^{12}C, ^{40}Ca, and ^{48}Ca measured the total cross section and the small-angle elastic cross sections. From these data the real and imaginary parts of the forward-scattering amplitude are derived. Six π energies between 222 and 120 MeV were used. Previously the group had measured $\pi^\pm$ on ^{16}O.

In the P^3 channel, the Virginia group has measured π^+d elastic scattering at 347 MeV/c, 443 MeV/c, 535 MeV/c, and 650 MeV/c.

Complete angular distributions have been taken with 50-MeV π^+ for ^{12}C, ^{16}O, ^{40}Ca, ^{90}Zr, and ^{208}Pb by a Univ. of South Carolina, Virginia Polytechnic Inst., ORNL, and LASL group. About 18 data points, from 25° to 160°, were obtained with 3-5% absolute accuracy.

A study was made of chemical effects in μ^- capture by comparing the intensities of K series x rays. Ten metal targets and five low-Z organic targets were exposed to the beam in the SMC. The purpose in running the metals was to determine the variation with Z of the intensities of the various members of the K series and to compare these results with analogous kaonic- and pionic-atom data. Such data will play an important role in understanding the basic capture mechanism. The low-Z organic targets included the series (CCl_4, CCl_4 + octane, CH_2Cl_2) and the pair (CH_2, CD_2). The former set was chosen to elucidate the effects of inter- vs intramolecular hydrogen transfer of the muon, and the latter set to test the effect of isotopic difference. The data are being analyzed.

Muonic x ray measurements of isotopes of osmium, platinum, and tungsten have been carried out. Static and dynamic hyperfine interactions have been observed and are being analyzed.

A study of μ-induced fission in the actinide elements ^{235}U, ^{238}U, ^{232}Tn, and ^{239}Pu, resulted in the capture rates to ~2%. A proposal covering a continuation of this work has been presented to the LAMPF administration.

Tests, Data Runs, and Analyses of Experiments

Total Pion Cross Sections (Exp. 2) (Univ. of Montana, New Mexico State Univ., Univ. of Basel, LASL, Univ. of Washington, Stanford Univ., California Inst. of Tech.)

The data-taking runs for the total π-nucleus cross-section experiment are completed. The run was successful, with all equipment performing up to design criteria. Cross sections for both π^+ and π^- on a number of nuclei were obtained; a list of the nuclei and energies is given in Table XI-I. All of the data points should be of high precision, but the level of precision for the lowest energy points remains uncertain because of problems arising from the coulomb interaction and π decay. All the data are being analyzed, but have not been studied sufficiently to be generally available.

Neutron Radii of ^{48}Ca and ^{18}O.

The accurate determination of neutron rms radii from pion total cross sections is made possible by the isospin coupling of the π-nucleon system through the (3-3)resonance. The strong π^--neutron coupling accentuates effects due to neutrons, which gives one the sensitivity necessary for an accurate measurement. The use of accurately measured proton rms radii from electron-scattering experiments[1] separates the problem of finding neutron radii from that of merely learning properties of the matter distribution. To the extent that coulomb effects can be properly accounted for in theoretical interpretations of the cross sections, obtaining the same result with both π^- and π^+ is a built-in systematic check of the pion physics.

Even with the special π^--neutron coupling, the absolute cross sections are not very sensitive to neutron distributions. However, the comparison of cross sections from isotopes of the same element is sensitive to differences in the neutron radii of these isotopes. Such a comparison cancels many experimental and theoretical uncertainties. For example, at kinetic energies above 100 MeV for π on ^{40}Ca, the contribution of coulomb-nuclear interference to the absolute cross section is large, but in the ^{48}Ca-^{40}Ca difference, it is negligible. On the theoretical side, models which predict very different values for the ^{40}Ca cross section predict nearly the same value for the difference. It is this model independence which allows the determination of relative radii.

In the cases where a good educated guess can be made for the neutron radius of one isotope, then the neutron radius of the other can be determined. Two such cases are ^{40}Ca and ^{16}O. In what follows, it is assumed that the proton and neutron rms radii are:

$$r_p(^{48}Ca) = r_p(^{40}Ca) = r_n(^{40}Ca)$$

and (1)

$$r_p(^{18}O) = r_p(^{16}O) = r_n(^{16}O) .$$

The equalities to the left in Eq. (1) are verified by electron scattering[1] to ±0.01 F. The equalities to the right are believed true because of the closed-shell nature of ^{40}Ca and ^{16}O and are verified by theoretical estimates (±0.02 F). If the theories are correct, the assumptions in Eq. (1) lead to smaller uncertainties

TABLE XI-I

NUCLEI AND PION KINETIC ENERGIES AT WHICH BOTH π^+- AND π^--NUCLEUS TOTAL CROSS SECTIONS WERE MEASURED BY THE LAMPF GROUP IN THE 1976 RUN

^{4}He	**24, 33, 43, 63, 87**
^{6}Li, ^{7}Li, ^{9}Be	**43, 63, 140, 165, 190, 215**
^{10}B, ^{11}B	**43, 63, 114, 140, 165, 190, 215**
^{12}C	**24, 33, 43, 63, 114, 140, 165, 190, 215, 238**
^{13}C, $^{16}OH_2$, $^{18}OH_2$	**43, 63, 114, 140, 165, 190, 215, 238**
^{27}Aℓ	**63, 114, 140, 165, 125**
^{40}Ca, ^{44}Ca, ^{48}Ca	**43, 63, 114, 140, 165, 190, 215, 238**
^{45}Sc, ^{51}V	**63, 114, 140, 165, 190, 215, 238**
Cu, Sn, ^{165}Ho, Pb	**63, 114, 140, 165, 215**

than those from other sources in the extraction of radii for ^{48}Ca and ^{18}O.

Predictions for the difference between the total cross sections for ^{48}Ca and ^{40}Ca or for ^{18}O and ^{16}O can be obtained from the optical model. The solid curves in Fig. XI-1 are calculated using the Kisslinger[2] model with a Fermi density distribution. Calculations on oxygen employ a modified Gaussian density. The curves are labeled according to the difference between the rms neutron and proton radii of ^{48}Ca.

Some qualitative features of the curves may be understood from free π^- nucleon scattering. The difference in the predicted cross sections for a given $r_n - r_p$ is approximately the free π^--neutron cross section times the number of unshielded neutrons outside the absorbing core of ^{40}Ca. The point where all the curves cross is where the model predicts the nuclei are largely transparent, and eight times the π^--nucleon cross section at this energy is in fair agreement with the value of 200 mb at the crossing point. The energy of the crossing point is model-dependent. The divergence at lower energies is probably a coulomb effect.

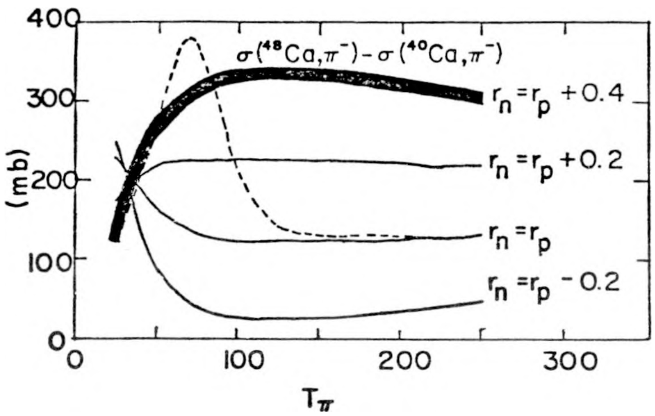


Fig. XI-1.

Predictions for the differences in the cross section of ^{48}Ca and ^{40}Ca. The solid lines are calculated with the Kisslinger model and the dashed with the local Laplacian model. The band represents the uncertainty in the rms radii due to variations of parameters in the Fermi density distribution.

The thick band which is the $r_n - r_p + 0.4$ curve, represents the ranges of predictions as a function of the parameters of a Fermi distribution when the rms radii are held fixed. The change which the band represents in the 10-90% skin thickness is ±0.2 F. This band puts a limit of ±0.02 F on the measurement of $r_n - r_p$ until measurements are made which further restrict the models.

The dashed curve for $r_n - r_p$ is calculated in the local Laplacian[3] model with a Fermi density distribution. Two features are evident: 1) above 150 MeV there is very little difference between the models, and 2) below 150 MeV there is large model dependence. These characteristics are found to be quite general for a large class of calculations. For example, they persist in the ^{13}C-^{12}C system when calculated using the phenomenological parameters of Sternheim and Auerbach,[4] even though the predicted total cross sections are quite different from those calculated from free π^--nucleon parameters. It appears, therefore, that the difference of cross sections provides a happy separation of phenomena. At higher energies, structural information may be extracted without model dependence. At low energies, details of the dynamics can be learned by employing the structure information learned at higher energies. The reason that all reasonable models predict the same values for the differences is not quite clear, but may be related to the blackness of the nucleus in this energy region.

The preliminary data from LAMPF for the ^{48}Ca-^{40}Ca differences are shown in Fig. XI-2. The errors shown include statistical and systematic errors arising from the extrapolation of measured cross sections to zero degrees and the coulomb-nuclear interference correction. For the π^+, statistical errors dominate; for the π^-, the small systematic contribution will probably be removed after a more complete analysis. The lowest energy point at 43 MeV should, at this time, be regarded with some skepticism, as it requires a large model-dependent coulomb-nuclear interference correction. Application of the technique given in Ref. 1 to the data, and the calculated curves, should give this point equal credibility with the others.

Qualitatively, the π^- data agree quite well with the Kisslinger model, but the π^+ data diverge from a single curve at lower energies. The π^- data do not show the pronounced peak which is calculated from the local Laplacian model (shown as the dashed curve in Fig. XI-1). The five highest energy points in

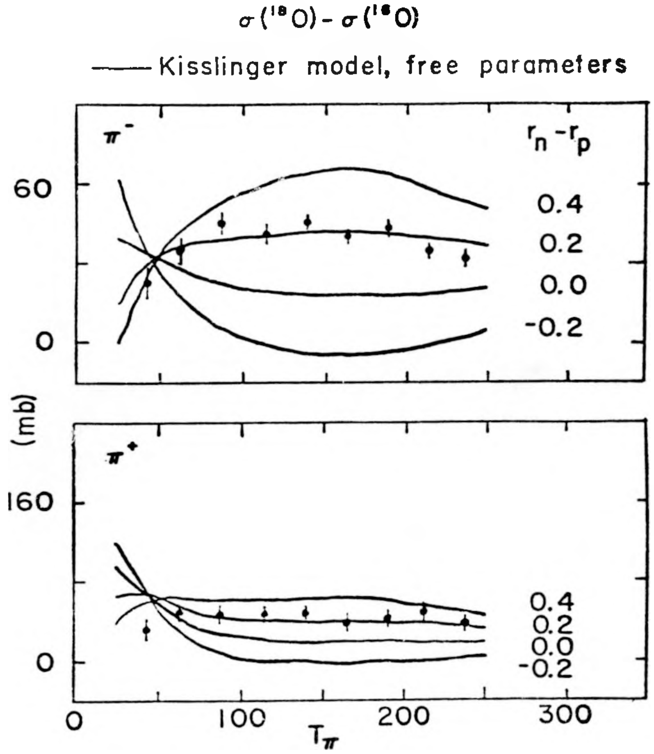


Fig. XI-2.

Preliminary data from LAMPF for the ^{48}Ca-^{40}Ca cross-section differences. The solid curves are the same predictions as those of Fig. XI-1 for the differences for several values of r_n-r_p.

the model-independent region have been combined to obtain a best value of r_n - r_p for ^{48}Ca:

$$\pi^-: \quad r_n(^{48}\text{Ca}) - r_p(^{48}\text{Ca}) = 0.08 \pm 0.02 \text{ F}$$
$$\pi^+: \quad r_n(^{48}\text{Ca}) - r_p(^{48}\text{Ca}) = 0.03 \pm 0.04 \text{ F} . \qquad (2)$$

The errors are experimental and do not reflect uncertainties in the models used to extract the radii. The goal of obtaining the same value for both π signs is barely achieved, but any discrepancy can be removed by a slight adjustment of the relative proton radii of ^{48}Ca and ^{40}Ca. This will raise the π^+ value in Eq. (2) without affecting the π^- value substantially. The necessary change is less than the uncertainty in the measured radii from electron scattering.

The values for r_n - r_p in ^{48}Ca are in good agreement with the latest α particle[5] and proton[6] scattering measurements, as well as coulomb energy differences.[7] Most theoretical Hartree-Fock calculations[8] which find r_n(^{40}Ca) - r_p(^{40}Ca) = 0.2 in contrast to Eq. (1) find 0.19 for r_n(^{48}Ca) - r_p(^{48}Ca) in disagreement with this measurement.

Whether or not this discrepancy between theory and experiment persists will depend on the completion of the LAMPF group's analysis, which includes:

1. refined data reduction to further reduce the error bars and remove coulomb effects,
2. more detailed calculations on the sensitivity of the results to the value of r_n - r_p in ^{40}Ca and the value of r_p(^{48}Ca) - r_p(^{40}Ca),
3. optical-model calculations with the Hartree-Fock matter densities,[8]
4. further tests of the π-physics and high-energy model independence by calculation with models which put in form factors to cut off pathologic off-shell behavior,[9] and
5. consistent understanding of data taken on ^{44}Ca, ^{45}Sc, and ^{51}V.

The oxygen isotopes, ^{18}O and ^{16}O, have not been as thoroughly examined either experimentally or theoretically as the calcium isotopes. The data presented in Fig. XI-3 are based on the assumption of analogous behavior. Using Eq. (1), the highest five energy points yield values for r_n(^{18}O) - r_p(^{18}O) = 0.185 ± 0.015 F

$$\pi^-: \quad r_n(^{18}\text{O}) - r_p(^{18}\text{O}) = 0.185 \pm 0.015 \text{ F}$$
$$\pi^+: \quad r_n(^{18}\text{O}) - r_p(^{18}\text{O}) = 0.202 \pm 0.040 \text{ F} . \qquad (3)$$

Nuclear Structure Physics Using Stopped Muons (Exp. 7)
(LASL, Florida State Univ., Purdue Univ., Oregon State Univ., Univ. of Kansas)

Study of the Electric Multipole Moments

A systematic study of the monopole and quadrupole charge distributions of the transition nuclei tungsten, osmium, and platinum is in progress. The investigation centers on observation of static and dynamic hyperfine interactions in these nuclei. Such effects in ^{188}Os, ^{190}Os, ^{192}Os, ^{194}Pt, ^{195}Pt, and ^{196}Pt have been measured and are being analyzed. As expected, the mixing of nuclear excited states in the even-even muonic platinum atoms is small (typically a few percent), because the energies of the first excited 2^+ states (E_{2^+}) in these nuclei are considerably larger (E_{2^+} > 300 keV) than the muonic

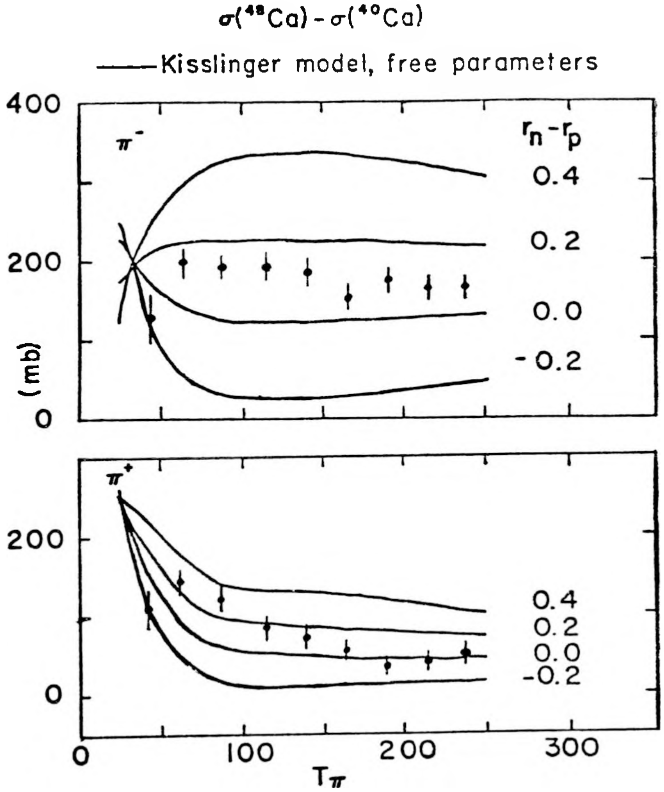


Fig. XI-3.
Preliminary data from LAMPF for the ^{18}O-^{16}O cross-section differences. The curves are analogous to the solid curves of Fig. XI-1.

$2p_{3/2}$ - $2p_{1/2}$ fine-structure splitting ΔE_{2p} (~150 keV). However, the populations and the energy shifts of two of the F = 3/2 and of one of the F = 1/2 levels that result from the interaction of the muonic 2p levels with the nuclear 2^+ state are sufficiently large to determine the nuclear $\{0^+[M(E2)]2^+\}$ and $\{2^+[M(E2)]2^+\}$ matrix elements, via the observed muonic x-ray transitions. Once the hyperfine splittings are known, accurate values of the nuclear monopole charge parameters, C and t, can be determined. Higher nuclear states are excited in these muonic atoms, but their excitation probability is, in general, too small to extract meaningful information about these nuclear states. However, some information about the relative phases of the matrix elements, that contribute to the excitation of higher excited nuclear states, can be obtained.

The values of C, t, β, $\{0^+[M(E2)]2^+\}$ and $\{2^+[M(E2)]2^+\}$, as determined from our muonic atom measurements, are shown in Table XI-II.

The mixing of nuclear and muonic states in the even-even osmium nuclei is quite strong (20-40%) because E_{2^+} is close to ΔE_{2p}. The difference between E_{2^+} and ΔE_{2p} in ^{188}Os is about 1.5 keV, and the finite natural width of the resulting mixed states must be taken into account in the analysis of the hyperfine mixing. This analysis is in progress.

The hfs of ^{192}Os was analyzed on the basis of a new model-independent method to obtain information on static and transitional nuclear quadrupole charge distributions.[10] The equivalent quadrupole charge radius R_Q was found to be approximately equal to the nuclear monopole charge radius, indicating that the electric quadrupole distribution is concentrated near the nuclear surface.

TABLE XI-II

NUCLEAR STRUCTURE RESULTS OBTAINED FROM EXP. 7

Nucleus	C(F)	t(F)	β	$\{2^+[M(E2)]2^+\}$ eF²	$\{0^+[M(E2)]2^+\}$ e F²
^{194}Pt	6.57648	2.09913	−0.16	+110 ± 15*	130 ± 10
^{196}Pt	6.58327	2.139850	−0.14	+ 74 ± 15*	118 ± 12
^{192}Os	6.55364	2.07839	+0.17	−125 ± 10*	143 ± 7

*Assuming the quadrupole charge to be concentrated near the nuclear surface.

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

Measurements of beam-associated backgrounds at 4 m of iron shielding have been completed, and we are in the process of measuring beam-associated backgrounds at 5 m of iron shielding. Preliminary measurements of cosmic ray-associated backgrounds have also been made.

A beam-associated neutral event is defined as an event which occurs inside the Cerenkov counter during a beam pulse and which is not vetoed by a 20-μs anticoincidence pulse from the surrounding scintillators. Events outside the beam spill are measured, as well, and a subtraction is made to correct for cosmic-ray events. A computer-controlled CAMAC ADC system gives total energy information on the Cerenkov events. True neutrino events will be in the energy range 20-60 MeV. The background events from 30-100 MeV are measured because, at these reduced shielding levels, thermal neutron-pileup contaminates the signal from 20-30 MeV; these background events are referred to as "prompts." We also measure rates in a 25.4- by 17.8- by 34.3-cm piece of scintillator biased above 24 MeV; these events are referred to as "scint." All events are expressed in terms of mA/s of protons on the beam stop. With the biomed target out, but no requirements on the upstream targets, we find:

$$\begin{aligned} &\text{prompts} \div \text{mA/s} = 4.38 \pm 0.20 \\ &\text{scint} \div \text{mA/s} = 74.3 \pm 0.3 \;. \end{aligned} \qquad (4)$$

All errors are statistical. There is not sufficient data at this beam stop position for a biomed target-in measurement, but from earlier measurements with the stop almost at the full east position, we find ratios, biomed out to biomed in, of

$$\begin{aligned} &\text{prompts, biomed out/biomed in} = 1.13 \pm 0.03 \\ &\text{scint, biomed out/biomed in} = 1.14 \pm 0.01 \;. \end{aligned} \qquad (5)$$

The neutrino shutter, a 75-cm-thick piece of shielding next to the beam stop, was lifted during these runs. This gives an effective shielding thickness of 3.25 m. We were unable to measure absolute rates in this condition, since they were very dependent on the exact position of the beam stop. We were, however, able to measure the ratios:

$$\begin{aligned} &\text{prompts, biomed out/biomed in} = 1.18 \pm 0.03 \\ &\text{scint, biomed out/biomed in} = 1.16 \pm 0.02 \;. \end{aligned} \qquad (6)$$

These ratios are consistent with the ratios measured at 4 m. From this we conclude that, to ~5%, we see no direct background from the biomed target. At 4 m, the effect observed is due to the degrading of beam energy in the target. Direct neutrons from the target would give an effect in the opposite direction.

Some measurements have been made of neutral cosmic-ray backgrounds from 20-60 MeV. This rate, scaled to include only beam-on time, is 3000/day. We have investigated what types of events these are, and have isolated two major contributions: μ decays in the last part of the roof, with the electron producing a photon which goes through the antis and converts in the Cerenkov counter; and μ bremsstrahlung in the roof, with the μ missing the antis, but the photon going through the converting in the counter. These will be referred to as μ-e-γ and μ-γ events, respectively. The number of μ-e-γ events has been measured to be 500 ± 150/day, and preliminary measurements indicate that the μ-γ events will easily account for the rest of the neutral rate. The μ-γ events will be reduced by installing lead just outside the scintillators, and the μ-e-γ events by installing a second detector layer outside the lead. We have installed lead on three sides of the counter; the new shielding is very close to a fourth side, and we have added the Exp. 148 scintillator tanks to our system as an anti (to catch some wide-angle muons). These changes have reduced the cosmic-ray neutral rate to 1600/day.

During the week of June 14, a fifth meter of iron shielding was installed in the neutrino house. In this new shielding condition, we find, with the biomed target out,

$$\begin{aligned} &\text{prompts} \div \text{mA/s} = (3.32 \pm 0.41) \times 10^{-2} \\ &\text{scint} \div \text{mA/s} = (5.72 \pm 0.26) \times 10^{-1} \;. \end{aligned} \qquad (7)$$

This gives attenuation ratios, 4 m to 5 m, of

$$\begin{aligned} &\text{prompts, 4 m/5 m} = 132 \pm 17 \\ &\text{scint, 4 m/5 m} = 130 \pm 6 \;. \end{aligned} \qquad (8)$$

From this we conclude that the amount of shielding we will need to achieve a beam-associated neutral background $\leq ^1/_{10}$ of our expected neutrino event rate is <7 m but >6 m. We are in the process of acquiring more data to reduce the statistical errors on these numbers. With the biomed target:

$$\text{prompts} \div \text{mA/s} = (4.34 \pm 54) \times 10^{-2}$$
$$\text{scint} \div \text{mA/s} = (6.18 \pm 0.41) \times 10^{-1} \ . \tag{9}$$

This gives ratios, biomed out to biomed in, of

$$\text{prompts, biomed out/biomed in} = 0.76 \pm 0.13$$
$$\text{scint, biomed out/biomed in} = 0.93 \pm 0.08 \ . \tag{10}$$

This indicates some background coming from the biomed target directly. We intend to investigate this matter further.

Elastic Scattering of $\pi^\pm$ on Deuterons (Exp. 34) (Univ. of Virginia, LASL)

We have analyzed all our data on π^+ scattering from deuterons using a data-reduction procedure which was efficient in terms of computer cost, but which requires some further checking to test biases. Our data were taken at nominal momenta of 350, 450, 550, and 650 MeV/c using the LAMPF P^3 beam. In general, the data at the three lower momenta seem reasonably satisfactory at a level of precision of 10-15%, still far from our ultimate goal of ~3%. At 650 MeV/c, the low cross sections combined with the low beam intensities available when the data were taken, seem to have resulted in data that are less satisfactory, with some angles not being analyzable.

Details of the experiment have been presented in earlier reports. Briefly stated, we scattered π from the P^3 beam in targets of CD_2 and D_2O and used targets of CH_2 and H_2O as well as carbon for background subtraction and for normalization against the known π-p scattering cross section. The scattered pions were detected in a magnetic spectrometer using helical wire proportional chambers as detectors. Recoil deuterons were detected in coincidence with the πs in a set of proportional chambers which were followed by NaI scintillation detectors. With this arrangement, the deuterons could be identified with the familiar E-ΔE technique. The data were analyzed by using the trajectories of the π and deuteron along with the E-ΔE data to test each event for conformity with the kinematics of two-body elastic scattering. Last spring we decided that our computer program could be introducing biases of the order of 10% or more, in some cases. Since these effects were of the order of magnitude of the statistical accuracy it seemed important to eliminate them. A different procedure, more costly in computer time, was developed by writing a computer program that could fit the various parameters measured for each event (a highly redundant set) to π-deuteron kinematics using a χ^2 minimization procedure. This should be more systematic in determining the quality of the separation between elastic data and background, but the χ^2 minimization for each event is more lengthy. The computer program will also be used in Exp. 90.

The results of the new analysis will be compared to the old results, and differences will be studied in detail. Tests will be made on certain selected cuts in the data to determine the efficiency in separating elastic events from background. It is possible to select data, using E-E, that contain no elastic scattering events, as well as data which are dominated by elastic-scattering (π-p events). The new analysis procedure was developed during the spring of 1976 and is currently being applied to the data. We expect to complete the analysis by early fall.

To indicate the quality of the data, our preliminary results at the three lower momenta are shown in Fig. XI-4. The large dip in the cross section at 450 MeV/c should probably not be taken seriously before we can complete our current checks. Also on the figure are lines showing the trend of data obtained at 290 MeV/c by Norem[11] and at 256 MeV (Ref. 12) by Gabathuler *et al.* The individual points in these two experiments have statistical accuracy similar to ours.

When the analysis is completed, our data should be of sufficient quality to warrant publication, but they will not satisfy the goals of our proposal or the capabilities of LAMPF. Therefore, we are preparing a proposal for a new set of measurements which will be submitted this fall. The new design will take advantage of experience gained in the previous runs and will be rather different in concept. High-energy deuterons will be identified by measurement of momentum and TOF. The π-momentum measurement will be eliminated, allowing us to move the target close to the P^3 exit quadrupole, which means

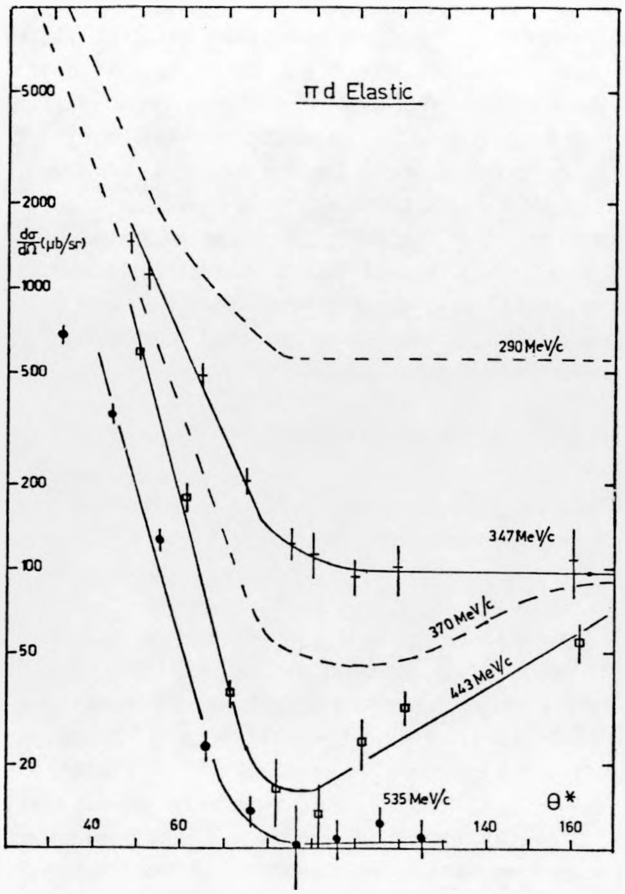


Fig. XI-4.
Preliminary results for the differential elastic scattering cross section as a function of center-of-mass angle for π^+ on deuterons obtained from Exp. 34. Lines drawn through the data are meant only to guide the eye. Also shown are lines giving the trend of data obtained by Norem at 290 MeV/c and by Gabathuler ***et al.*** *at 370 MeV/c.*

we will have more πs and smaller beam spots. The E-ΔE system for low-energy deuterons will be more compact, use few detectors, and will be heavily shielded. In general, effects that have required rather large corrections in our present data will be eliminated.

Precision Measurements of Muonium HFS Interval and Zeeman Effect at LAMPF (Exp. 37)
(Yale Univ., Univ. of Bern, Univ. of Heidelberg, LASL, Univ. of Wyoming)

Using the high-intensity and high-purity π^+ beam from the SMC at LAMPF in 1974, we have measured the hfs interval, $\Delta\nu$, in the ground state of muonium (μ^+e^-) to high precision in a weak field (Exp. 37).[13] Two different microwave magnetic-resonance techniques were used to observe the transitions $(F,M_F) = (1,\pm1) \leftrightarrow (0,0)$ at very weak magnetic field (<2 mG). Both of these techniques — "old" muonium and separated oscillating fields[14,15] — are line-narrowing techniques and have higher statistical power than the conventional resonance technique.[16] Data were taken in argon and krypton at pressures from 1.7 to 5.3 atm. Analysis of the data has been completed, and the value reported[13] for $\Delta\nu$ is:

$$\Delta\nu = 4\ 463\ 302.2(1.5)\text{kHz}\ (0.3\ \text{ppm})\ .$$

This value agrees within one standard deviation with the value of $\Delta\nu$ reported by the Chicago group,[17] having an accuracy of 0.4 ppm. From our value for $\Delta\nu$ we obtain values for the μ magnetic moment and mass:

$$\mu_\mu/\mu_p = 3.183\ 329\ 9(25)\ (0.8\ \text{ppm})$$
$$m_\mu/m_e = 206.769\ 27(17)\ (0.8\ \text{ppm})\ . \quad (11)$$

The accuracy of μ_μ/μ_p and of m_μ/m_e is limited by the accuracy of the calculation of an α^3 radiative correction term in the theoretical expression[18] for $\Delta\nu$.

A second experiment (Exp. 37A) is now under way at LAMPF to measure the transitions $(M_J,M_\mu) = (^1/_2,^1/_2) \leftrightarrow (^1/_2,-^1/_2)$ and $(-^1/_2,-^1/_2) \leftrightarrow (-^1/_2,^1/_2)$, designated ν_{12} and ν_{34}, respectively, at a strong magnetic field of 13.6 kG, from which both $\Delta\nu$ and the μ-magnetic moment μ_μ (or actually the ratio of the μ-magnetic moment to the proton magnetic moment, μ_μ/μ_p) can be determined. The goal is a precision of $\simeq$1 ppm in μ_μ/μ_p and $\simeq$0.1 ppm in $\Delta\nu$.

Recent improvements in the LAMPF SMC, which include, most importantly, the evacuation of the channel as well as a better tuning condition for the initial channel magnets, have resulted in an increase by a factor of 6 in the ratio of stopped muons to primary protons for our thin gas target, as compared to that obtained with the operating conditions in 1974. With an average primary proton current of 100 μA and a μ^+ beam with a mean momentum of 50 MeV/c, we obtain a μ^+ stopping rate averaging 1.3 $\times$ 10^4/s in a 19-cm krypton gas target of 1.7 atm, or an instantaneous stopping rate of 2.6 $\times$ 10^5/s during the on-time of the accelerator.

Our experiment is a precision microwave magnetic-resonance measurement using a strong magnetic field. A major piece of equipment designed and constructed at Yale Univ., is a high-precision eighth-order solenoid, which provides a magnetic field stable to 1 ppm and homogeneous to 4 ppm over the region 19-cm diam by 19-cm long, occupied by the microwave cavity. The magnet is powered from a well-regulated 1-MW power supply and is stabilized with reference to an NMR signal. The microwave system provides outputs in the range of 1.9 GHz to 2.5 GHz of ~50 W, which are stabilized in frequency to 0.01 ppm and in power level to $\simeq$1%. For our target, the purity, temperature, and pressure of the krypton gas are of critical importance. Scintillation and PWC counters are used. We are able to use the μ-stopping rate resulting from the 100-μA beam without difficulty. The experiment is largely under control of the PDP-11/20 computer in the SMC counting house.

Excellent resonance curves have been obtained with krypton pressures of 2 and 6 atm, which are our planned operating pressures (Fig. XI-5). These data are now being analyzed, and a careful consideration of all systematic errors is being made before the main data-taking begins in the fall of 1976.

Neutron Spectra at 0° from p-p Collisions at 647, 771, and 805 MeV (Exp. 56)
(Texas A&M Univ., Univ. of Texas, LASL)

Data for the process, pp $\rightarrow$ npπ^+, have been completely analyzed for three incident energies: 647, 771, and 805 MeV. Approximately 10^6 events were recorded and analyzed, of which ~100 000, divided about evenly among the three energies, were accepted as candidates for the above reaction. A commensurate amount of background and auxiliary data (e.g., using chopped beam) was also analyzed for use in the measurement of the neutron spectra depicted in Fig. XI-6. The errors shown are statistical only, and the absolute cross sections are normalized with an accuracy of ~15%, due primarily to two factors; the np charge-exchange cross-section uncertainty, and the instability of the proton-beam toroidal current monitor, each of which contributes ~10% error in quadrature. Below 400 MeV/c, the spectrometer efficiency begins to drop from ~100%. Data taken below this momentum were not considered reliable enough to include in these spectra.

Also shown in Fig. XI-6 are the results of a calculation originated by J. Stephenson, B. Gibbs, and B. Gibson of the T-5 group, who were kind enough to make their program (SGG) available to us. After some slight modification to the original program, involving parametrization and Lorentz frame considerations, the fits shown were obtained. Only the 805-MeV data were used to fix the value of the

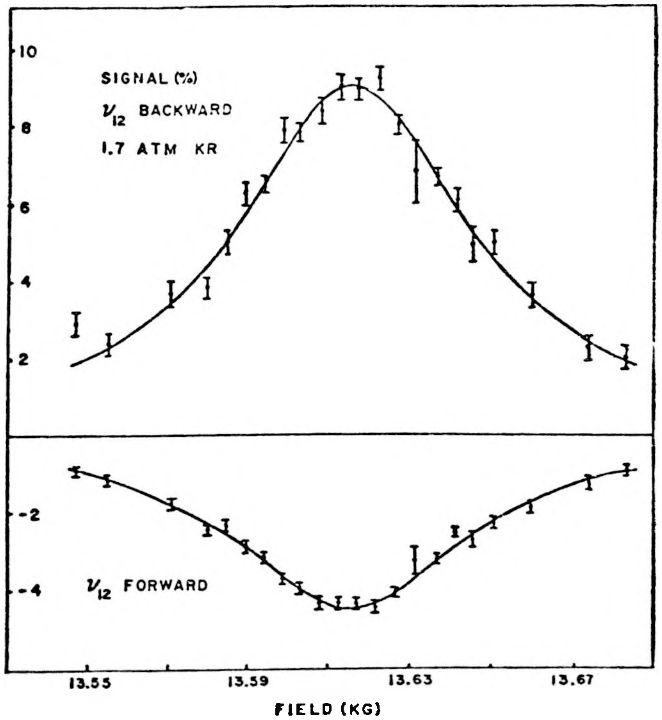


Fig. XI-5.
High field muonium resonance curve in 1.7 atm krypton target. The signals are defined as the ratio $[(e^+/\mu_{stop})_{RF\,ON}/(e^+/\mu_{stop})_{RF\,OFF}{}^{-1}] \times 100\%$ *in the forward (downstream) and backward (upstream) directions. The data were obtained in 12 h with a proton current of 70 μA.*

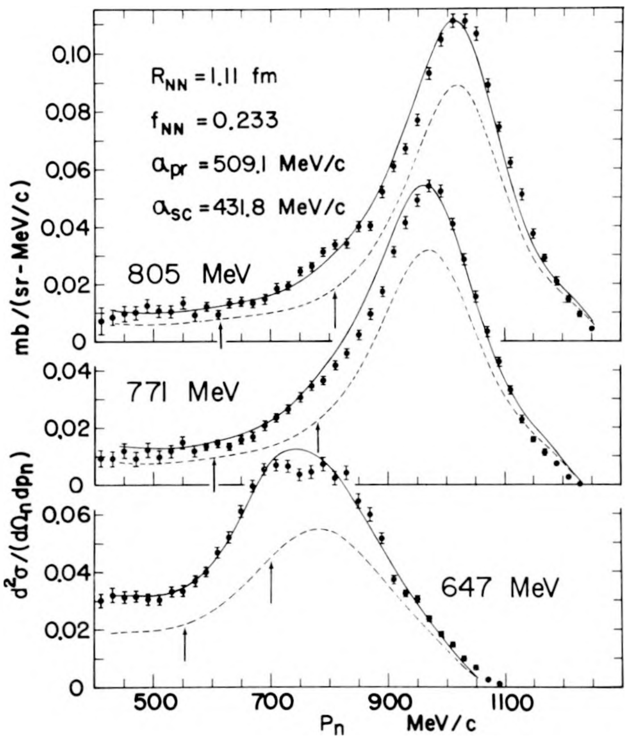


Fig. XI-6.
Three neutron spectra at 0°. The left hand arrow in each case indicates the neutron laboratory momentum, P_n, for which the neutron is stationary in the CM system while the right hand arrow locates that values of P_n where the two final state nucleons are expected to have the largest interaction.

parameters, R_{NN}, f_{NN}, α_{pr}, and α_{sc}. These parameters derive their meaning from a phenomenological one-pion-exchange (OPE) model, modified by the addition of diagrams to account for the nucleon-nucleon final state interaction (FSI). R_{NN} is a characteristic nucleon separation distance, and f_{NN} is a fractional factor to account for the presence of the pion in this nucleon-nucleon FSI. The parameters α_{pr} and α_{sc} account for the off-shell effects of the virtual exchanged pion in an OPE diagram at the pion-production and scattering vertices, respectively. The solid lines represent the full SGG calculation with the nucleon-nucleon FSI included, whereas the dashed lines indicate the results of the calculation when the nucleon-nucleon FSI is not included.

That the solid lines fit the data as well as they do is both surprising and encouraging, in view of the physical simplicity underlying the SGG calculation and the completely independent absolute normalizations applied to the three sets of data. The disagreement between the solid lines and the data is statistically significant (e.g., ~770 MeV/c in the 647-MeV data) and eventually is expected to be resolved with refinements to the SGG calculation.

A manuscript for publication of these results will be submitted shortly to Phys. Rev.

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

During 12 shifts each in cycles 1 and 3, 10 metal targets and 5 low-Z organic targets were irradiated at the SMC. Our purpose in running the metals was to determine the variation with Z of the intensities of the various members of the K series and to compare these results with analogous kaonic and pionic atom data. Such data will play an important role in understanding the basic capture mechanism. The low-Z organic targets included the series (CCl_4, CCl_4 + octane, CH_2Cl_2) and the pair (CH_2, CD_2). The former set was chosen to elucidate the effects of inter- vs intramolecular hydrogen transfer, and the latter set to test the effect of isotopic difference. Analysis of these data is now in progress.

In cycle 6, we shall finish the metal series and complete the series of metal oxides begun in 1974. Also, we expect to complete the series of low-Z organic targets.

Forward Elastic Scattering of π^+ and π^- from ^{12}C, ^{13}C, ^{16}O, ^{40}Ca, and ^{208}Pb (Exp. 80)
(Rice Univ., Univ. of Houston, Washington Univ.)

Pion-Nucleus Forward Scattering Amplitudes Near the 3/2, 3/2 Resonance

During the second period of beam time allotted to Exp. 80,the small angle elastic cross sections and the total cross sections were measured for $\pi^\pm$ from ^{12}C, ^{40}Ca, and ^{48}Ca in the energy region of the π-nucleon 3/2, 3/2 resonance. These two sets of data, the known coulomb scattering and the optical theorem, will allow the extraction of the real and imaginary parts of the forward nuclear-scattering amplitudes.[19] The ^{12}C data will be compared to previous results[20,21] as a check of the overall normalization of this experiment. The comparison of π scattering from the calcium targets should provide interesting information about the wave functions of the eight additional neutrons in ^{48}Ca.

The experimental setup used to measure the small angle elastic cross sections is shown in Fig. XI-7. Higher beam intensity and several refinements were responsible for improved data from this phase of Exp. 80. With the more intense primary beam available (20-35 μA) it was feasible to take π^- data in a reasonable length of time; in addition, the P^3 channel's momentum-defining slits were stepped down to provide a pion beam with a momentum bite of <1%. Since the spectrometer momentum resolution was ~1%, a better separation of elastic and inelastic events was obtainable. The MSSCs had an improved coding scheme which eliminated errors in the beam phase space and intensity measurements. Due to the small target size, a veto scintillator was used to confine the beam to a 2.5-cm spot. This decreased the spectrometer solid angle dependence on beam phase space. A summary of the new small-angle elastic data is presented in Table XI-III.

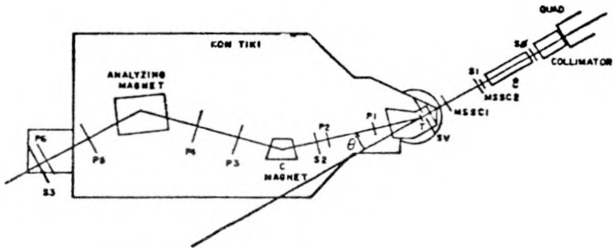


Fig. XI-7.
Small angle spectrometer. The apparatus consisted of four scintillators (S0-S3), a veto scintillator (SV), an electron detecting CO_2 Cerenkov counter (C), two bending magnets, two XY-coordinate multistrip scintillation counters (MSSC), the target (T), and six XY-coordinate MWPCs (P1-P6). The C magnet was used to divert the scattered pions away from the beam line to prevent the beam particles from interfering with P3-P6 and the analyzing magnet.

The setup for the total cross section portion of Exp. 80 is shown in Fig. XI-8. Six MWPCs were used to measure the incident and scattered trajectories for all events with a scattering angle ≤15°. The scattered pions indistinguishable from the beam ($\theta \leq 2.5°$) were scaled and vetoed by a hardwired analogue rejection system. The number of pions which were absorbed or scattered outside the 15° range were also scaled. The measurements were made for $\pi^\pm$ from all three targets at laboratory kinetic energies 222, 200, 180, 160, 140, and 120 MeV.

The data analysis has begun and is proceeding satisfactorily.

Study of Neutron-Proton and Proton-Proton Coincidence Spectra from p + d → n + p + p Reaction (Exp. 81)
(Rice Univ., Univ. of Houston, National Science Foundation)

Pion Production by 800-MeV Protons on Light Nuclei

The second phase of Exp. 81 has been devoted principally to the study of π-production mechanisms by protons on ^1H, ^2H, and ^6Li. The experimental apparatus has been described in detail in previous progress reports. A magnetic spectrometer arm and a TOF arm, each employing MWPCs, were used to detect charged particles in coincidence, and thereby completely determine the kinematics of three-body final states. This arrangement allowed particular π-production mechanisms to be investigated for various reactions, as detailed in the last quarterly report.

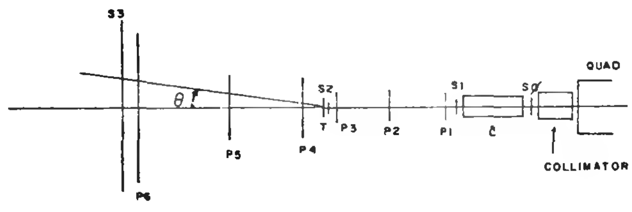


Fig. XI-8.
Total cross section setup. Scintillator S2 was required because the π beam was larger than the cross-sectional area of the calcium targets.

TABLE XI-III

SMALL ANGLE ELASTIC DATA

E_{lab}	Charge	Targets	Angles
200 (MeV)	±	^{12}C, ^{40}Ca, ^{48}Ca	7°, 11°, 15°, 19°, 23°
180	±	^{12}C, ^{40}Ca, ^{48}Ca	7°, 11°, 15°, 19°, 23°
160	±	^{12}C, ^{40}Ca, ^{48}Ca	8°, 12°, 16°, 20°
140	±	^{12}C, ^{40}Ca, ^{48}Ca	9°, 13°, 17°, 21°

E_{lab} is the incident π kinetic energy. The angles listed are the spectrometer central angle settings. The angular acceptance of the spectrometer was ±3.5°.

The analysis of the p-p and p-d elastic scattering data, used to test the experimental apparatus, is near completion. The angular distributions of these elastic cross sections are in close agreement with those previously presented.[22]

The early analysis of π-production data has been concentrated on the coincidence measurements of the reactions

i) $pp \rightarrow d\pi^+$
ii) $pp \rightarrow d^*\pi^+ \rightarrow p\pi^+n$
iii) $pd \rightarrow d\pi^+n$
iv) $p^6Li \rightarrow d\pi^+\ {}^5He$
$\rightarrow d\pi^-\ {}^5Li$

where d* refers to a n-p FSI system. Preliminary results of the analysis of the above reactions have recently been presented at the International Topical Conference on Meson-Nuclear Physics in Pittsburgh.[23]

The analysis of reactions (i) and (ii) is nearing completion, and final corrections are being made to calculate absolute cross sections. Preliminary results for reaction (i) are shown in Fig. XI-9, where the c.m. cross section is plotted as a function of the cosine of the c.m. deuteron angle. A CERN group[24] has measured the inverse reaction, $\pi^+d \rightarrow pp$, and using detailed balance has calculated the differential cross section for $pp \rightarrow d\pi^+$ at 810-MeV proton energy. The solid line in Fig. XI-9 is a fit to the CERN data, which agrees closely with the preliminary results of Exp. 81. A fit to the Exp. 81 data is forthcoming.

Data on reaction (ii) are shown for a single d*, π^+ angle pair in Fig. XI-10 where the cross section divided by phase space has been plotted vs the n-p relative momentum, k_{np}. The strong peaking at $k_{np} = 0$ is clear indication of a n-p FSI in the $^1S_0$ and $^3S_1$ states. The singly differential cross section for $pp \rightarrow d^*\pi^+$, integrated out to $k_{np} \simeq 75$ MeV/c, is being calculated for comparison with the $pp \rightarrow d\pi^+$ data.

The analysis of data on reactions (iii) and (iv) is still in progress. For reaction (iii) in which deuterons were detected at lab angles <25°, π production has been found to proceed mainly via the mechanism

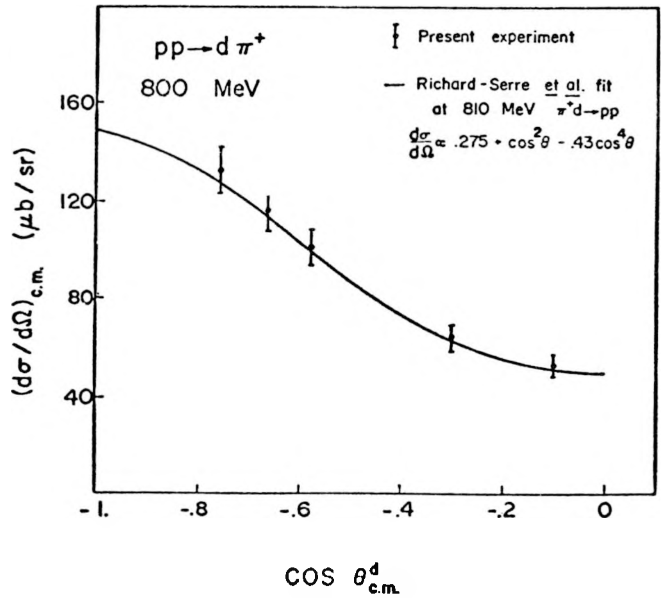


Fig. XI-9.
Preliminary angular distribution for $pp \rightarrow d\pi^+$.

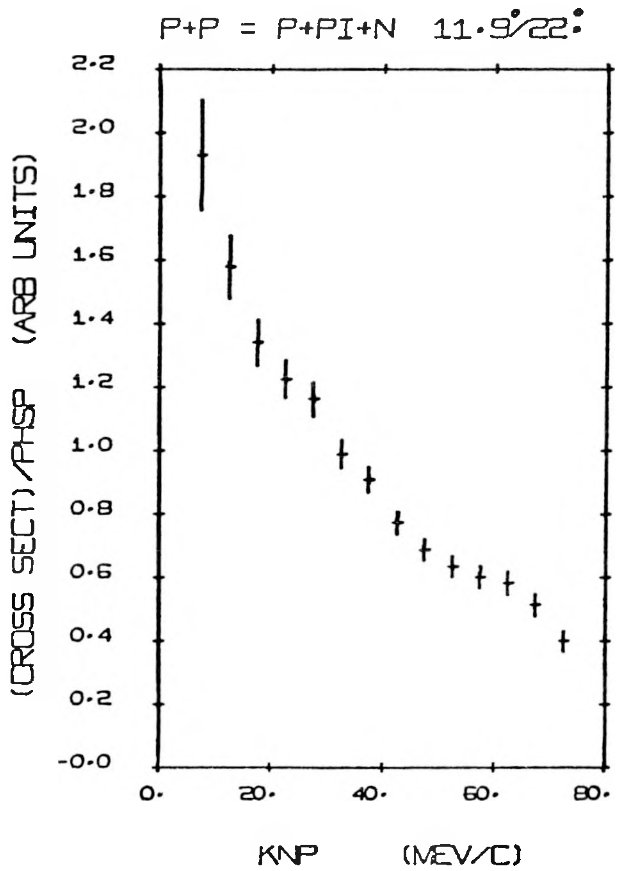


Fig. XI-10.
Cross section vs n-p relative momentum for pp $\rightarrow d^*\pi^+ \rightarrow p\pi^+n$, with $\Theta_p = 11.9°$ and $\Theta_\pi = 22°$.

shown in Fig. XI-11(a). This process is simply the reaction pp $\rightarrow d\pi^+$ with the neutron in the target remaining as a spectator. For kinematic conditions in which the neutron is required to remove momentum from the reaction, the neutron momentum essentially maps out the momentum components in the target deuteron wavefunction. A similar diagram, shown in Fig. XI-11(b), has been found to make a significant contribution to the cross section for reaction (iv). This process is also dominated by the pp $\rightarrow d\pi^+$ reaction, leaving the (n-^{4}He) system as a spectator. The analysis of this reaction is complicated by a possible contribution from the reaction ^{6}Li (p, $d\pi^-$)^{5}Li since the charge of the coincident pion was not determined.

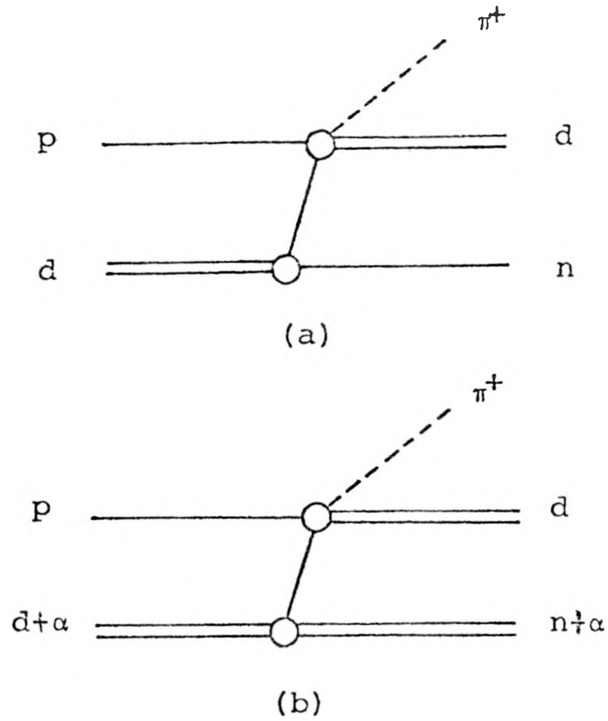


Fig. XI-11.
Reaction diagrams for (a) d(p,$d\pi^+$)n and (b) ^{6}Li(p,$d\pi^+$)^{5}He.

Counter Experiments in the Thin Target Area (Exp. 86)
(LASL, LBL, ORNL, BNL, Texas A&M Univ.)

Time-of-Flight Studies of 800-MeV Proton-Induced Nuclear Reactions

We have used ΔE-E and TOF techniques to study the low-Z nuclear reaction products resulting from the interaction of 800-MeV protons with a thin uranium target at the LAMPF TTA. We have recently implemented a unique TOF system which resulted in a dramatic improvement in the mass resolution of our experiment. First, the flight time of a nuclide was determined to within 150 ps over a 39-cm flight path between a ΔE and an E detector; this resulted in a mass resolution of ΔA/A = 2.4% for carbon, as shown in Fig. XI-12. A simultaneous time measurement, utilizing a fast-bipolar beam pickoff signal for the stop signal, allowed the determination of the flight time (and thus the mass) over the full 433-cm distance from the target to the ΔE detector. This vernier-type technique resulted in a final mass

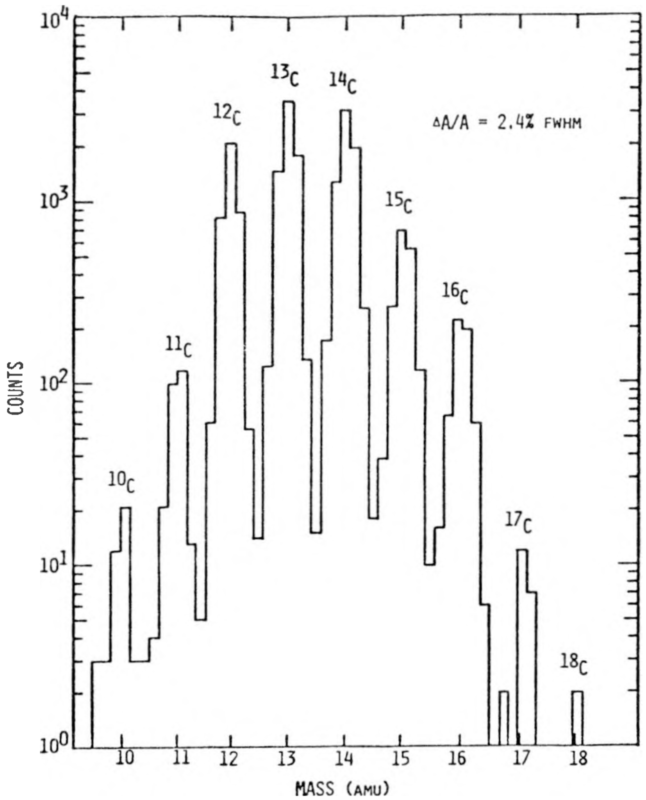


Fig. XI-12.
Carbon mass spectrum calculated over a 39-cm flight path.

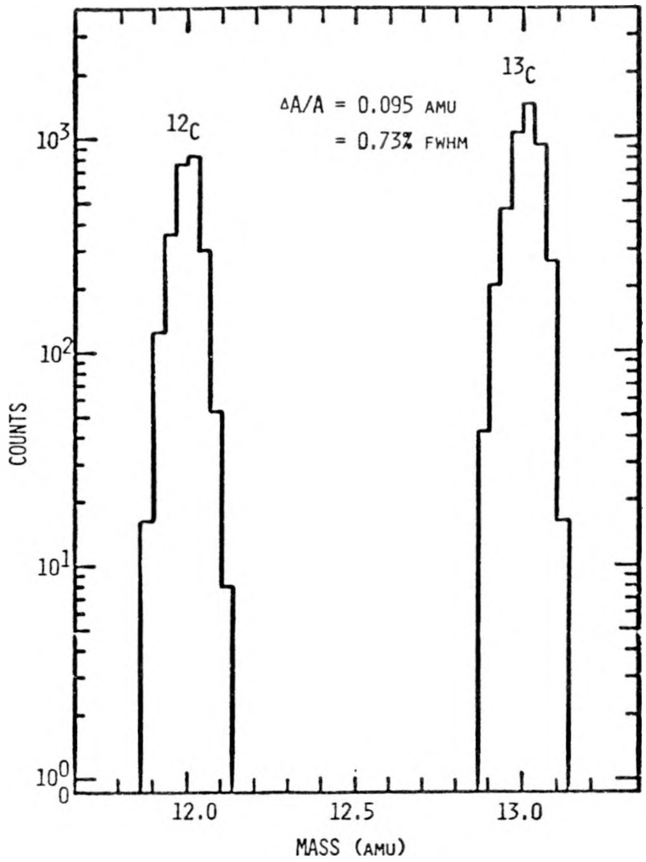


Fig. XI-13.
Portion of the carbon mass spectrum calculated over a 433-cm flight path. Notice that the zero count level is displayed.

resolution of 0.73% for carbon, as shown in Fig. XI-13; this represents a considerable improvement over the results shown in Fig. XI-12.

Although the yields of Z ≅ 10 nuclei are very low, we have used this improved TOF technique to search for previously undiscovered neutron-rich nuclei. We have so far been able to identify the new isotope ^{31}Mg, as shown in Fig. XI-14, thereby proving that it is stable with respect to neutron emission. We are currently searching for new isotopes in the neon to argon region (Z = 10 to Z = 18).

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

New data have been obtained on the radioactive decay of ^{148}Tb (70 min) and ^{149}Tb (4.1 h), produced by 800-MeV proton bombardment of tantalum. These spallation-product activities were isolated for off-line study with an isotope separator, in combination with standard radiochemical procedures. High-resolution Ge(Li) detectors were used to record the γ-ray singles spectra and γ-γ coincidence spectra. Our γ-γ coincidence measurement capability was recently upgraded through the acquisition of two large coaxial Ge(Li) detectors, which have increased the rate at which we can acquire data by about a factor of 5.

In the case of ^{148}Tb decay, many previously unobserved γ-ray transitions have been found. Also, we have shown that most of the energies reported[25] by the Dubna group are inaccurate, some being in error by as much as 6 keV. In the case of ^{149}Tb decay, preliminary analysis of 14.3×10^6 γ-γ coincidence events has shown that the decay scheme proposed[26] by the Dubna group is seriously in error. The data are still being analyzed.

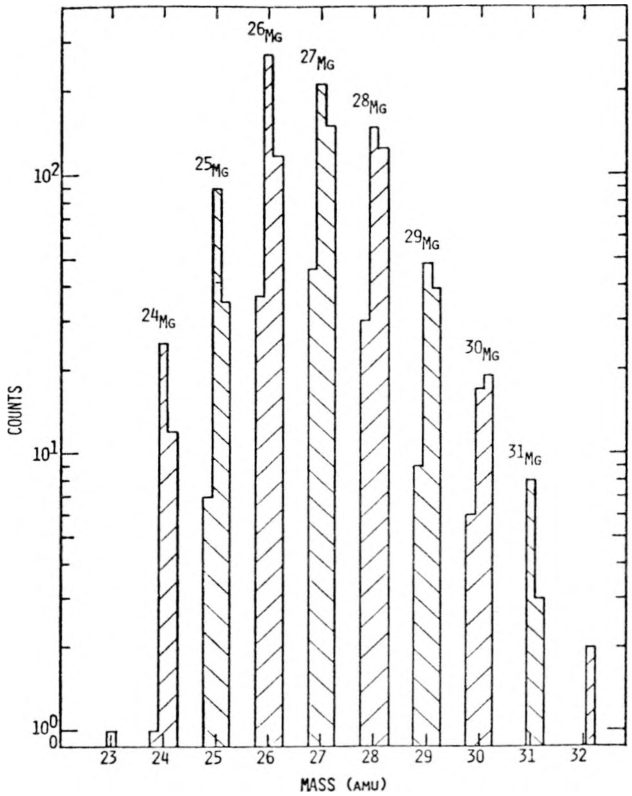


Fig. XI-14.
Magnesium mass spectrum showing several events of ^{31}Mg, a previously undiscovered neutron-rich nuclide.

As mentioned in the previous quarterly report, we have calculated a value of 1372^{+10}_{-20} keV for the decay energy (Q_β-value) of ^{131}Ba on the basis of a comparison of our measured electron capture to positron ratio with theoretical predictions. However, cases have recently been reported[27] where the experimental EC/β^+ ratios appear to deviate considerably from those predicted by theory, and it is suggested[27] that this might be a generally occurring phenomenon. Such a possibility obviously casts some doubt on the reliability of our ^{131}Ba Q_β-value. However, further information now exists which sheds light on this question. From the measured Q-value of the ^{130}Ba(d,p) reaction,[28] a value of 1348 ± 7 keV is deduced[29] for the ^{131}Ba β-decay energy, in reasonably good agreement with our value. (The lower limit must, in fact, be >1342 keV since we observe EC feeding of a 1342-keV level.) Based on the Q_β-value determined from the (d,p) results, the skew ratio (the ratio of our experimental EC/β^+ ratio to the theoretical value)[27] is $0.38^{+0.7}_{-0.2}$. This skew ratio is compatible with the conventional theory (i.e., a skew ratio = 1.0 is possible). Further, most of the calculated range of the skew ratio is less than unity, whereas all cases discussed in Ref. 27 have ratios larger than unity. We thus conclude that the use of our EC/β^+ ratio to deduce the Q_β-value of ^{131}Ba is justified, and that the type of anomaly discussed in Ref. 27 does not occur here.

Proton-Induced Spallation Reactions Related to the Isotope-Production Program at LAMPF (Exp. 106)
(LASL, Univ. of New Mexico)

Our experiments during this reporting period include cross-section studies of iron and scandium nuclides in a nickel target, copper and gallium nuclides in arsenic, thallium nuclides in lead and bismuth, and lead nuclides in bismuth. In addition, a molybdenum target was irradiated for the following radiochemical studies: 1) chemical recovery of the radio-bromine fraction; and 2) isolation of ^{82}Sr for continued studies of ^{82}Sr/^{82}Rb radioisotope generator chemistry.

Although the analyses of results from these experiments are continuing, some general comments can be made at this time. The cross section for ^{52}Fe from nickel appears to be low (1 to 2 mb), but sufficient amounts for compound labeling research should be available at the higher beam intensities. The yield of ^{67}Cu from arsenic is similar to that of ^{52}Fe, while the yield of ^{64}Cu is perhaps an order of magnitude greater. The yield of ^{67}Ga from arsenic is about 30 mb, demonstrating the fact that it can readily be produced at LAMPF.

Chemical procedures for the recoveries of zirconium, yttrium,[30] and strontium[31] from molybdenum targets have been developed. Research is in progress on the chemical isolation of the bromine fraction, where ^{77}Br is the nuclide of interest.

Two ion-exchange systems (BioRex 70 and Chelex 100) have been proposed for the strontium-rubidium generator.[32,33] Our recent study of these systems showed the following results:

1. A minimum of 0.5 mg of stable strontium had to be present before the Chelex 100 column exhibited a minimum strontium

breakthrough. Thereafter, up to 20 mg of added carrier produced no change in behavior.

2. The BioRex 70 system exhibited significant and rapid-strontium breakthrough after 400 to 600 mℓ of eluant passed through the column. The Chelex 100 system remained stable after 6ℓ of eluant passed through. These studies are continuing.

Measurements of "P," "R," and "A" Parameters in $\pi^{\pm}$-p Elastic Scattering/Measurements of "D," "R," and "A" Parameters in p-p Elastic Scattering (Exp. 132/160)
(LASL), Virginia Polytech. Inst. and State Univ., State Univ. of New York at Geneseo, and Texas A&M Univ.)

These experiments are not yet mounted because the polarized proton target is not ready. The study of the spectrometer is nearly complete. Shunts to be used in the experiments have been calibrated against the standard and are found to be ~0.2% high. The final analysis, using the spectrometer magnet, is now in process.

Investigations of Changes in Charge Distributions for Nuclei Near Z = 28 by Electron Scattering and Muonic X Rays (Exp. 163)
(LASL, Florida State Univ., Univ. of Mainz, Purdue Univ., Oregon State Univ., Massachusetts Inst. of Tech.)

Study of Nuclear Charge Distribution in the Mass-60 Region

The results of precise measurement of the energies of the $2p_{3/2} \rightarrow 1s_{1/2}$ and $2p_{1/2} \rightarrow 1s_{1/2}$ muonic x-ray transitions of ^{54}Fe, ^{56}Fe, ^{57}Fe, ^{58}Fe, ^{59}Co, ^{58}Ni, ^{60}Ni, ^{61}Ni, ^{62}Ni, ^{64}Ni, ^{63}Cu, ^{65}Cu, ^{64}Zn, ^{66}Zn, ^{68}Zn, and ^{70}Zn are reported. Using a highly linear digitally-stabilized Ge(Li) spectrometer system, the absolute energies and energy shifts between nuclei were measured with total errors of ~40-60 eV (110 eV for ^{70}Zn).

The data were analyzed in terms of the Barrett moments $\langle r^k e^{-\alpha r}\rangle$ of the nuclear charge distributions from which the equivalent nuclear radii R_k and the isotopic and isotonic differences δR_k were computed.

Particular attention was given to higher order corrections of the energies of the muonic states. Appropriate quantum electrodynamical corrections were calculated to all significant orders. Nuclear polarization corrections for multipole interactions up to and including L = 4 were computed for each isotope.

The $\Delta A = 2$ isotone shifts δR_k for even A isotopes show a strong shell-closure effect at Z = 28, which is quite independent of the neutron number. The $\Delta N = 2$ isotope shifts, between even nuclei, decrease smoothly and uniformly with increasing N from N = 28 to N = 40 and are essentially independent of Z. This unexpected behavior suggests that the added neutrons interact with the entire proton core rather than with the valence protons.

The $\Delta N = 1$ isotope shift results show a pronounced odd-even staggering effect, which, however, is somewhat smaller than theoretical predictions. The isotone series ^{58}Fe-^{59}Co-^{60}Ni, which is just below the Z = 28 shell closure, show strong odd-even staggering, whereas the series ^{64}N-^{65}Cu-^{66}Zn and ^{62}Ni-^{63}Cu-^{64}Zn just above Z = 28 exhibit only a very small staggering effect.

A comparison of the experimental data of the rms radii $\langle r^2\rangle^{1/2}$ with the results of spherically-constrained Hartree-Fock calculations shows good agreement for all four zinc isotopes and the heavier nickel isotopes (^{60}Ni, ^{62}Ni, and ^{64}Ni), but poor agreement for the iron isotopes and ^{58}Ni.

A paper entitled "Systematics of Nuclear Charge Distribution in Fe, Co, Ni, Cu, and Zn Deduced from Muonic X-Ray Measurements" has been accepted for publication in Phys. Rev. **14C**.

Measurement of the $\pi^- p \rightarrow \pi^0 n$ Angular Distribution at Low Energies and Calibration of the π^0 Spectrometer (Exp. 181)
(Case Western Reserve Univ., LASL, and Tel Aviv Univ.)

π^0-Spectrometer Design Parameters

The π^0-spectrometer design parameters were measured with two test runs in July using the LAMPF test channel (Area A) and the Case Western Reserve Univ. MWPC and data-acquisition system. The goals were:

- to set up e^+ and tagged γ beams using the copious supply of e^+'s in the 18.1-m test channel;
- to measure the energy resolution of the lead-glass total absorption Cerenkov counter and converter;
- to determine the conversion point position resolution that can be achieved with 3-MWPC wire planes placed behind a 0.6 radiation length lead-glass converter.

This configuration of active lead-glass converters backed by MWPCs and total absorption lead-glass Cerenkov detectors represents the design of each arm of the π^0 spectrometer. The position and energy resolution of these elements determine the π^0 energy resolution. The test channel setup of e^+/γ beams is shown in Fig. XI-15.

An isobutane-filled Cerenkov counter[34] $\check{C}_1$ in the beam telescope gave clean positron identification. Typical rates were 10^3 - 10^4 e^+/s at 100 MeV for channel slit widths of 2 to 6 cm. The sweeping magnet (SM) was installed to measure the test channel resolution and to produce a tagged γ beam. The channel resolution was determined by deflecting 100-MeV e^+'s ($\check{C}_1 \cdot SC_1$) through the SM and measuring the ratio $e^+ \cdot SC_2 \cdot SC_3/e^+$ (the fraction of the e^+ beam accepted by the magnetic spectrometer) vs channel momentum (Fig. XI-16). The observed energy resolution (FWHM = 14%) results almost entirely from the channel setting since $(\Delta p/p) \times \ell \gg$ beam spot size at SC_3 (Fig. XI-15). The energy resolution of a 100-MeV tagged γ beam was determined by passing 100-MeV e^+'s through a $0.082x_0$-lead converter behind SC_1 and measuring the deflected beam $e^+ \cdot SC_2 \cdot SC_3/e^+$ vs channel momentum. Since the fractional energy resolution of the channel $(\Delta p/p)$ and the probability of losing a fraction (E^-/E) of the incident e^+ energy to bremsstrahlung in the converter are both independent of energy, the spectrum shape of 100-MeV photons produced by 200-MeV E_{e+} with the SM set to 100 MeV/c is determined, and it is plotted in Fig. XI-16.

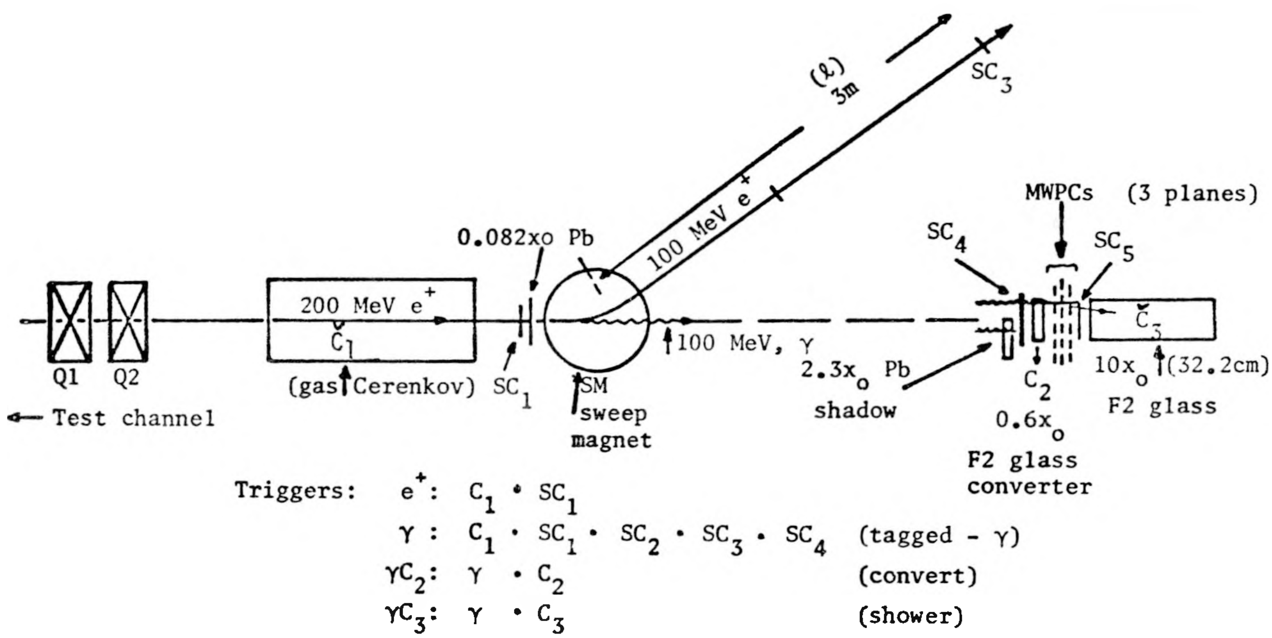


Fig. XI-15.
Plan view of π^0-spectrometer test channel setup. Detector sizes:
SC_1 = 7½ by 7½ cm
SC_2 = 7½ by 7½ cm
SC_3 = 5 by 5 cm
SC_4 = 18 by 18 cm
SC_5 = 15 by 15 cm

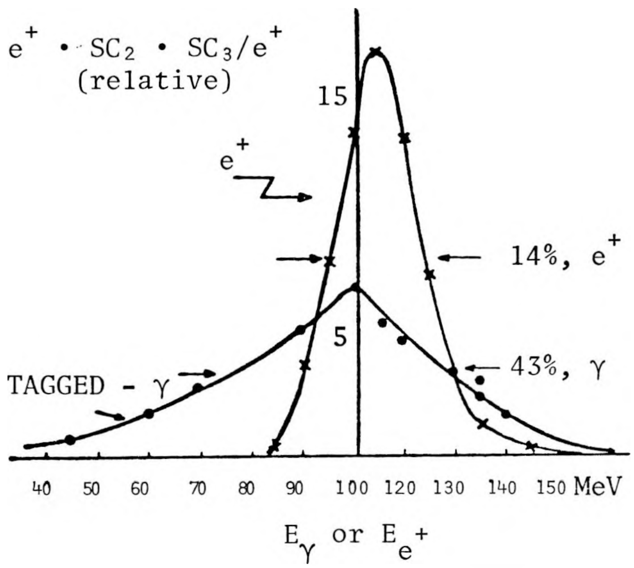


Fig. XI-16.
Resolution measured for positron beam of test channel (Area A) and for tagged γ beam using setup shown in Fig. XI-15.

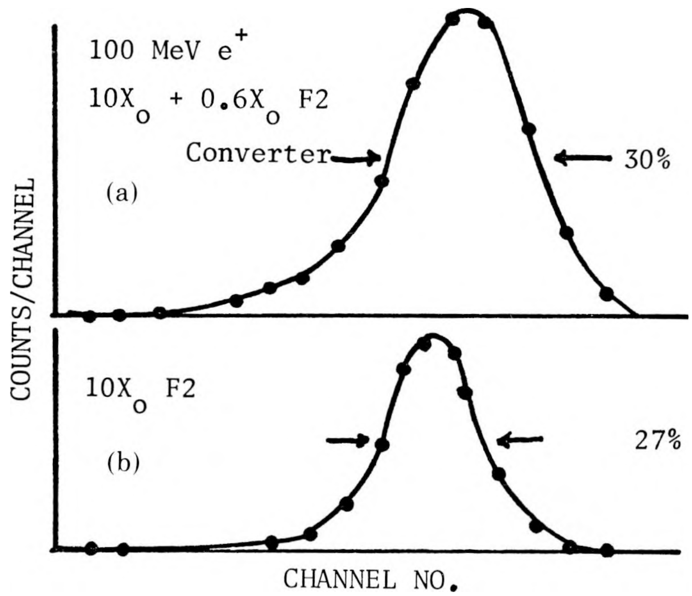


Fig. XI-17.
Pulse-height distributions for Cerenkov light produced by a 100-MeV e^+ beam incident on 0.6 X_0 (converter, F2) + 10 X_0 (light added) (a); and 10 X_0 of F2 glass (b).

As can be seen, the photon resolution is much deteriorated by the lead converter and is too broad to measure the resolution of the glass total-absorption counter ($\check{C}_3$) and converter ($\check{C}_2$). Typical rates were 1-5 γ/s for $E(e^+)$ = 200 MeV and E_γ = 100 MeV. Since the differences in resolution of total-absorption Cerenkov counters for electromagnetic showers initiated by γs and e's are negligibly small in the present geometry, the e^+ beam could be used.

The resolution of the lead-glass block and converter obtained with a 100-MeV e^+ beam is shown in Fig. XI-17(a).

Light from the converter $\check{C}_2$ was collected on one edge (2 by 15 cm) via a 3-strip light guide coupled to a 12.5-cm EMI 9618KR phototube.[35] The $\check{C}_3$ light was collected with a second such tube, coupled directly with Dow Corning Q2-3059 optical coupling compound to the back face (15 by 15 cm^2) of the block. Both tubes were selected for good cathode sensitivity (94 and 105 μA/1 m, respectively). For these energy resolution studies, the size of SC_5 was 5 by 5 cm in order to select e^+'s which interacted near the axis of the lead-glass Cerenkov detectors. The light from $\check{C}_2$ and $\check{C}_3$ was added in an LRS 127 linear fan-in, and gave a pulse-height resolution of 30% FWHM (Fig. XI-17(b)). Taking the channel contribution as 14%, the Cerenkov light resolution is 26.5%. When $\check{C}_2$ was physically removed, the resolution of $\check{C}_3$ was 27%, giving 23% for the light resolution. The best value achieved by Holder *et al.*[36] for 1-GeV e^- onto $15x_0$ of SF5 glass was 8.6% FWHM which scaled by $E^{-1/2}$, gives 27% at 100 MeV. To our knowledge, the value of 23% of Fig. XI-17(a) is the best ever achieved for total-absorption Cerenkov counters.

The conversion-point position resolution was measured with the 100-MeV tagged γ beam incident on a $0.6x_0$ F2 glass converter (C_2) which was partially shadowed by a $2.3x_0$ lead plate (Fig. XI-15). The MWPC coordinated (Y1,Y2) of single- and double-pronged events were projected back to the converter midplane to give coordinate Y_0 for 1-prong events and $Y_0 = (Y_{01} + Y_{02})/2$ for 2-prong events. Typical histograms of Y_0 are displayed in Fig. XI-18(a) and XI-18(b). These, as well as the $\overline{Y}_0$ histograms, demonstrate directly that the position of the lead edge is determined to $\lesssim$2.5 mm. The observed position resolution is approximately equal to the wire spacing (2.5 mm). The data shown in Fig. XI-18(b) was taken with the lead plate displaced 1.25 mm relative to the data of Fig. XI-18(a). The movement of the edge is clearly visible. To analyze the data further, Monte Carlo events were generated which

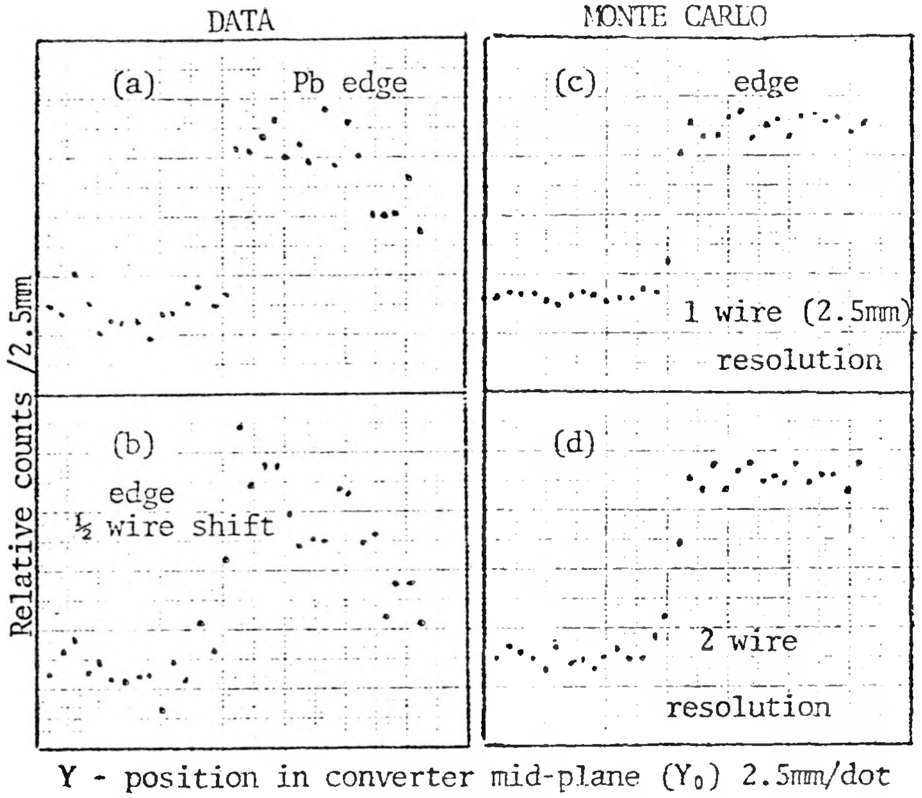


Fig. XI-18(a), (b), (c), and (d).
Position of lead edge determined from two MWPC wire planes.

include the effects of multiple scattering of the charged particles in the converter and of finite wire resolution. These are displayed in Fig. XI-18(c) and (d). In (c) one sees that if a resolution width of one wire is assumed, the Monte Carlo events reproduce the data (a) very well. An assumed two-wire resolution width (d) smears the edge more than is observed in the data (a). In evaluating the multiple-scattering, we find that the sharp edge of (a) restricts the multiple-scattering contribution to $\sigma_{rms} \leq$ 0.7 mm projected onto the converter midplane. A value of 0.7 mm was expected from our studies[37,38] of shower development.

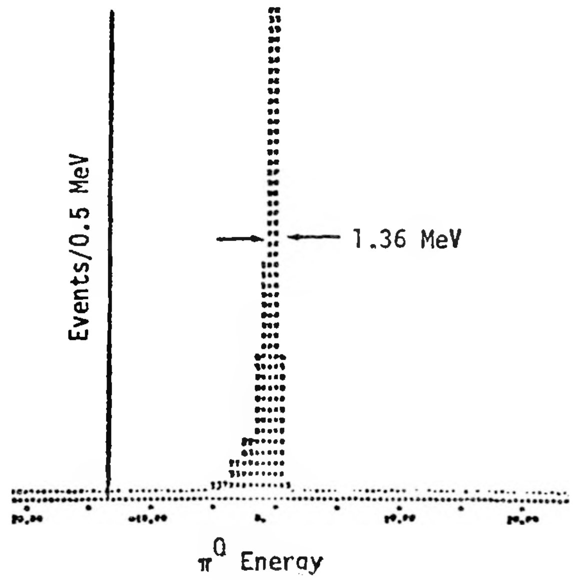
The above results are a direct test of the feasibility of achieving the energy and position resolutions needed to build the π^0 spectrometer. We have obtained an energy resolution of 26.5% FWHM and a position resolution 2.5-mm FWHM at 100 MeV. The configuration of detectors used was a simplified version of each arm of the π^0 spectrometer.

The π^0-energy resolution was calculated employing a Monte Carlo code to simulate the resolution of the spectrometer using the parameters measured in the test run. Figure XI-19 shows a spectrum for T_π = 60 MeV, requiring detection of 100-MeV γ rays at an opening angle of 87°. Beam energy spread and target thickness were set to zero. From the figure one sees that the spectrometer resolution function has a FWHM of 1.4 MeV which is better than we had assumed in the design proposal.

Nuclear Resonance Effect in Pionic Atoms (Exp. 195)
(LASL, Univ. of Mississippi, National Research Council of Canada)

Data taking for all isotopes and analysis for palladium and ruthenium has been completed. The measured value of the attenuation of the pionic 4 → 3 transition in ^{110}Pd (19.4 ± 2.8)%, shows conclusively that the zero-energy P-wave pion-nucleus interaction has, indeed, changed to being repulsive at this large value of Z(46), in agreement with the hitherto untested theoretical prediction.

The E2 nuclear resonance effect in hadronic atoms occurs when an atomic deexcitation energy is nearly



Monte Carlo Parameters

T_{π^0} = 60 MeV	σ_x (MWPC) = 0.22 cm
R = 1 m	xcut = 0.1
δE_γ = 27% at 100 MeV	Ω = 0.4 msr
σ_y (MWPC) = 0.07 cm	

Fig. XI-19.
Resolution function of the π^0 spectrometer with parameters measured in the test runs.

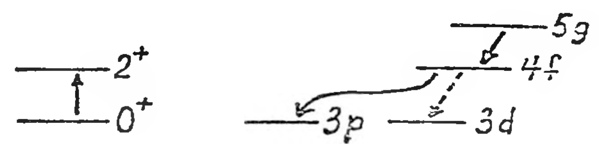


Fig. XI-20.
Nuclear and atomic energy levels involved in the nuclear resonance effect in pionic ^{110}Pd and ^{104}Ru.

degenerate with an appropriate nuclear excitation energy, so that the (E2)-coulomb-coupling produces significant configuration mixing. The resulting induced width of the mixed n,ℓ state can then attenuate the (n,ℓ → (n-1,ℓ-1) hadronic x-ray line, an effect which is readily observable (see Fig. XI-20). For palladium, calculation using a phenomenological pion-nucleus potential, predicts for the pionic 3p level a strong interaction shift of about -10 keV ("-" meaning repulsion) and a width of about 30 keV; naive extrapolation, i.e., no sign change and scaling according to Z^4 from data for Z = 30, yields a shift of about +15 keV and, again, 30-keV width. The different energy shifts imply significantly different values of attenuation of the 4 → 3 line, and hence can readily be distinguished experimentally.

The experiment consists of comparing the pionic intensity ratio (4 → 3: 5 → 4) in pairs of targets which are identical except for isotopic composition. Pairs of separated isotope targets were simultaneously exposed to moderated π^- beams at the P^3 and biomed channels. A germanium detector, viewing both targets symmetrically, provided the x-ray energy spectra, while a scintillator telescope determined in which target each pion stopped.

The implications of these resonance-effect measurements can best be discussed by considering the behavior of the attenuation as a function of the complex energy difference (i.e., the energy denominator of perturbation theory). In the energy difference plane, contours of fixed attenuation are circles centered on the imaginary axis and intersecting the origin, which itself corresponds to exact degeneracy; such a plot for ^{110}Pd is shown in Fig. XI-21, with the attenuation (in %) for each contour indicated. The dashed curve comes from setting the real potential parameters to zero and varying the imaginary parameters; the region to the left of this curve corresponds to pion-nucleus repulsion, the right to attraction. Points predicted by the phenomenological potential and by naive extrapolation are also shown. It is quite clear that the measured value of attenuation (shaded area) lies well inside the repulsive region. Furthermore, the large magnitude of attenuation favors a 3p width, significantly less than the predicted value of ≈30 keV.

Data analysis for other isotopes is in progress.

Precision Measurement of the Decay Rate for the Dalitz Decay Mode of the π^0 Meson/Measurement of the Decay Rate for $\pi^0 \rightarrow e^+e^-$ (Exp. 221/222) (LASL)

Construction has started for most of the equipment for these experiments. The MWPCs, counters, liquid hydrogen target, and muon shielding are being fabricated. The converters and targets for Exp. 221 ($\pi^0 \rightarrow e^+e^-\gamma$) have been made and are being tested for thickness uniformity (to an accuracy of 0.1%)

and for chemical impurities. The on-line data-acquisition program is being written.

A large Cerenkov counter has been designed for Exp. 222 ($\pi^0 \rightarrow e^+e^-$) to identify electrons. The orders for the focusing spherical mirrors and the photomultiplier tubes have been placed.

The field of the magnet which will be used for both Exps. 221 and 222 has been mapped with the rapid mapper equipment. Maps of the three components of the magnetic field were made over a volume of 30 by 75 by 280 cm with a grid of 5 by 2.5 by 2.5 cm at two current settings. Additional data to check the field symmetry were also taken. Analysis of this data is now proceeding and the overall quality of the data looks quite good.

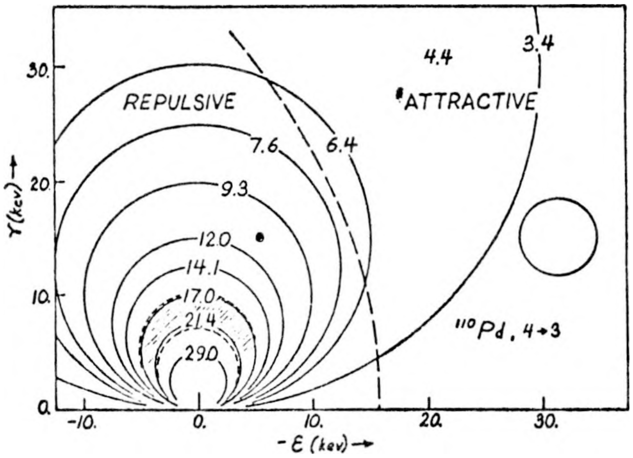


Fig. XI-21.
The complex energy difference plane for pionic ^{110}Pd (real part ϵ, imaginary part γ). The broken curve comes from setting the real phenomenological potential parameters to zero while varying the imaginary ones; the region to the left of this curve corresponds to pion-nucleus repulsion, the right to attraction. The solid point is the predicted value while the circle to the right is from naive extrapolation of the data for Z = 30. Contours of fixed attenuation are shown (marked in %). The shaded region is the result of this experiment.

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

This experiment was designed to test the possible existence of an energy threshold for direct lepton production. The apparatus is shown in Fig. XI-22. The last progress report discussed the analysis procedure in some detail and the results of the 256-MeV data and part of the 800-MeV data. These results indicated no direct lepton production at these energies.

We have now completed the analysis of the 800-MeV data, extending our measurements down to $p_\perp$ = 100 MeV/c. This allows us to search for the possible existence of a light charged vector boson as has been proposed by Lederman and White.[39] The 800-MeV data were taken using two settings of the magnetic field. The raw momentum spectra appear to differ by either a factor of 2 in normalization or a momentum shift of 15%. We are unable to find justification for either type of error. Since our primary running was at the higher field, we have greater confidence in these data. We assign an overall normalization uncertainty of 20% for the high-magnetic-field data and 2x for the lower-field data.

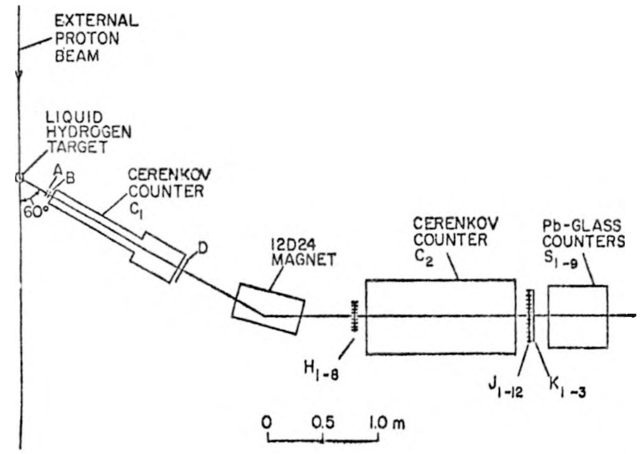


Fig. XI-22.
The experimental apparatus.

The results for the direct positron yield as a function of the positron momentum are shown in Fig. XI-23. The error bars represent the statistical errors and the uncertainties in the radiative corrections. The results are consistent with zero at all momenta. Combining all of the data from $p_\perp$ = 110 to 310 MeV/c yields an invariant cross section of $E\, d^3\sigma/dp^3 = (-14 \pm 12) \times 10^{-32}$ cm^2/ [sr(GeV/c)^2] at 800 MeV.

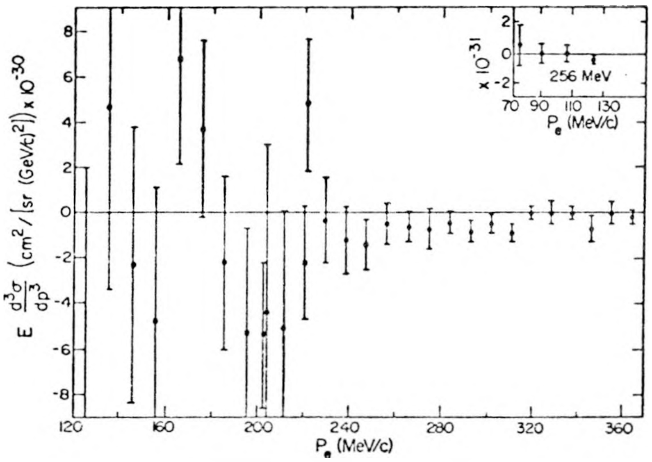


Fig. XI-23.
Direct positron yields at 800 MeV as a function of the positron momentum. The open and closed circles correspond to two different magnetic field settings. The inset shows the yields at 256 MeV.

There are, in addition, errors due to uncertainties in the amount of material available for photon conversion, in the value of the Dalitz ratio and the pair cross section, and in the relative detection effeciency for positrons from Dalitz decay of π^0 and from pair production. These errors contribute an uncertainty of $\pm 10 \times 10^{-32}$ cm²/ [sr(GeV/c)²].

The data are thus consistent with no direct lepton production at all; $p_\perp$ indicating the existence of a threshold for this process.

These results have been submitted to the XVIII International Conference on High Energy Physics, Tbilisi, USSR (1976). A Phys. Rev. article is in preparation.

Radiation Damage Effects of 800-MeV Protons (Exp. 269) (LASL)

The two proton irradiations required to complete Exp. 269 were finished by early May. The first irradiation of annealed high-purity aluminum was carried out in the SY at a current density of 250-μA cm^{-2} for 30 h. The objective of the irradiation was to produce a displacement damage state approaching 1 dpa in a real metal, so that a comparison could be made to damage produced by neutrons, and to demonstrate the use of LAMPF high-energy proton irradiations in radiation-damage studies.

The sample received a displacement damage level of ~1/3 dpa in high-energy displacement spikes caused mostly by heavy spallation impurity atoms, a helium gas production of ~20 appm, and an inferred total spallation impurity atom production of 30 appm according to calculation. Electron-transmission microscopy was carried out to establish the form of radiation damage produced.* Preliminary observations showed that voids were produced on the midplane of the 10-mil-thick irradiated sheets. The void concentration was $\sim 1 \times 10^{15}$ cm^{-3}; the average void size was ~90 Å; and the calculated volume fraction was ~0.05%.

The second proton irradiation, which was performed on copper and aluminum foils, was completed to a lower dose (755-μA h for aluminum and 162-μA h for copper). One objective of the irradiation was to produce helium by (p, nxHe) reactions, and test the accuracy of the total helium production cross sections. The helium extraction by vacuum fusion will be done in the near future. The copper irradiations were completed, and determinations were made of the hardening produced by high-energy proton irradiation. Hardening results when debris, produced by point-defect clusters, blocks dislocation glide. The hardness data have been taken but not yet analyzed.

Muonic Analysis of Core Samples from Oil-Bearing Formations (Exp. 277) (Univ. of Houston, Univ. of Texas, LASL)

Experiment 277 received six shifts of beam at SMC July 4-5, 1976.

The muon beam is collimated to a 5- by 5-cm square by lead shielding and monitored by crossed scintillator paddles located at the collimator. A veto counter is used behind the target. Stopping muon rate was $\sim 10^5$ s^{-1}. Figure XI-24 shows the experimental geometry. Targets consist of concrete to which was added variable amounts of NaCl. These targets are disks 20 cm in diameter by 1.5-cm thick. The muonic x-rays are detected in a Ge(Li) detector

*Dr. H. Jang under the direction of Prof. J. Moteff, both of the Univ. of Cincinnati, carried out this work on a contractual basis. The experience of Moteff in the field of irradiation-damaged metals was utilized in this way.

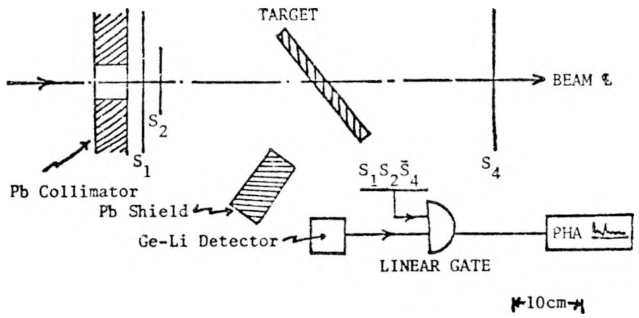


Fig. XI-24.
Experimental geometry.

of 4-cm diam by 1.3-cm thickness, and analyzed in a pulse analyzer. In addition, aqueous solutions of NaCl were irradiated as calibration standards, and a sample of Berea sandstone was also used as one target. A sample of crystalline NaCl was also irradiated as a standard.

The intensity of Kα x rays from sodium produced by stopping muons in the concrete targets is normalized to oxygen content in each target. Figure XI-25 is a plot of the normalized sodium Kα intensity vs added sodium chloride in the concrete. The dotted line is a least-squares fit given by $y = 0.351 \times +0.794$. Error bars amount to $\sim \pm 8\%$ and are indicated only for statistical errors; systematic errors are not taken into account. In particular, we did not measure absolute oxygen in the targets; for this reason the apparent excellence of the data may be somewhat fortuitous.

As a check on our experimental method, we repeated the measurements of Knight *et al.*[40] for the intensity ratios of the sodium Kβ/Kα muonic x rays in aqueous solution and in crystalline NaCl. Results, shown in Table XI-IV, are in excellent agreement with those of Knight *et al.* A plot of mass of NaCl in aqueous solution vs NaKα intensity, Fig. XI-26,

TABLE XI-IV

MUONIC X-RAY RELATIVE INTENSITIES: Na Kβ/Kα (X 10^{-3})

	Knight, *et al.*[4]	This Work
Crystal	98. ± 12.	84. ± 8.0
Aqueous Solution	212. ± 104	220. ± 51.

demonstrates the quantitative nature of these measurements.

The sample of Berea sandstone was of such a shape as to give poor signal-to-noise ratio in this experiment. Figure XI-27 shows the muonic x-ray spectrum obtained from this target.

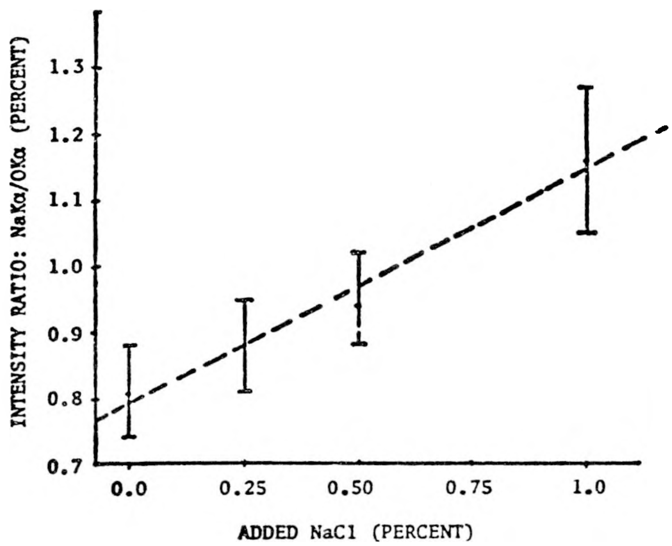


Fig. XI-25.
Sodium Kα yield relative to oxygen; Kα yield from concrete.

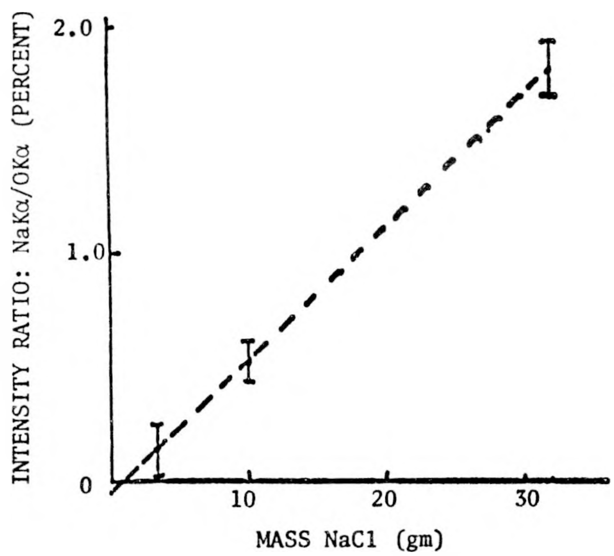


Fig. XI-26.
Sodium Kα yield relative to oxygen; Kα yield from NaCl solution.

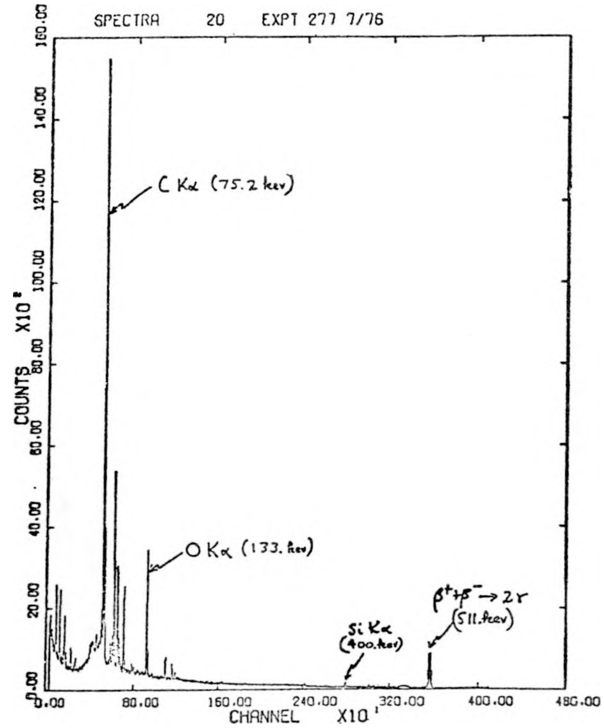


Fig. XI-27.
Muonic x ray spectrum from Berea sandstone.

These preliminary measurements demonstrate the usefulness of muonic x-ray analysis for the determination of the composition of bulk samples.

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

The second phase of this activation experiment is about half completed. This phase utilized the absolute cross sections of the $^{12}C(\pi^{\pm},\pi N)^{11}C$ monitor reactions measured in the earlier, low-intensity phase of the experiment.[41] Now at the higher pion beam intensities available we have undertaken the measurement of the cross sections of some more practical monitor reactions, $^{27}Al \xrightarrow{\pi^{\pm}} {}^{18}F$ (110 m), $^{27}Al \xrightarrow{\pi^{\pm}} {}^{24}Na$ (15 h), and $Si \xrightarrow{\pi^{\pm}} {}^{24}Na$, all relative to the $^{12}C(\pi^{\pm},\pi N)^{11}C$ reactions. Because of the higher production yields of π^+ compared to π^- at the LAMPF proton energy we have concentrated to date on measuring the cross sections for the π^+ reactions.

For these determinations, sandwich targets consisting typically of a 1.59-mm-thick Pilot B plastic scintillator disk, three 0.635-mm-thick aluminum disks, and two 1.02-mm-thick SiO_2 disks have been irradiated for 40-min periods in the π^+ beam from the P^3 or LEP channel. The plastic scintillator disk is first counted between a pair of 76-mm by 76-mm NaI(Tl) scintillation detectors set up to count the coincident β^+ annihilation quanta and then counted in a β^+-γ coincidence system to determine the absolute activity of the induced 20.4-min ^{11}C. This procedure serves to establish the counting efficiency of the γ-γ system for positron counting. One of the aluminum disks is counted in this γ-γ system for the yield of ^{18}F (a pure β^+ emitter) while the other two aluminum disks are counted on a 76-mm by 76-mm-diam NaI(Tl) scintillation detector set to count the 1.37- and 2.75-MeV γ rays of ^{24}Na. The two SiO_2 disks are counted with this latter system for ^{24}Na only.

Our preliminary results for the cross sections for the production of ^{18}F and ^{24}Na from aluminum and ^{24}Na from silicon by π^+-induced reactions are shown in Fig. XI-28. The smooth curves are hand drawn and serve merely to guide the eye. The errors associated with most of the experimental points are estimated to be ±10% or less. The ^{24}Na excitation functions for both aluminum and silicon targets appear to have essentially the same shape and show a peak near the free nucleon-pion (3,3) resonance. In contrast, the excitation function for the $^{27}Al \xrightarrow{\pi^{\pm}} {}^{18}F$

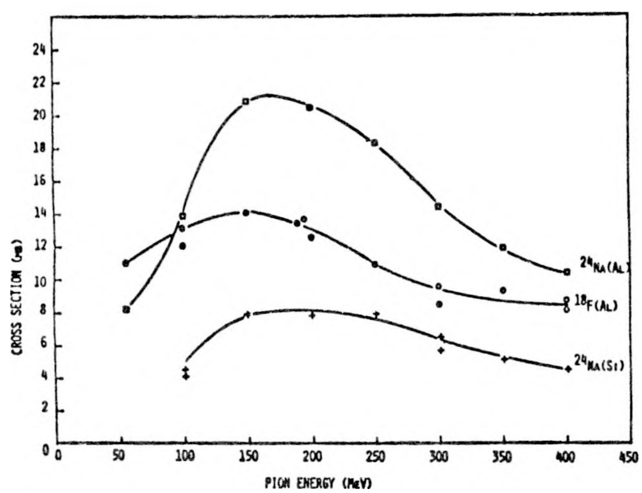


Fig. XI-28.
Cross sections for the production of ^{24}Na from aluminum and silicon and of ^{18}F from aluminum with π^+.

reaction involving the removal of nine nucleons appears to be flatter and falls off less rapidly at the lower energies, indicating a greater "washing out" of the effect of the resonance. The relatively high cross section for this reaction and its small sensitivity to pion energy makes it a very desirable pion beam monitor reaction.

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

Initial work on this activation study of the interactions of stopped pions (π^-) with complex nuclei has been carried out. Two shifts on the LEP channel were utilized to check out our three-element ($12\bar{3}$) scintillator telescope to establish differential range curves for 80-MeV (170-MeV/c) negative pions, and to irradiate targets of copper and tantalum. The proton current on the A-1 production target was 35 μA. We have made range measurements at slit settings corresponding to $\Delta P/P$ of ± 0.1, 0.5, and 1.0% using 1-g/cm² copper and graphite degraders. The peak width remains essentially constant (FWHM = 1.5 g/cm² of graphite) in going from $\Delta P/P = \pm 0.1$ to $\pm 1.0\%$ due to straggling.

After the timed exposures of 1 g/cm² copper and tantalum targets, they were removed to a low background environment where the yields of the residual radioactive nuclides were determined by high resolution Ge(Li) γ-spectrometry. Most of the copper data have been analyzed and our preliminary yields are presented in TABLE XI-V. The data are derived from counting two copper targets, one exposed for 64 min at $\sim 6 \times 10^4$ π^- stops/s and the other exposed for 4.75 h at $\approx 4 \times 10^5$ π^- stops/s. The shorter irradiation at the lower intensity was carried out to determine the absolute yield of ^{56}Mn per π^- stop. Because of erratic behavior of the second scintillator of our counter telescope, that determination is unreliable. Therefore, the quoted yields are only relative to ^{56}Mn yield.

Prior to this experiment, the yields of products from stopped pion interactions with copper and tantalum were calculated using the VEGAS intranuclear cascade code followed by the DFF evaporation code. For these preliminary calculations a simplified model was used in which the kinetic energy of the incoming π^- was set to 1 MeV and a 20-MeV pion-nucleus attractive potential was assumed, to ensure the nuclear absorption of the pion. The cascade results from the two fast nucleons ($\sim$65 MeV) obtaining their kinetic energy from conversion of the rest mass of the absorbed π^- on a pair of nucleons. Table XI-V also shows the calculated relative yields, normalized to unity for ^{56}Mn. As can be seen, the calculated values from this simple model for the pion absorption process are in fair agreement with the measured values.

Efforts are in progress to include the pionic-atom radial-distribution functions as a prior subroutine to the cascade calculations in order to simulate a more realistic model of the pion-absorption process.

We are still recording the γ spectra of the long-lived products from the 2-h irradiation of a tantalum target. These results will be reported at a later date.

TABLE XI-V

RELATIVE YIELDS FROM STOPPED NEGATIVE PIONS ON COPPER

Nuclide		Relative Yields Measured	Calculated
^{56}Ni	I*	<0.057	0.003
^{57}Ni	I	<0.072	0.14
^{65}Ni	I	<0.034	0.23
^{55}Co	I	<0.070	0.10
^{56}Co	I	<0.902	0.91
^{57}Co	I	<3.08	2.35
^{58}Co	I	<7.11	3.62
^{60}Co	I	<4.0	1.88
^{61}Co	I	<1.65	0.80
^{52}Fe	I	<0.0027	----
^{59}Fe	I	<0.863	0.65
^{52}Mn	I	<0.262	0.27
^{54}Mn	I	<2.61	1.94
^{56}Mn	I	*<1.00*	***1.00***
^{49}Cr	C	<0.015	0.00
^{51}Cr	C	<0.780	0.41
^{48}V	C	<0.059	0.02
^{43}Sc	C	<0.017	----
^{46}Sc	I	<0.037	0.005
^{47}Sc	I	<0.027	0.015
^{48}Sc	I	<0.015	0.032

*The I or C refer to independent yield or cumulative chain yield.

Theory

An estimate has been made of the contribution of phonon emission to the thermalization of $\mu+$ in solids. It appears that this energy-loss mechanism dominates over electron excitation for μ energies between $\sim 10^{-1}$ and 10^{-3} eV. This will affect the probabilities for the μ^+ being captured by interstitial sites and defects. Phonon emission does not appear to play a role in the stopping of negative muons.

Beam Position Monitors

Six prototype models of the linear BPM have been installed in the accelerator at modules 5, 9, 11, 14, 15, and 16. Initial tests indicate that the sensitivity to position is ~30% greater than calculated from the loop geometry. A resistor change in the difference amplifier will allow the units to be calibrated to give the desired sensitivity of 0.05V/mA-mm (equivalent to IV for 10-mm displacement with 2-mA-peak beam current). The overall gain as measured at the SUM output varied from 0 - 25% higher than desired because of errors in calibrating with the BPM test stand. This was corrected by setting the gain and gain balance with a 2-mA centered beam as determined by the toroid current monitors and the wire scanners.

Poor statistics from the wire-scanner position measurements made it difficult to compare the position sensitivity measured using the beam, with the position sensitivity using the wire test stand. However, plots of position vs steering magnet current demonstrate satisfactory performance of the BPMs. Further tests will check performance at reduced beam currents and an analog divider will be added to each unit to eliminate beam-current dependence of the position signal.

Programming for Experiments

The off-line analysis program for the ZGS parity experiment was debugged on the IBM 370/195 at ANL and used during the May run. The 6600 version at LASL was modified to automate the process of cutting out wild points. To do this, a quad variable, computed by adding together four successive points with alternating signs, is sorted and an estimate of its standard deviation is made which is not influenced by the wild points; then cuts are made using this estimate. This procedure successfully eliminated the usual first pass through the data which was needed to determine cuts.

Means and standard errors of scalers and DVMs were punched for June runs of the parity experiment on the Van de Graaff. These will be used as input to a new regression program which was developed in order to combine data from several similar runs.

The PDP-11 analysis program for Exp. 179 was converted for interactive use on the 6600. A new input routine, which accepts events directly from the MBD instead of reading them from tape, was tested on the PDP-11/20 at the site of the experiment. The plotting routines which normally use the printer were converted for use on the Tektronix 4010. With the new input and plotting routines, the program will display histograms and spectrum plots immediately upon the completion of a run. A new particle identification scheme was added to all versions of the program. Given E, ΔE, and a detector thickness, it computes a new variable which is independent of E.

An off-line analysis program was written for Exp. 181 for use under RSX. The program decodes run numbers, ADCs, TDCs, and wire chamber centroids and numbers of hits for four chambers. It computes simple traceback information from the wire chambers and produces histograms, 2-D plots, and event dumps.

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XII. NUCLEAR CHEMISTRY

Nuclear Chemistry Laboratory

Counting Room Equipment

Design work has been completed and fabrication started on the control module and CAMAC interface for the new dual parameter Ge(Li)-Ge(Li) γ-γ coincidence system described in the previous quarterly report. The heart of the system, a PDP-11/03-AA microcomputer, is expected to be delivered in the near future and the entire system should be completed and operational by the end of the next quarter.

A new lead brick shield with an iron liner has been constructed for our third and vertical Ge(Li) detector (eff. 12.0%, resol. 1.89 keV, p/c = 42.5/1). One of our horizontal Ge(Li) detectors failed because it developed a vacuum leak in its cryostat and had to be sent to a commercial firm for refurbishing. Return delivery is expected by the end of this quarter. A rollaway shield door was fabricated and installed on the lead brick shield surrounding the second pair of 76-mm by 76-mm-diam NaI(T1) detectors set up in coincidence array for β^+ annihilation radiation counting.

A new Canberra 8100 pulse-height analyzer (4096 channels) has been received. It had been ordered without a magnetic tape unit since, via a CAMAC interface, it is to be controlled by and to deliver its spectral information to the magnetic disk or tape units of the data-acquisition computer. The first task of this new analyzer will be to record simultaneously, by means of a mixer-router circuit, the spectral information from four gold surface-barrier α detectors for Exp. 150.

Data-Acquisition System (DAS)

Significant progress has been made in software development this quarter. A preliminary version of a program to control the CAMAC scaler-timers has been used for Exp. 67. A program to control a Canberra 8100 multichannel analyzer used with a four-input mixer-router has been written and is being checked out. These programs found errors in the Program Q due to the use of obsolete sections of the code. These sections have been updated and Q appears to be running well. Also, programs to convert output tapes from the various analyzers to a standardized format, take data from the standardized tapes and plot it on the 4010 scopes, and list the data on the DECwriter have been developed.

The hardware problem of overheating TEC terminals apears to have been solved by the installation of new back covers with an extra cooling fan. The CAMAC scaler-timers have been changed to a crystal-control time base with selector switches for the length of the unit time, and the input selectors have been changed from jumpers to switches.

Computer Programs

During this quarter the main operating system on one of the CCF computers was changed, making inoperable some system software necessary for the operation of our general plotting program, PALL. A new program is being written using a different software package which promises to be more versatile and produce plots of higher quality than the old program.

Pneumatic "Rabbit" System

A special 102-mm-diam branch of the "rabbit" system has been activated to facilitate the rapid transfer of target material irradiated in the Line B proton beam from the Nuclear Chemistry Cave to the Hot Cell. This is a unidirectional line that has already been utilized for Exp. 243 and will soon be used frequently for Exp. 150. It requires manual loading of the target material into the carrier and then insertion of the carrier in the pneumatic tube.

Development work on the main 76-mm-diam system has continued, with special emphasis placed on getting into operation the Energetic Neutron Station at the main beam stop. In order to clean out the major pneumatic tubes of the system a special "rabbit," consisting of a pair of circular wire brushes bolted to the ends of a steel bar, was blown several times through the lines. An appreciable amount of rust, dirt, etc., was successfully removed from the lines. The "snake" with its microswitch which will signal the arrival of a target carrier at the beam stop location was completed electrically by means of m.i.

wire. The drive mechanism has been installed for moving the "snake" and thereby remotely establishing the stopping location of the target carrier over a range of ~3000 mm (from ahead of to far behind the A-6 beam stop). A control box for local control of the drive mechanism has been fabricated and installed. The electronic components for controlling and displaying the location of the end of the "snake" or stopping location of the target carrier have been ordered. These will be mounted in the control console of the pneumatic "rabbit" system.

For the special WNR "rabbit" system the J-tube assemblies have been fabricated by an outside firm and have been delivered. Drawings for the remotely removable head to the J-tube have been released to the main LASL shop for fabrication.

Theoretical Support

The VEGAS Intranuclear Cascade Program

A meeting was held on May 15, 1976, to review again the status of the current medium-energy version of the VEGAS intranuclear cascade code, called ISOBAR,[1] and also the evaporation code (DFF) which follows the intranuclear cascade. Present at the meeting were C. Butterfield (Univ. of Maryland), B. Dropesky (CNC-11), J. N. Ginocchio (T-5), G. Harp (consultant), N. Metropolis (T-7), J. Miller (Columbia Univ.), G. Stephenson (T-5), and A. L. Turkevich (Univ. of Chicago and LASL). The specific purpose of the meeting was to review the changes that have been made in the code since the last meeting on August 2, 1975, and to look into future projects. The changes made in the code have been reported in previous progress reports.

The consensus of the group was that three topics of current interest should be pursued. Of primary importance is completion of the modification of the VEGAS program so that stopped pions are included. The second most important is to study the feasibility of including coherent charge exchange as a nucleon moves through the nucleus. The third is to try to include fission as a possible mode for the breakup of the residual nucleus after the fast-cascade process.

The absorption of stopped π^- on nuclei is not understood in detail. A model is being developed which is the one referred to in the above paragraph in which the pion is assumed to be absorbed on two nucleons in the nucleus. These two nucleons will be followed as they pass through the nucleus and interact with the other nucleons, as in the VEGAS intranuclear cascade program.

The point of absorption in the nucleus will be determined by the divergence of the total pionic current,

$$\vec{\nabla} \cdot \vec{j} = (ih)/(2\mu)\ \Sigma_k\ [\nabla\psi_k \cdot \nabla\psi_k^* - \nabla\psi_k^* \cdot \nabla\psi_k]$$

where ψ_k are the pion wave functions. These wave functions are determined from solving the Klein-Gordon equation using a pion-nucleus potential[2] determined from pion x-ray data.

The pion can be absorbed on either a neutron-proton pair or two protons. The relative probability will be determined by the ratio of neutron-proton pairs to proton pairs,

$$R_0 = \frac{NZ}{Z(Z-1)/2}$$

where N and Z are the number of neutrons and protons, respectively. This ratio compares well with the ratio of correlated neutron pairs to correlated proton-neutron emission R measured in stopped pion reactions.[3] This suggests that R_0 may be a reasonable choice. The ratios R and R_0 are compared in Table XII-I.

TABLE XII-I

COMPARISON OF THE RATIOS R AND R_0

Target	R	$R_0 \equiv 2N/(Z-1)$
^{6}Li	3.0 ± 0.8	3.0
^{7}Li	3.7 ± 1.0	4.0
^{9}Be	3.3 ± 0.9	3.3
^{10}B	2.3 ± 0.8	2.5
^{11}B	4.4 ± 1.3	3.0
^{12}C	2.5 ± 1.0	2.4
^{14}N	3.7 ± 1.1	2.3
^{16}O	3.8 ± 1.0	2.3
^{27}Al	2.4 ± 0.9	2.3
Cu	2.0 ± 1.4	2.5
Pb	4.7 ± 4.7	3.1

(R is ratio of two correlated neutrons to two correlated protons produced in stopped π^- reactions.)[3]

This model will be able to calculate both the particle spectra and spallation products which can then be compared with experiment results (see p. 95 of this report[4]).

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1. G. D. Harp, K. Chen, G. Friedlander, Z. Fraenkel, and J. M. Miller, Phys. Rev. **C8**, 581 (1973).

2. D. K. Anderson, D. A. Jenkins, and R. J. Powers, Phys. Rev. Lett. **24**, 71 (1970).

3. M. E. Nordberg, K. F. Kinsey, R. L. Burman, Phys. Rev. **165**, 1096 (1968).

4. LAMPF Exp. 247, "Distributions of Products from Interactions of Stopped π^- with Several Medium- and Heavy-Mass Nuclei," C. J. Orth, W. R. Daniels, B. J. Dropesky, J. N. Ginocchio, and R. A. Williams.

XIII. PRACTICAL APPLICATIONS OF LAMPF

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

Pion Biomedical Program

Channel Operations

During the past quarter the LAMPF biomedical channel was operated for the following experiments:

- **44** Radiobiology of Negative Pi Mesons, A Preliminary Study
- **151** An Investigation of Pion Dosimetry by Passive Particle Detectors
- **195** Nuclear Resonance Effect in Pionic Atoms
- **235** Radiation Repair of Normal Mammalian Tissues
- **236** Biological Effects of Negative Pions
- **270** Therapy Beam Development — Biomedical Channel Tuning
- **271** Therapy Beam Development — Dosimetry
- **272** Therapy Beam Development — Microdosimetry
- **273** Therapy Beam Development — LET Measurements
- **274** Pion Radiobiology
- **275** Pion Clinical Trials

Therapy Beam Development — Channel Tuning (Exp. 270)

Multiwire proportional chambers have been routinely used for biomed channel tuning during this quarter in a pulsed voltage mode. One out of ten accelerator pulses is of low intensity, and voltage is applied to the chambers only during this pulse. No rapid degradation of chamber performance has been observed. Scintillation counters are also used in the pulsed mode with potentials on two dynodes changed to reduce gain when the high-intensity pulses are present. The biggest problem is the high activation induced by the main beam causing high singles rates in chambers and scintillators. The activation singles rates are nearly as much as those produced by the pion beam. The low-intensity pulse is a factor of 10^4 less intense than the main beam. The large reduction in the low-intensity pulse is achieved by electrostatically deflecting the normal low beam pulse from the ion source for an additional decrease of a factor of 100-200.

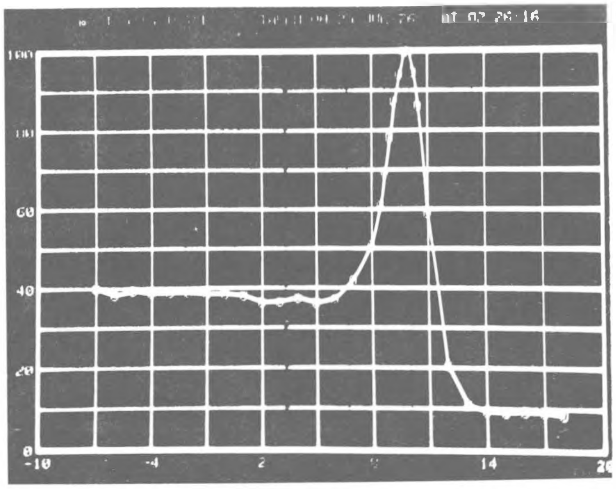
Beam development for patient treatment has taken place in several areas. Studies have been made to find a tune with maximum dose rate consistent with uniformity requirements in a 4-cm-diam by 4-cm-wide pion peak. In addition, the edges of the beam were to be as sharp as possible under the collimator. Several scattering experiments were tried to redistribute the Gaussian-like profiles of the beam into a more uniform distribution. The most effective method was found to be by collimating a beam that was slightly diverging in both planes, which gives sharp edges and good uniformity at some sacrifice in dose rate.

The depth-dose distribution was shaped for the first cycle of patient treatments in 1976 by detuning the entrance triplet slightly to give a broader momentum distribution using the optimum wedge degrader at the momentum focus. The second cycle of treatments used a nonoptimum wedge degrader to achieve a momentum distribution that is roughly three times wider than for the first treatments. The optimum wedge converges a 7% $\Delta p/p$ rms momentum spread into a 1.5% rms $\Delta p/p$ width. By changing the shape of the wedge, intermediate widths can be obtained.

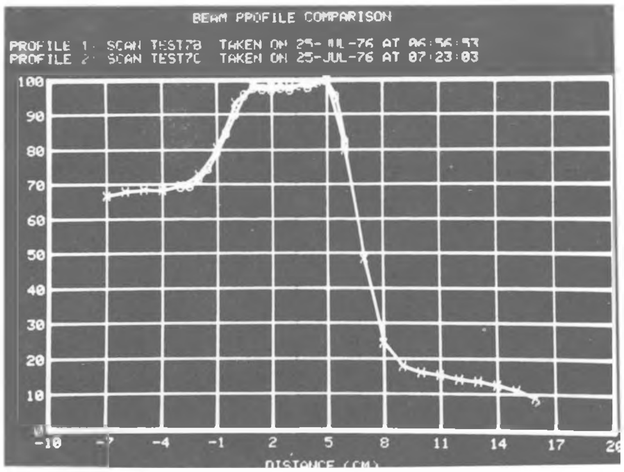
Therapy Beam Development (Exp. 271)

Work has continued on adapting the dynamic range shifter for use at the biomedical pion channel. Experimental data obtained last quarter, as well as modifications in range-shifter design have resulted in much improved performance this quarter.

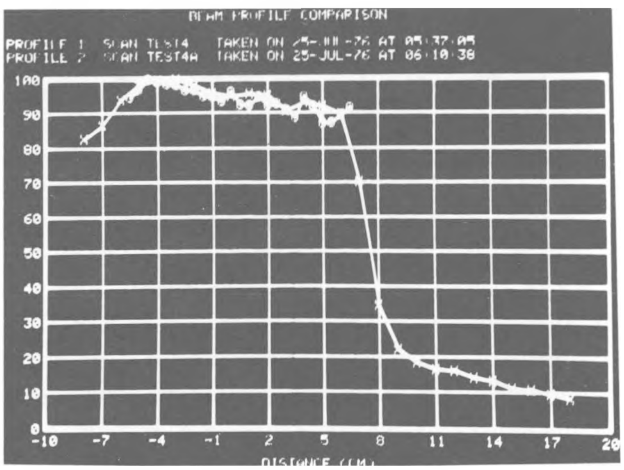
A new computer code has been written which, in conjunction with the dose-modeling code BUCKET, calculates the range-shifter motion which is required to produce a desired depth-dose distribution. Several of these calculated functions have been programmed into the range-shifter controller and it is now possible to produce depth-dose distributions which flatten either physical dose, or "effective dose" over a range in depth of up to 10 cm. Some typical results are shown in Fig. XIII-1.



Unmodified depth-dose curve.



Modified for 5-cm flat dose.



Modified for 10-cm flat "effective" dose.

Fig. XIII-1.
Typical depth-dose distributions.

The three curves shown were all produced from the same initial pion beam, using only the range shifter to alter the depth-dose distributions. The dosimetry data-acquisition system has also been modified so that all dosimetry data with the range shifter can be obtained on-line using the biomed PDP-11/45 computer.

Several experimenters from H-Division, and the Univ. of New Mexico Cancer Research and Treatment Center (CRTC) have already utilized the range shifter for radiobiological experiments, and plans are under way to utilize it for future clinical applications.

Pion Microdosimetry (Exp. 272)

A new system was developed for measuring pion fluence in the biomedical channel which involves measuring the amount of C activation in a plastic scintillator. The technique has been tested in the laboratory and will be used soon in the pion beam. This method will also be used in conjunction with ionization chambers and LET chambers to investigate problems in pion dosimetry and to estimate W values (i.e., the energy per ion pair) in various gases being used for dosimetry.

The high intensity of the biomedical pion channel has limited the types of counting experiments which can be performed. It has been necessary to develop new types of microdosimetry systems which are capable of utilizing the low-intensity (1-in-10) pulse developed at LAMPF. Two prototypes have been constructed and testing has begun. Initial results with these systems have been encouraging.

Dose Model Calculations

The pion dose-modeling program BUCKET, described in previous reports, has been used extensively for the evaluation of pion beams with potential applications in radiobiology and radiotherapy, and also to test the feasibility of the dynamic range shifter.

Many of the calculations were later verified by experiment, and preliminary results were presented at the June meeting of the Radiation Research Society. The code quite accurately predicts the shapes of isodose contours in a homogeneous phantom, and in estimating the magnitude of the absolute dose and the effects of the dynamic range shifter. The output formats have been greatly improved, and two-dimensional isodose contours can now be plotted directly on either Calcomp or 35-mm film. As a result of the good agreement between BUCKET calculations and experiment, a modified version of the code has been incorporated into the treatment planning code PIPLAN for future clinical application.

Work is being continued on modifications to sections of the code which are still not functioning properly. The most important problems still remaining include accurately treating collimators and inhomogeneities and overcoming errors in regions of low dose. The code can calculate, with good accuracy, the dose distributions in and near the pion stopping region (i.e., where the dose is high), but underestimates the dose as much as 20-25% in regions of low dose, particularly in the "plateau" or entrance region of the beam. We are currently investigating the effects of pion attenuation, multiple coulomb and nuclear scattering, and statistical fluctuations in order to correct these errors.

Muonic X-Ray Tissue Analysis (Exp. 100)

Muonic x-ray yields from eight tissue samples and several nonbiological samples were measured. Detailed analysis of these data is in progress.

Preliminary analysis of yields from two different glycine solutions was carried out. The nitrogen concentration in sample #1 was 2.44% by weight, while in sample #2 the concentration was 2.95%. The ratio 2.44%/2.95% = 0.83 can be compared with the ratio of the nitrogen muonic x-ray yields. This ratio was 0.71 ± 0.11, which compares well with the theoretical ratio.

A similar measurement was made of the phosphorus and calcium x-ray yields from plastic samples made to simulate bone. The ratio of phosphorus concentrations in the two samples was 0.77 while the x-ray yield ratio was 0.81 ± 0.20. The ratio of calcium concentrations was 0.80 while the x-ray yield ratio was 0.75 ± 0.04. Again we see that experiment agrees well with theory.

Technology Transfer

LCF Tumor Therapy

Treatment of animal tumors with LCF heating, and LCF/radiation combination therapy is continuing at the CRTC, with support from LASL. The single human case treated with LCF at the CRTC (a floor-of-mouth squamous-cell carcinoma mentioned in the previous progress report) this calendar year has responded to treatment with a significant regression of the tumor mass.

With the completion of two portable LCF generators, experimental treatment of squamous-cell carcinoma of the eye and lid in Hereford cattle has begun. These generators, which are designed to operate off 12-V cigarette-lighter receptacles in automobiles, have been used in remote locations to treat the cattle. To date, 14 animals have been treated to determine whether the technique will be successful enough to pursue. Preliminary evaluation should be available for the next progress report.

Organ Preservation Studies

Further progress has been made in the effort to develop a technique for the rapid, uniform thawing of kidneys. New apparatus allows rapid removal of the kidney from the jig after thawing is complete. Improved rf circuitry reduces the probability of localized hot spots during the warming procedure.

The transplant of canine kidneys which have been frozen and then thawed by this technique will be attempted when further improvements are made in the thawing apparatus and when the logistics for the joint experiment (LASL/CRTC) are worked out.

Proton Radiography

Calculations have been performed which indicate that, in principle, a proton axial tomography (PAT) system can produce a reconstruction of the density distribution of a section from a human head with the same density resolution as achieved with commercial x-ray scanners at dose levels which are an order of magnitude lower than delivered by the x-ray units. Much of this dose advantage for protons arises from the intrinsically good statistical nature of the energy-loss mechanism. A proposal has been submitted to do an experiment on the P^3 channel. The objective of this experiment is to demonstrate the feasibility of measuring the proton energy loss in a specimen to the high degree of accuracy required to produce a PAT reconstruction of good quality.

Further work on the theory of multiple coulomb scattering has resulted in the discovery of an explicit relationship between parameters of the Moliere theory and the definition of the radiation length. It is found that corrections of between 10 to 30% should be applied to the usual Rossi formula in order to accurately describe the width of the equivalent Gaussian multiple-scattering distribution.

ISORAD Facility

The major retrofit of the radioisotope targeting mechanism in the ISORAD Facility is nearing completion. Improvements in the isotope stringer and stringer housing designs (see Figs. XIII-2 and XIII-3) have minimized radiation leakage, and mechanical movement is now both smooth and reliable. The new rack-and-pinion drive mechanism has been installed exterior to the building and is readily accessible for required maintenance. The electrical wiring is in the final checkout phase. Alignments of the remote-handling tools with each of the nine isotope stringers, the target-transfer cart with the stringers, and the transport shield have been completed. Final testing of the plumbing system is expected to be finished by mid-August.

Nine redesigned target holders have been fabricated and pressure tested to 400 psi. Figure XIII-4 shows an exploded view of the target, target holder, and stringer-coupling arm. The maximum target dimensions are 7.6-cm diam by 2.3-cm thick. The outlet water line in the target holder head is equipped with a replaceable metallic filter to prevent target spills escaping from the chamber.

In-beam target stability studies are expected to commence during cycle 7 (mid-August).

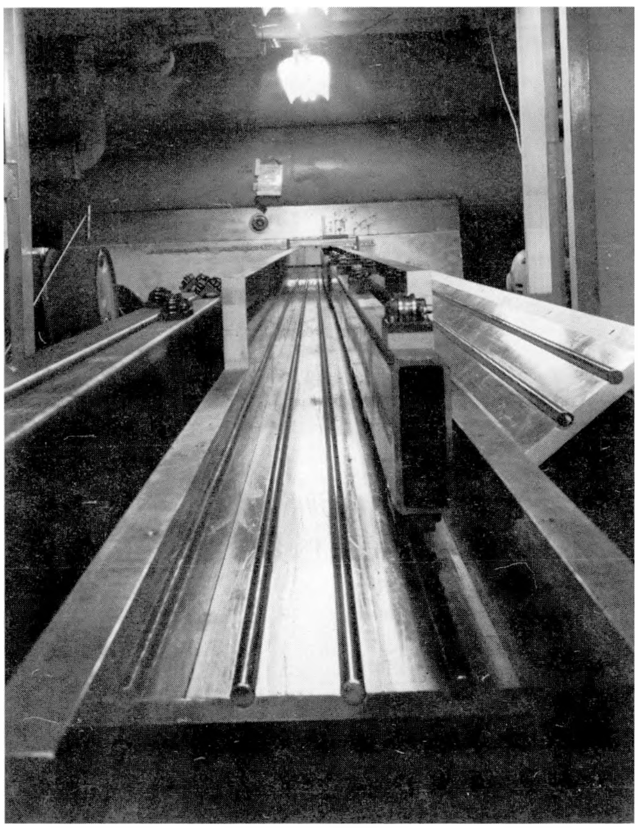


Fig. XIII-2.
Isotope-production stringer and housing.

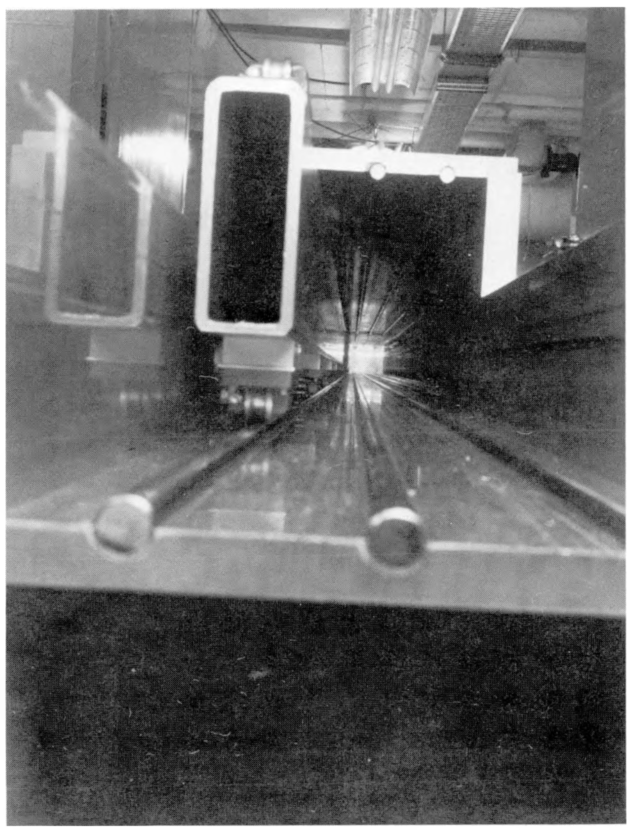


Fig. XIII-3.
Isotope-production stringer and housing.

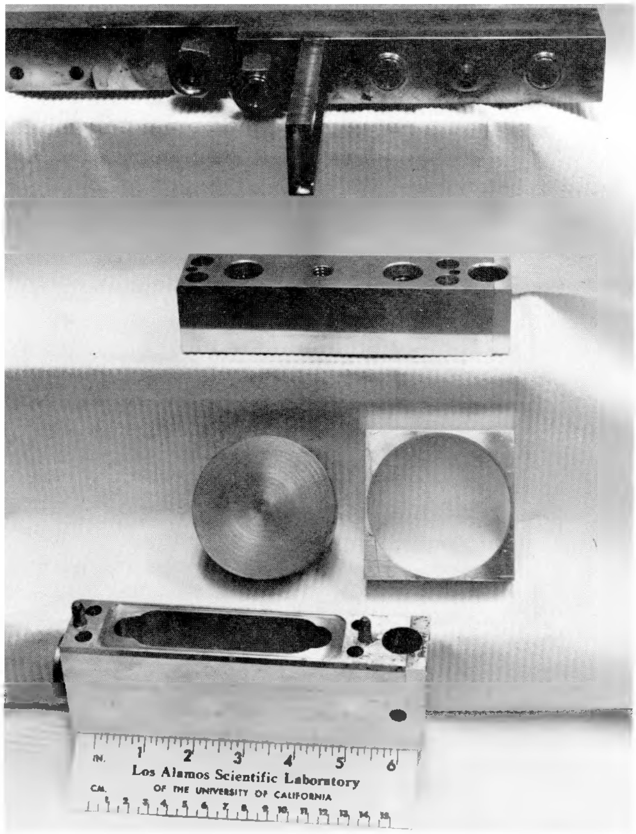


Fig. XIII-4.
Isotope-production target, target holder, and stringer-coupling arm.

XIV. MANAGEMENT

Budget and Personnel Levels

Total operating costs for FY-76 were $18 460k. The average number of full-time-equivalent employees chargeable to medium-energy physics is 346.

Safety

Radiological Safety

Individual, as well as total, man-rem exposures continued at acceptable levels. Excluding craft workers, 138 LAMPF-associated personnel received 17 man-rem during April, May, and June. The maximum individual exposure was 0.83 rem. Craft personnel were not included in this figure because many received exposures at areas other than LAMPF.

Forty-one operational plans for work involving radiation were reviewed and approved.

At the beginning of this quarter, several corrective measures were taken to improve control of radioactive material (e.g., nuts, bolts, scrap metal, etc.). A significant decrease in the number of untagged radioactive items during recent site surveys indicates that control measures were effective. Site surveys continue monthly.

Progress was made on the sensitive gamma-detector system for monitoring vehicles as they leave the LAMPF site. All components have been ordered, and specifications were given to Group ENG-4 for mounting the detector beneath the road surface of the guard station and providing electrical power, cable, and conduit.

Safety Manuals

The LAMPF Safety Manual and the Emergency Preparedness Program are being updated and revised.

Safety Committee Meetings

LAMPF Safety Committee — Major topics covered were: lock and tag procedures, beam-on indicator lights, personnel safety systems, radioactive gas production, close-of-business inspections, first-aid and radiation training, and safety meetings.

Group Safety Officers — Major subjects discussed included: personnel protective systems for magnets, a potential electrical accident, high-noise areas, and electrical inspection results. Guest speakers discussed LASL control and handling of radioactive waste, and the production of radioactive gas at ISORAD and in the CNC-11 nuclear chemistry cave.

Experimental Areas Safety Committee — Items considered were: ion-pump hazards, ladders and stairways, audible alarm systems, electrical standards for panel indicator lights, bicycle and forklift maintenance, and gas-bottle storage racks.

LAMPF Hydrogen and Cryogenics Safety Committee — The alternate LD_2 target for Exp. 193 was discussed.

LAMPF Radiological Safety Committee — The installation of area- and site-boundary radiation monitors and the production of radioactive gas in the A-5 target cell were discussed.

Safety Review of Experiments

Safety reviews were conducted for five experiments. No unusual safety items were identified, with the exception that one experiment uses significant quantities of cyclohexane (explosive, flammable). Special control procedures have been developed by the experimenter for its handling. Safety review forms are sent routinely to experiment spokesmen.

Area A Evacuation Alarm

The evacuation alarm system for Experimental Area A was modified and satisfactorily tested. It can be actuated by any one of five alarm stations located throughout Area A. The sound is that of a variable pitched siren, similar to that of emergency vehicles. It is produced electronically through two speaker systems.

Inspections

Nine site inspections were conducted by the LAMPF Health & Safety Office (HSO) this quarter.

A special site-wide electrical inspection was conducted by Group H-3. Deficiencies were reported to the proper groups for corrective action.

Accidents

Twenty-two accidents resulting in injuries were reported this quarter. These were minor, and consisted of lacerations, strains, abrasions, and foreign bodies in eyes. They did not result in any significant loss-of-work time.

LAMPF Visitors Center

In order to ease the problems associated with the shortage of housing units available to Laboratory visitors, the LASL administration has formed a Housing Office. With the exception of the 20 kitchenette apartments designated for use, on a priority basis by LAMPF users, the LASL Personnel Department has been assigned the responsibility for obtaining leases for housing units and assigning all LASL-administered units to official visitors to the Laboratory. In addition to assigning the 20 kitchenette apartments, LAMPF housing office will continue to be the contact point for requests for housing from LAMPF visitors, and will assist in coordinating our guests' needs with the Personnel Department.

In addition to visitors on conducted tours, 250 "casual" visitors were received at LAMPF, with representatives from 10 foreign institutions. There were 225 visitors received at the site this quarter to participate in research programs at LAMPF, with 184 check out.

LAMPF Users Group, Inc.

Board of Directors

The Board of Directors of the LAMPF Users Group, Inc. met in Los Alamos on July 27, 1976, following the meeting of the TAP. The first order of business was the annual meeting of the LAMPF Users Group, Inc. to be held on November 8-9, 1976. The format will be the same as last year. The speakers have been invited and most invitations have been accepted. The matter of fees for the meeting was discussed. An all-inclusive fee not to exceed $20.00/member will be charged, which will include registration, banquet, and entertainment.

A status report was submitted by the Committee on Graduate Student Welfare consisting of Harvey Willard, John Allred, and Hillard Howard. As reported in the last quarterly report, part-time work has been made available to graduate students at LAMPF who have the blessing of their thesis advisors. This program was initiated by LAMPF management to help alleviate some of the problems associated with the cost of living in Los Alamos. The Committee felt there has not been adequate publicity for this program and an attempt will be made to rectify this.

The LAMPF Summer Lecture Series has had its ups and downs. The theory lectures had an exponential decay in attendance, but the experimental talks have been well-attended. The conclusion is that formal continued series have lower attendance because if people miss one lecture they tend to drop the remainder. Flexible scheduling, which has only one or two lectures on a topic and can generate later talks out of earlier talks, is most successful. This program will be continued throughout the year on a less regular basis and again next summer. The MP-Division colloquia have not been well-attended by graduate students or the users community.

The cost of living appears to be the largest problem for graduate students in Los Alamos. Chairman David Lind has sent a letter to the LAMPF users explaining the additional cost of living in Los Alamos faced by students. There does not appear to be any active interest in organized social activity among the graduate student population. No students have come to either Allred, Willard, or Howard to discuss problems. Either there are no problems or the formal "Dean of Students" approach is not the correct one. The committee will make a formal report to the Director of LAMPF at the end of the summer.

The expected long discussion on housing was short because the available options to the LAMPF Users Group are few at this time. The LAMPF Users Group, Inc. will not be funded by ERDA to pick up leases. The atmosphere for active involvement by the LAMPF Users Group in the housing market is not optimistic at this time. The scarcity of cheap land almost precludes new construction of low-cost housing for the users' need of short-term housing. At some point, the LAMPF Users Group, Inc. may have to take an active role and try to obtain ERDA land for the construction of transient-type housing.

Hillard Howard reported that the major medical group insurance for visitors at LAMPF is a dead issue. Both ERDA and LASL are unable or unwilling to fund the insurance plan. There was not sufficient interest from the users to support the plan without ERDA funds. A letter will be sent to users informing them of the situation. The consensus of Lind, Allred, and Willard is that participation in a voluntary insurance plan, which is more expensive than a group plan but less expensive than a private plan, should be available to visitors at LAMPF. Efforts to obtain this voluntary insurance plan will be pursued by Howard for the Board of Directors.

At the time of the annual election, the membership will be polled about modest dues ($10.00) for the LAMPF Users Group. An explanation of the need for money will be included with the ballot.

The Board will not appoint a new TAP representative from the LEP to replace Michael Saltmarsh until the LEP Working Group meets in November and can nominate one of its members.

Technical Advisory Panel

After Chairman David Lind called the meeting to order, a report was heard from Andrew Browman (LASL) on the overall operation of LAMPF. Since the Great Shutdown, beam time was scheduled assuming 65% availability of beam; the actual availability has been better than 80%. Efforts have been stepped up in remote-handling systems as 300 μA is scheduled in early FY-78 assuming LAMPF budget projections are realized.

Darragh Nagle (LASL) reported on the progress made with the priority list submitted by the TAP on January 13, 1976. Almost all of the items on the priority list have been met. The only items not accomplished or on schedule are the polarized target and health insurance for LAMPF users.

Reports were heard from all working group representatives except the Radiation Damage Working Group. George Glass (Texas A&M Univ.) reported for the Nucleon Physics Laboratory; Al Caretto (Carnegie-Mellon Univ.) reported for the Nuclear Chemistry group; W. Kenneth McFarlane (Temple Univ.) reported on P^3; Peter Nemethy (Yale Univ.) reported for the Neutrino Facility; Richard Powers (California Institute of Technology) reported for the SMC group; Paul Todd (Pennsylvania State Univ.) reported for the Biomedical Facility; Edward Flynn (LASL) reported for the HRS; R. J. Peterson (Univ. of Colorado) reported on EPICS; Klaus Ziock (Univ. of Virginia) reported for the LEP group in place of Michael Saltmarsh (ORNL); and Bill W. Mayes (Univ. of Houston) reported on the Experimental Facilities. In general, there are no major problems; all channels are now working near design parameters. The users of the Neutrino Facility and Biomedical Facility are anxiously awaiting higher intensity. Area B users need access to lower beam energy to complete experiments and are also waiting for the polarized beam (which should be available in FY-77) and polarized targets.

Reports from the TAP Subcommittees were presented. Glen Rebka (Univ. of Wyoming) substituted for Cryogenic Targets Subcommittee chairman Roy Haddock (UCLA) and stated that there are two major concerns: 1) shortage of manpower and spare parts for four operational systems, and 2) lack of progress on the polarized targets. There was no report on the Computing Facilities Subcommittee because there will be a summer study in August to look at LAMPF's needs. W. Kenneth McFarlane (Temple Univ.) reported for the LEEP Subcommittee, stating that the LEEP is generally in good shape. There is a shortage of data-acquisition computers now that the modular electronics equipment inventory has been built up over the past few years. Reporting of module faults so that follow-up maintenance can be done is a problem that needs attention. The LEEP will keep an inventory of used scintillators. A compromise was reached concerning maintenance for users' computers at LAMPF. MP-Division contracted with LASL's E-5 and DEC for 24-h coverage. Group E-5 is to be called first and they are to call DEC if needed. Users' computers at LAMPF have the same right of call but are charged on a per-call basis.

It was noted that more work space is needed near the counting houses.

The following action was taken by the TAP: 1) Cyrus Hoffman (LASL) was appointed to replace Richard Mischke (LASL) on the LEEP Subcommittee, and 2) the New Facilities Subcommittee and the Accelerator Development Subcommittee were disbanded.

The folowing recommendations were made by the TAP to LAMPF Director Louis Rosen:

1. LASL should get IBM under a 24-h contract for service of the IBM 729 tape drives.
2. Additional support is needed for the general cryogenic systems; one additional technician and the half-time services of a draftsman should be added to the MP-Division cryogenic effort.
3. MP-Division should study the problem of supplying variable energy beams to Areas B and C and report to the TAP at the next meeting.
4. MP-Division should set up at least one trailer with sleeping facilities, hot plate, and refrigerator in the trailer park near the CCR.

Nominating Committee

The Nominating Committee consisting of Vernon W. Hughes, Chairman (Yale Univ.), Peter D. Barnes (Carnegie-Mellon Univ.), Bruce J. Dropesky (LASL), Sherman Frankel (Univ. of Pennsylvania), George J. Igo (UCLA), and Glen A. Rebka (Univ. of Wyoming) prepared the following slate of nominees for the fall election of officers for the LAMPF Users Group, Inc.:

Chairman-Elect:

Norton M. Hintz (Univ. of Minnesota)
W. Kenneth McFarlane (Temple Univ.)

Members:

Ed V. Hungerford, III (Univ. of Houston)
Ralph C. Minehart (Univ. of Virginia)
Glen A. Rebka, Jr. (Univ. of Wyoming)
Benjaman Zeidman (ANL)

LAMPF Users Liaison Office

The May issue of the LAMPF Users Group Newsletter was distributed to all members. The minutes of the HRS Working Group Meeting held in Washington, DC on April 29, 1976, were mailed to all members of the HRS Working Group. Ballots for the chairman of the Biomedical Facility Working Group were mailed to all members of that Working Group. Arrangements for the EPICS Working Group Meeting, held in Los Alamos on July 9, 1976, were made by the Liaison Office and the minutes of this meeting were mailed to the Working Group members.

APPENDIX A

RESEARCH GUESTS AT LAMPF DURING PERIOD MAY 1, 1976 - JULY 31, 1976

Douglas M. Alde . . . . Univ. of Illinois
John C. Allred . . . . Univ. of Houston
James Amann . . . . Carnegie-Mellon Univ.
Bryon D. Anderson . . . . Kent State Univ.
Leonard B. Auerbach . . . . .Temple Univ.
Norman Austern . . . . .Univ. of Pittsburgh
Helmut W. Baer . . .Case Western Reserve Univ.
Thomas J. Baird . . . . Rensselaer Poly. Inst.
Robert L. Barnard . . . . . . .UNM Cancer Center
Peter D. Barnes . . . . . . Carnegie-Mellon Univ.
Stephen M. Bart . . . . Univ. of Houston
John A. Becker . . . Lockheed Missiles/Space Co.
Stanley Bernsteen . . . . . Carnegie-Mellon Univ.
Philip R. Bevington .Case Western Reserve Univ.
Dattatraya G. Bhave . . . . Univ. of New Mexico
Swarajranjan Biswas . . . . .Purdue Univ.
C. W. Bjork . . . . Univ. of Wyoming
Gary S. Blanpied . . . . .Univ. of Texas
Felix H. Boehm . . . . . . California Inst. of Tech.
Joseph E. Bolger . . . . .Univ. of Texas
C. A. Bordner . . . . Colorado Coll.
Jonathan S. Boswell . . . . Univ. of Virginia
Kenneth Boyer . . . . .Univ. of Texas
W. J. Braithwaite . . . . .Univ. of Texas
Hubert Brandle . . . . .UC, Los Angeles
George A. Brooks . . . . .UC, Irvine
Robert C. Broughton . . . . .Yale Univ.
John C. Browne . . . . . Lawrence Berkeley Lab.
H. C. Bryant . . . . Univ. of New Mexico
Ernest E. Burr . . . . Univ. of Virginia
James A. Buchanan . . . . .Rice Univ.
Joseph J. Burgerjon . . . . .TRIUMF
G. R. Burleson . . . . . . New Mexico State Univ.
James R. Cadifux . . . . Univ. of Chicago
Albert A. Caretto . . . . . Carnegie-Mellon Univ.
Roger D. Carlini . . . . Univ. of New Mexico
Donald E. Carlson . . . . .Univ. of Texas
Donald E. Casperson . . . . .Yale Univ.
Renate Chasman . . . .Brookhaven National Lab.
Herbert H. Chen . . . . .UC, Irvine
David T. Chiang . . . . .Univ. of Washington
Willie H. Christian . . . . Tuskegee Inst.
Larry B. Church . . . . Reed College
James L. Clark . . . . Carnegie-Mellon Univ.
Terrance P. Cleary . . .Oak Ridge National Lab.
John M. Clement . . . . .Rice Univ.
Joseph M. Cohenca . . . . Univ. of Sao Paulo
Nicholas J. Colfella . . . . .Temple Univ.
John M. Collier . . . . .Tulane Univ.
Josefino C. Comiso . . . . Univ. of Virginia
Joseph N. Craig . . . . . . Carnegie-Mellon Univ.
Dorothy M. Crawford . . . . .UNM Cancer Center
Frank H. Cverna . . .Case Western Reserve Univ.
Colgate W. Darden . . . Univ. of South Carolina
Arthur B. Denison . . . . Univ. of Wyoming
Nick Depolo . . . . .Univ. of Colorado
Michael J. Devereux . . New Mexico State Univ.
Kailash C. Dhingra . . . . . Univ. of New Mexico
Byron Dieterle . . . . Univ. of New Mexico
Nicholas J. Digiacomo . . . . . .Univ. of Colorado
Joey B. Donahue . . . . Univ. of New Mexico
Hermann J. Donnert . . . . . .Kansas State Univ.
Mohan Doss . . . . Carnegie-Mellon Univ.
William H. Dragoset . . . . .Rice Univ.
Jean Duclos . . . . CEN, Saclay
Steven A. Dytman . . . . . Carnegie-Mellon Univ.
I. E. Economou . . . . Univ. of Chicago
Ronald D. Edge . . . . . Univ. of South Carolina
Patrick C. Egan . . . . .Yale Univ.
Robert A. Eisenstein . . . Carnegie-Mellon Univ.
David J. Ernst . . . . Texas A&M Univ.
Albert R. Erwin . . . . Univ. of Wisconsin
John C. Evans . . . . .Brookhaven National Lab.
Richard C. Felder . . . . .Rice Univ.
Herman Feshbach . Massachusetts Inst. of Tech.
Edward L. Fireman . . . . Center for Astrophysics
Thornton R. Fisher Lockheed Missiles/Space Co.
John C. Fong . . . . .UC, Los Angeles
Dan R. Fortney . . . . .Purdue Univ.
Hans Frauenfelder . . . . Univ. of Illinois
Rudolf Frei . . . . L. Hartmann, Switzerland
Stephen S. Friedland . . . . Tel-Aviv Univ.
Jozica Gabitzsch . . . . Rice Univ.
John P. Galvin . . . . .Brookhaven National Lab.
David R. Giebink . . . . Univ. of Texas
Shalev Gilad . . . . Tel-Aviv Univ.
George Glass . . . . Texas A&M Univ.
Gary A. Glatzmaier . . . . . Univ. of New Mexico
Roy J. Glauber . . . . Harvard Univ.
Paul F. Glodis . . . . .UC, Los Angeles

Robert L. Gluckstern . . . . . . Univ. of Maryland
Joyce A. Goldstone State Univ. of NY, Stony Brook
Kazoo Gotow . . . . Virginia Poly. Inst.
Charles A. Goulding . . . . .TRIUMF
Steven J. Greene . . . . Univ. of Colorado
Mark B. Greenfield . . . . . . Florida A&M Univ.
Edward E. Gross . . . . .Oak Ridge National Lab.
Shmuel Gurvitz . . . . .Weizmann Inst. of Science
Hosein M. Haghighi . . . . .UC, Los Angeles
Alan A. Hahn . . . . California Inst. of Tech.
Klaus Halbach . . . . . . Lawrence Berkeley Lab.
Isaac Halpern . . . . Univ. of Washington
Clifford K. Hargrove Nat'l Res. Council of Canada
Paul A. Heckert . . . . Univ. of New Mexico
John C. Hiebert . . . . Texas A&M Univ.
Virgil L. Highland . . . . .Temple Univ.
John F. Hills . . . . Univ. of New Mexico
Norton M. Hintz . . . . Univ. of Minnesota
Martha V. Hoehn . . . . .Florida State Univ.
William J. Hoffert . . . . .Univ. of Indiana
Gerald W. Hoffmann . . . . Univ. of Texas
John H. Hoftiezer . . . . .Rice Univ.
Vernon W. Hughes . . . . .Yale Univ.
George J. Igo . . . . .UC, Los Angeles
Harvey Israel . . . . LASL
Steven G. Iversen . . . . Northwestern Univ.
Rama S. Iyer . . . . .UC, Irvine
Harold E. Jackson . . . . . Argonne National Lab.
Richard J. Jacob . . . . Arizona State Univ.
Mahavir Jain . . . . Texas A&M Univ.
Mark J. Jakobson . . . . .Univ. of Montana
David A. Jenkins . . . . Virginia Poly. Inst.
R. H. Jeppesen . . . . .Univ. of Montana
Kenneth F. Johnson . . . . .Temple Univ.
William Johnson . . . . Univ. of Rochester
David M. Judd . . . . .Rice Univ.
Constance K. Kalbach . . . . Duke Univ.
Jan Källne . . . . Univ. of Uppsala
Paul J. Carol . . . . Carnegie-Mellon Univ.
Sheldon Kaufman . . . . . Argonne National Lab.
Charles A. Kelsey . . . . . . .UNM Cancer Center
Nicholas S. P. King . . . . UC, Davis
Thomas R. King . . . . Univ. of Wyoming
Harimut F. Klonk . . . . Purdue Univ.
H. B. Knowles . . . . . . Washington State Univ.
Lynn D. Knutson . . . . Univ. of Washington
Kenneth L. Koester . . . . Univ. of Houston
Thomas H. Kopera . . . . .Temple Univ.
I. G. Kostoulas . . . . .UC, Los Angeles
Thomas Kozlowski . . . Brookhaven National Lab.
Kenneth S. Krane . . . . .Oregon State Univ.
J. J. Khaushaar . . . . Univ. of Colorado
Kay Kunselman . . . . Univ. of Wyoming
Gary Kyle . . . . Univ. of Minnesota
Jerome J. LaRosa . . . . Univ. of Chicago
Richard G. Lane . . . . .UNM Cancer Center
Phillip Lang . . . . Northwestern Univ.
John Lathrop . . . . .UC, Irvine
Alan G. Law . . . . Univ. of Regina
Malcolm A. LeCompte . . . . . Univ. of Wyoming
Christopher P. Leavitt . . . Univ. of New Mexico
Rodger P. Liljestrand . . . . Univ. of Texas
David A. Lind . . . . Univ. of Colorado
M. Stanley Livingston . . . . .Consultant
Joseph W. Lo . . . . Univ. of Houston
Earle L. Lomon . . . Massachusetts Inst. of Tech.
Daniel C. Lu . . . . Yale Univ.
Steven C. Luckstead . . Washington State Univ.
Carl A. Ludemann . . . .Oak Ridge National Lab.
William Paul Madigan . . . . .Rice Univ.
Peter Majewski . . . . . . Washington State Univ.
D. J. Malbrough . . . . . Univ. of South Carolina
Pesseha Mariam . . . . .Yale Univ.
Thomas Marks, Jr. . . . Univ. of South Carolina
Daniel R. Marlow . . . . . Carnegie-Mellon Univ.
Roscoe E. Marrs . . . . . California Inst. of Tech.
Nina Marsh . . . . .UNM Cancer Center
Harvey Marshak . National Bureau of Standards
Nancy Matz . . . . .UC, Los Angeles
Bill W. Mayes . . . . Univ. of Houston
James S. McCarthy . . . . Univ. of Virginia
David K. McDaniels . . . . Univ. of Oregon
W. Kenneth McFarlane . . . . .Temple Univ.
John A. McGill . . . . Univ. of Texas
M. W. McNaughton Case Western Reserve Univ.
Hans Otto Meyer . . . . Univ. of Basel
Luise S. Meyer . . . . Argonne National Lab.
James P. Miller . . . . . California Inst. of Tech.
R. Russell Miller . . . . Univ. of Virginia
Murray Moinester . . . . .Tel-Aviv Univ.
C. Fred Moore . . . . Univ. of Texasd
C. L. Morris . . . . Univ. of Virginia
Edward Moy . . . . Univ. of New Mexico
Zvonko Mozetic . . . . J. Stefen Inst.
Donald W. Mueller . . . . LASL
Gordon S. Mutchler . . . . .Rice Univ.
Bruce G. Nardi . . . . Argonne National Lab.
Robert A. Naumann . . . . Princeton Univ.
B. M. K. Nefkens . . . . .UC, Los Angeles
Peter Nemethy . . . . .Yale Univ.

Charles Newsom . . . . Univ. of Texas
L. C. Northcliffe . . . . Texas A&M Univ.
Andrew W. Obst . . . . Northwestern Univ.
Pedro H. Oillataguerre . . . . UC, Los Angeles
Michael A. Oothoudt . . . . . . Univ. of Minnesota
Alden T. Oyer . . . . Univ. of Wyoming
Harry Palevsky . . . . . Brookhaven National Lab.
Alden E. Park . . . . Univ. of Colorado
R. J. Peterson . . . . Univ. of Colorado
Gerald C. Phillips . . . . Rice Univ.
Lawrence S. Pinsky . . . . Univ. of Houston
Franz Plasil . . . . Oak Ridge National Lab.
William W. Plumlee . . . . UC, Los Angeles
Norbert T. Porile . . . . Purdue Univ.
Richard J. Powers . . . . California Inst. of Tech.
Barry M. Preedom . . . . Univ. of South Carolina
Glen A. Rebka . . . . Univ. of Wyoming
Hans-Walter Reist . . . . Univ. of Berne
Louis P. Remsberg . . . Brookhaven National Lab.
Martin E. Rickey . . . . Univ. of Indiana
Robert J. Ridge . . . . UC, Los Angeles
Peter J. Riley . . . . Univ. of Texas
Robert A. Ristinen . . . . Univ. of Colorado
Peter L. Roberson . . . . Univ. of Wyoming
Robert M. Rolfe . . . . UC, Los Angeles
Isaac I. Rosen . . . . Univ. Of New Mexico
Frank H. Ruddy . . . . . Washington State Univ.
Ted. D. Rupp . . . . Univ. of New Mexico
Loyd L. Rutledge . . . . Northwestern Univ.
Marvin Sachs . . . . Univ. of New Mexico
Oscar R. Sander . . . . Consultant
Mark A. Schardt . . . . Arizona State Univ.
John P. Schiffer . . . . . . Argonne National Lab.
Gerhard Schmidt . . . . Princeton Univ.
Wolf-Udo Schroeder . . . . Univ. of Rochester
Randy S. Schwartz . . . . Temple Univ.
Ralph E. Segel . . . . Argonne National Lab.
Carol A. Selheimer . . . . . . UNM Cancer Center
Walter Selove . . . . Univ. of Pennsylvania
Kamal K. Seth . . . . Northwestern Univ.
Yair Shamai . . . . Tel-Aviv Univ.
Hasan Sharifian . . . . Univ. of New Mexico
Tilak C. Sharma . . . . Oregon State Univ.
Joseph D. Sherman . . . . Carnegie-Mellon Univ.
Donald G. Shirk . . . . Iowa State Univ.
Frank T. Shively . . . . . Lawrence Berkeley Lab.
Alfred R. Smith . . . . UNM Cancer Center
Gregory Smith . . . . Univ. of Colorado
Lester E. Smith . . . . Univ. of Texas
William S. Smith . . . . UC, Irvine
Larry B. Sorensen . . . . Univ. of Illinois
Paul Souder . . . . Yale Univ.
Rolf M. Steffen . . . . Purdue Univ.
Ellis P. Steinberg . . . . . Argonne National Lab.
Marcus D. Stevens . . . . . . UNM Cancer Center
Richard J. Sutter . . . Brookhaven National Lab.
Earl Swallow . . . . Univ. of Chicago
L. Wayne Swenson . . . . Oregon State Univ.
Samuel L. Tabor . . . . . . Argonne National Lab.
Richard Talaga . . . . Univ. of Chicago
Charles A. Taylor . . . . Norfolk State Coll.
R. M. Thaler . . . . . Case Western Reserve Univ.
Willard Thomas . . . . Univ. of New Mexico
James D. Thomasson . . . . Univ. of Houston
Hossein Tootoonchi . . . . . Univ. of New Mexico
Werner Triftshauser . Hoohschule der Bundeswehr
G. E. Tripard . . . . Washington State Univ.
A. Lawrence Trudell . . . . Yale Univ.
J. K. Valentine . . . . Temple Univ.
Philip Varghese . . . . Univ. of Oregon
Stephen L. Verbeck . . . New Mexico State Univ.
Steven E. Vigdor . . . . . . Argonne National Lab.
Elizabeth Vine . . . . Washington Univ.
Jean-Luc Vuilleumier . . California Inst. of Tech.
Charles A. Waddell Univ. of Southern California
E. A. Wadlinger . . . . Univ. of Virginia
Louis K. Wagner . . . . Florida State Univ.
John B. Walter . . . . Univ. of Wyoming
Keh-Chung Wang . . . . California Inst. of Tech.
M. L. Warneke . . . . Univ. of Houston
John E. Warren . . . . Lakehead Univ.
Bruce A. Watson . . Lockheed Missiles/Space Co.
William G. Weitkamp . . . . Univ. of Washington
W. R. Wharton . . . . Carnegie-Mellon Univ.
Gordon R. White . . . . UC, Los Angeles
James B. Whitenton . . . . Univ. of Texas
Kay E. Whitner . . . . Univ. of Virginia
R. Roy Whitney . . . . Univ. of Virginia
R. Roy Whitney . . . . NA/INDO/MA
Charles A. Whitten . . . . UC, Los Angeles
Harvey B. Willard . . Case Western Reserve Univ.
T. M. Williams . . . . Rice Univ.
Suzanne Willis . . . . Yale Univ.
Kentner E. Wilson . . . . Remotion Co.
Nord F. Winnan . . . . UC, Los Angeles
David Wolfe . . . . Univ. of New Mexico
James Worthington . . . . . Univ. of New Mexico
Yoshishige Yamazaki . . . . . . Florida State Univ.
Mary Ann Yates . . . . LASL
Hans J. Ziock . . . . Univ. of Virginia
Klaus O. H. Ziock . . . . Univ. of Virginia
Klaus P. Ziock . . . . Univ. of Virginia