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Progress at LAMPF

July—December 1980

Clinton P. Anderson Meson Physics Facility

University of California

LOS ALAMOS SCIENTIFIC LABORATORY

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CONTENTS

GLOSSARY OF TERMS	viii
I. RESEARCH	1
Nuclear and Particle Physics	1
Parity Violation in Proton-Nucleus Scattering at 6 GeV/c	1
Charged-Particle Identification with Modules of the Plastic Ball (Exp. 536)	5
A Search for Nuclear Critical Opalescence Using the Reaction $^{40}\text{Ca}(\pi^+, \pi^+ \gamma)$ (Exp. 541)	5
Nuclear Reactions of ^{127}I with Pions (Exp. 349)	8
Measurement of the Residual Muon Polarization in ^3He Muonic Atom (Exp. 529, Part I)	8
Measurement of the Cross-Section Difference for Longitudinal Polarized Beam and Target (Exp. 498)	9
A Study of Inclusive Inelastic Pion Scattering Near the $\Delta(3/2, 3/2)$ Resonance (Exp. 390)	10
Measurement of the Angular Dependence of Tensor Polarization in the $^2\text{H}(\pi^+, \pi^+) ^2\text{H}$ Reaction (Exp. 483)	11
Measurement of the Dalitz Decay of the Neutral Pion (Exp. 221)	12
A Study of the Decays $\pi^0 \rightarrow \nu \nu'$	14
The Crystal Box Experiment (Exps. 400/445)	14
Asymmetries for Elastic pp Scattering in the Coulomb-Interference Region at 800 MeV (Exp. 15)	16
$\bar{p}$ -Nucleus Elastic Scattering at 800 MeV (Exp. 311)	17
Large-Angle Proton Scattering from $^{12,13}\text{C}$ (Exp. 354)	20
Large-Angle $\bar{p} + ^{208}\text{Pb}$ Elastic Scattering at 800 MeV (Exp. 355)	22
Forward-Angle Quasi-Free Proton-Neutron Analyzing Powers at 0.8 GeV (Exp. 385)	23
The Reactive Content of the Optical Potential (Exp. 470)	24
The Analyzing Power for $p + ^{24,26}\text{Mg}$ at 800 MeV (Exp. 476)	26
Measurement of the Spin-Rotation Parameter "Q" in Scattering of 0.5-GeV Polarized Protons from ^{40}Ca (Exp. 479)	27
Inelastic Proton Scattering at 800 MeV to the ^{12}C 15.11-MeV State: A Search for Nuclear Critical Opalescence (Exp. 486)	28
Pion-Induced Double Charge Exchange on Helium Isotopes (Exp. 74)	29
Pion Scattering from ^3He (Exp. 87)	30
Inelastic Pion Scattering from Light Nuclei: ^{10}B , ^{11}B , ^{14}N (Exp. 389)	31
Elastic and Inelastic π^+, π^- Scattering on ^7Li (Exp. 391)	32
Study of the Inclusive Double-Charge-Exchange Reaction (Exp. 442)	37

$\pi^{\pm}$ D Comparison at 143 MeV (Exp. 478)	37
Excitation of High-Spin States in ^{28}Si by Pion Inelastic Scattering (Exp. 481)	39
Strong Cancellations of Proton and Neutron Transition Amplitudes Observed in Pion Inelastic Scattering from ^{14}C (Exp. 539)	40
Study of (π^-, n) Reactions in ^3He and $^3\text{He}(\pi^-, \pi^0)t$ (Exp. 248)	41
Nonresonant Pion Production in $np \rightarrow pp\pi^-$ (Exp. 366)	43
Measurement of $\Delta\sigma_T$ in p-p Scattering (Exp. 504)	43
Energy Dependence of $A_{nn}(90^\circ)$ in p-p Elastic Scattering from 0.84 to 1.45 GeV/c (Exps. 504/505)	44
Transverse Spin-Spin Asymmetry in the Reaction $pp \rightarrow d\pi^+$ (Exps. 504/505)	44
Analyzing Power Measurement for the Reaction $\bar{p} + d \rightarrow ^3\text{He} + nn$	44
Nuclear Chemistry	
Medical Radioisotope Production (Exps. 106 and 267)	46
Materials Science	47
Isotopic Discrimination Between Plutonium Isotopes Using Muonic X Rays (Exp. 51)	47
Muon-Spin-Rotation Study of Diffusion in Metals in the Presence of Paramagnetic Ions (Exp. 375)	47
Muon Longitudinal and Transverse Relaxation Studies in Spin-Glass Systems (Exp. 499)	49
The Effect of Dislocation Vibration on Void Growth in Metals During Irradiation (Exp. 407)	51
Biomed	52
Computerized Treatment Planning Development	52
Therapy Beam Development — Dosimetry (Exp. 271)	53
Therapy Beam Development — Microdosimetry (Exp. 272)	53
Biological Intercomparisons of High-LET Beams Used for Radiation Therapy (Exp. 384)	54
Biomedical Instrumentation	55
Theory	57
On Regularities Observed in Pion Elastic, Single, and Double Charge Exchange in the Resonance Region	57
MP-Division Publications	61
II. FACILITY AND EXPERIMENTAL DEVELOPMENTS	63
III. ACCELERATOR OPERATIONS	78
IV. EXPERIMENTS RUN	79
V. NEW PROPOSALS	84

VI.	MEETINGS	88
VII.	LAMPF NEWS	96
	MILESTONES	100
	ERRATA	103
	INFORMATION FOR CONTRIBUTORS	105
	APPENDIX A	
	ACTIVE AND COMPLETE EXPERIMENTS BY CHANNEL	106
	APPENDIX B	
	ACTIVE SPOKESMEN, INSTITUTIONS, AND EXPERIMENTS	136
	APPENDIX C	
	VISITORS TO LAMPF	139

GLOSSARY OF TERMS

ADC	- Analog Digital Converter	pc	- Printed Circuit
ADS	- Analog Data System	PHA	- Pulse-Height Analyzer
AMO	- Area Manager's Office	PIGMI	- Pion Generator for Medical Irradiations
AP	- Activation-Protect	PIP	- Proton Irradiation Port
APF	- Alternating Phase-Focusing	PMT	- Photomultiplier Tube
ASCII	- American Standard Code for Information Interchange	RAM	- Random Access Memory
bpi	- Bytes Per Inch	RBE	- Relative Biological Effectiveness
BPM	- Beam-Position Monitor	RICE	- Remote Information and Control Equipment (remote data terminal)
CCF	- LASL Central Computer Facility	ROM	- Read-Only Memory
CCR	- Computer Control Room	SCR	- Silicon Control Rectifier
CPU	- Central Processing Unit	SY	- Switchyard
CRT	- Cathode Ray Tube	TDC	- Time-to-Digital Converter
CT	- Computerized Tomography	TOF	- Time of Flight
cw	- Continuous Wave	TR	- Transition Region
C-W	- Cockcroft-Walton	WNR	- Weapons Neutron Research Facility
DPM	- Digital Panel Meter		
DVM	- Digital Volt Meter		
ETL	- Equipment Test Laboratory		
fh	- Filament Hours		
FSI	- Final-State Interaction		
FWSS	- Fast-Wire-Scanner System		
hfs	- Hyperfine Structure		
IC	- Integrated Circuit		
I&C	- Instrumentation and Control		
ICR	- Injector Control Room		
IDS	- Information Display System		
IFA	- Interface Amplifier		
I/O	- Input/Output		
IPA	- Intermediate Power Amplifier		
ISIC	- Insertable-Strip Ion Chambers		
ISTS	- Ion Source Test Stand		
LAM	- Look-at-Me Interrupt		
LAMPF	- Clinton P. Anderson Meson Physics Facility		
LED	- Light-Emitting Diode		
LEEP	- LAMPF Electronics and Equipment Pool		
LET	- Linear-Energy Transfer		
LM	- Loss Monitor		
LRS	- Low-Resolution Spectrometer		
LTSS	- Livermore Time-Sharing System		
LUGI	- LAMPF Users Group, Inc.		
MBD	- Microprogrammed Branch Driver		
MG Set	- Motor-Generator-Set		
m.i.	- Mineral Insulated		
MT	- Master Timer		
MWPC	- Multiwire Proportional Chamber		
NCL	- Nuclear Chemistry Laboratory		
NIM	- Nuclear Instrumentation Module		
NMR	- Nuclear Magnetic Resonance		
OER	- Oxygen Enhancement Ratio		

Experimental Areas

Primary beam lines in experimental areas:

Line A	- Main Beam Line for Pion and Muon Channels
Line B	- Neutron Beams and 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
P ⁺	- High-Energy Pion Channel
SMC	- Stopped Muon Channel
TA-1	- Target A-1
TA-2	- Target A-2
TTA	- Thin Target Area
Beam Area B (Room BR):	
AB	- Neutrons
AB	- Nuclear Chemistry
EPB	- External Proton Beam
Beam Area C:	
CCH	- Area C Control and Counting House
HRS	- High-Resolution Proton Spectrometer
Beam Area A-East:	
Biomedical Pion Channel	
TA-5	- Target A-5
ISORAD	- Isotope Production and Radiation Damage
Neutrino Area	

PROGRESS AT LAMPF

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ABSTRACT

Progress at LAMPF is the semiannual progress report of the MP Division of the Los Alamos National Laboratory. The report also includes brief reports on research done at LAMPF by researchers from other institutions and Los Alamos divisions.

I. RESEARCH

Nuclear and Particle Physics

Parity Violation in Proton-Nucleus Scattering at 6 GeV/c

(Work Performed at Argonne National Laboratory)
(Ohio State Univ., Los Alamos National Laboratory,
Elmhurst College, Univ. of Chicago, Univ. of Illinois,
Argonne National Laboratory, California Institute of
Technology)

We have searched for parity violation (PV) in proton-nucleus scattering at 6 GeV/c by studying the dependence of the total cross section on the helicity of the incident polarized proton beam. This dependence is expressed by the PV asymmetry $A_L = (\sigma_+ - \sigma_-)/(\sigma_+ + \sigma_-)$,

where $\sigma_+(\sigma_-)$ is the total cross section for positive-(negative-) helicity protons on a water target. At present, investigation of PV phenomena is the only way to gain experimental knowledge of the strangeness-conserving hadronic weak interaction.

A PV asymmetry A_L can arise from the interference of the strong and weak interactions between nucleons. Measurements at low energies^{1,2} yield $A_L \simeq 10^{-7}$, in agreement with calculations.³⁻⁵ The first measurement at 6 GeV/c found $A_L = (5 \pm 9) \times 10^{-6}$ using a beryllium target.⁶ A value $A_L = (-15.0 \pm 2.8) \times 10^{-6}$ was obtained when the experiment was repeated using a water target.⁷ At that time it was realized that a nonzero transmission asymmetry can result from the production and subsequent decay of longitudinally polarized hyperons. A focusing magnetic spectrometer was added to eliminate hyperon decay products.⁸ Here we report our

most recent measurement $A_L = (2.65 \pm 0.60) \times 10^{-6}$, which is an order of magnitude larger than an existing prediction⁹ of $A_L \sim 10^{-7}$ for both pp and pn scattering.

This experiment used a vertically polarized proton beam from the Argonne National Laboratory Zero Gradient Synchrotron (ZGS). The beam had an average polarization $|\bar{P}| = 0.71 \pm 0.03$, an average intensity of 3.2×10^8 protons/pulse, a spill width of roughly 700 ms, and a repetition rate of 0.3 Hz. The polarization direction was reversed at the source between ZGS pulses. An upward bend of the beam rotated the polarization to a longitudinal direction. The horizontal position of the beam centroid at the target was stabilized with the aid of a feedback loop controlling the current in an upstream bending magnet.

A schematic representation of the experiment is shown in Fig. 1. The transmission Z through an 81-cm-long water target was measured by two independent detector systems, which have been described previously.⁶ One system comprised a pair of identical plastic scintillation counters, each viewed by four photomultiplier tubes. The second system was a set of three identical ionization chambers. The output currents from ion chambers upstream and downstream of the target were subtracted before amplification. The difference signal was normalized to the beam intensity with a third ionization chamber. Integral counting techniques allowed high beam intensities to be used so a sensitivity of $<10^{-6}$ could be achieved in a few days. Auxiliary scintillation detectors (shown in Fig. 1) monitored various beam properties.

The data include 184 data runs and 54 control runs, each consisting of ~ 1600 pulses, for a total of 10^{14} incident protons. Consecutive data runs were started on alternate polarization states to avoid any effects from drifts. The fractional change of transmission with helicity reversal, $\Delta Z/2Z = (Z_+ - Z_-)/(Z_+ + Z_-)$, was computed for each pair of pulses. An average $\langle \Delta Z/2Z \rangle$ was calculated for each run. The error was determined from pulse-to-pulse fluctuations in $\Delta Z/2Z$ and was typically three times as large as fluctuations due to the finite number of incident protons. Approximately 10% of the pulse pairs were rejected because of poor beam conditions. Weighted average values of $\langle \Delta Z/2Z \rangle$ are given in Table I.

A small reduction in the statistical fluctuations was obtained by a linear-regression analysis of $\Delta Z/2Z$ in each run against horizontal and vertical beam position, beam position squared, and beam intensity. The regression coefficients were determined from the correlations

Fig. 1.

Schematic of parity-violation experiment. The components are SOL - a solenoid magnet for rotating the plane of polarization by a few degrees; B1 - a dipole magnet that bends the beam by 7.75° , producing a longitudinally polarized beam; Y1 and Y2 - arrays of scintillators arranged as polarimeters; P1, P2 and P3 - position monitors; MON, DIF1, and DIF2 - the ion chambers for measuring beam intensity and transmission; and I and T - the scintillator detectors for measuring the transmission. C is a brass collimator, S indicates the counters used to look for any beam halo that might interact with matter while passing through the evacuated beam pipe in the spectrometer, and X is a left-right polarimeter designed to measure asymmetry owing to beam-matter interactions upstream of the target.

between polarization-independent linear combinations of data from sets of four consecutive pulses. The regression variables were found to be independent of helicity; thus the noise-reduction process did not appreciably change the value of $\langle \Delta Z/2Z \rangle$ (Table I).

The observed $\langle \Delta Z/2Z \rangle$ for each data run was corrected for known background processes arising from:

1. interactions with air and monitors in the beam channel where the beam polarization is vertical (beam-matter interaction);
2. the imperfect alignment of the beam polarization with its momentum-producing residual horizontal and vertical polarization components of the beam that interact with the water target. These scattered particles, which have a helicity-correlated spatial

TABLE I
SUMMARY OF $\langle \Delta Z/2Z \rangle$ VALUES IN UNITS OF 10^{-6}

Stage of Analysis	Scintillation Counters	Ionization Chambers
Raw asymmetry	-5.32 ± 0.77	-6.66 ± 0.87
After regression	-5.05 ± 0.69	-6.23 ± 0.84
Corrected for:		
Transverse polarization	-4.75 ± 0.68	-6.14 ± 0.82
Beam-matter scattering	-2.92 ± 0.80	-4.96 ± 0.99

asymmetry, strike the detectors measuring the incident and transmitted beam intensities. If the centers of these detectors are not the same as the beam center, a nonzero value of $\langle \Delta Z/2Z \rangle$ will result; and

3. correlations of the transverse polarization with beam phase space.^{1,9} This produces helicity-dependent changes in the transmitted beam intensity. Another source of asymmetry, hyperon production and decay, was eliminated by the spectrometer shown in Fig. 1.

The form of these background terms is $\gamma \cdot d \cdot \langle \Delta H \rangle$. In this expression, $\gamma(\text{cm}^{-1})$ is the sensitivity constant for the term; $d(\text{cm})$ is the displacement of the beam from the symmetry axis; and $\langle \Delta H \rangle$ is the average change with polarization reversal of the asymmetry measured by auxiliary scintillation detectors. The asymmetries were monitored during each beam pulse, and the sensitivities were measured in control runs in which the size of the relevant variable was enhanced. To measure the effects of transverse polarization, the horizontal and vertical components at the target were increased using solenoids in the beam line. In the runs measuring the beam-matter interaction, the number of interactions was increased by adding material upstream of magnet B1. During each type of control run the beam position and angle were varied. This procedure established the symmetry axis of the experiment, where the contributions from these background processes vanish.

The values of γ and d were determined in a least-squares fit of the measured values of $\langle \Delta Z/2Z \rangle$ from the data and control runs to a parity-violation signal and the sum of background terms. In addition to the term for

beam-matter interactions, the model included terms for horizontal and vertical transverse polarization. The contribution from the third background was calculated separately. Approximately 10% of the runs have a $\chi^2 > 5$ and were rejected; the remaining data are consistent with this model, since χ^2 per degree of freedom = 1.17 for both detector systems. The net asymmetry after each correction is given in Table I, and Table II summarizes these contributions to $\langle \Delta Z/2Z \rangle$. The correlation coefficient between values of $\langle \Delta Z/2Z \rangle$ from the two systems for individual runs was 0.2, indicating that they are substantially independent measurements. A combined fit to all the data gives $\langle \Delta Z/2Z \rangle = (-3.73 \pm 0.62) \times 10^{-6}$.

To calculate the contribution to $\langle \Delta Z/2Z \rangle$ from a correlation between transverse polarization and position in the beam, we measured the average transverse polarization for the upper, lower, left, and right portions of the beam. The result is expressed as $\langle \Delta H \rangle$ in Table II. The coefficient γ for this term is the same as for a net transverse polarization, and d , in this case, is the root mean-square (rms) size of the beam. Correcting for this effect yields a net $\langle \Delta Z/2Z \rangle = (-3.23 \pm 0.72) \times 10^{-6}$.

The PV asymmetry is related to the net $\langle \Delta Z/2Z \rangle$, valid only for small ΔZ , by the expression $A_L = (-\bar{P}|\epsilon n Z)^{-1} \langle \Delta Z/2Z \rangle$. The average transmission was $\langle Z \rangle = 0.18 \pm 0.01$. Our result is $A_L = (2.65 \pm 0.60) \times 10^{-6}$, and the quoted error is 1 std dev.

Since at low energies calculations are consistent with measurements of A_L for pp scattering, the discrepancy between our result and the existing calculation¹⁰ was unexpected. This experiment suggests that the interference between the strangeness-conserving hadronic

TABLE II

CONTRIBUTIONS TO $\langle \Delta Z / 2Z \rangle$ DUE TO BACKGROUND PROCESSES

Term	Residual Transverse Polarization						Phase-Space Correlation ^c Both
	Beam-Matter Scattering		Horizontal		Vertical		
	S.C. ^a	I.C. ^b	S.C.	I.C.	S.C.	I.C.	
$\gamma(10^{-3} \text{ cm}^{-1})$	5.7 ± 0.3	5.8 ± 0.4	-3.9 ± 1.6	-3.9 ± 2.2	-6.0 ± 4.0	-4.4 ± 8.4	-4.0 ± 2.0
$d(\text{cm})$	0.09 ± 0.02	0.06 ± 0.03	-0.36 ± 0.15	-0.27 ± 0.15	1.1 ± 0.4	0.3 ± 0.4	1.0 ± 0.1
$\langle \Delta H \rangle (10^{-5})$	-350.0 ± 0.2		-4.7 ± 0.2		$+3.5 \pm 0.5$		$+12.5 \pm 7.0$
$\gamma d \langle \Delta H \rangle (10^{-6})$	-1.80 ± 0.49	-1.18 ± 0.60	-0.07 ± 0.04	-0.05 ± 0.04	-0.23 ± 0.18	-0.05 ± 0.10	-0.50 ± 0.37

^aScintillation counters.^bIon chambers.^cTransverse polarization correlated with beam phase space.

weak and strong amplitudes has a large energy dependence. It is also possible that the observed PV effect is caused not only by the pp system but also has a large contribution from the np system. Finally, since we used a water target, it is possible that the disagreement with calculation involves nuclear structure effects. This experiment is part of our program to measure A_L at several energies. An experiment at 1.5 GeV/c is under way at LAMPF (Exp. 137).¹¹

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Charged-Particle Identification with Modules of the Plastic Ball (Exp. 536)

(Gesellschaft für Schwerionenforschung, Lawrence Berkeley Laboratory, Univ. of California at Berkeley)
Spokesman: Hans H. Gutbrod (Gesellschaft für Schwerionenforschung)

The LEP channel at LAMPF was used to calibrate the response of 13 modules of the Plastic Ball detector¹ for positive pions and protons at various energies. An assembly of 13 modules was used, since then the central module was completely surrounded by all possible neighbors. This configuration specifically permits studying the two dominating effects that determine the detection efficiency: (1) the scattering out of particles during the slowing-down process, and (2) the detection probability for the positrons stemming from π^+ decay. (These positrons are emitted isotropically with a maximum energy of 53 MeV and have a high probability of leaving the module.) Both effects make it necessary to take information in the neighboring modules into account and to reconstruct the event. A detailed description of the experiment and the results have been published elsewhere.²

It had been proved earlier in tests at the Bevalac that the energy resolution of the plastic scintillator and of the CaF_2 crystal is good enough for particle identification.¹ For protons of 75 MeV the energy resolution in the plastic scintillator is 3.5 MeV, FWHM, while in the CaF_2 where the protons lose about 8 MeV the resolution is 1 MeV, FWHM.

Figure 1 shows the ΔE -E contour plot for all measured pion and proton energies. The two branches are well separated. The spectrum in the upper right corner is a projection of the interval indicated by dashed lines projected onto the ΔE -axis. It illustrates in a more quantitative way the quality of the particle discrimination. The dashed line at 32 counts in this spectrum indicates the intensity threshold in the contour plot.

Detection efficiencies for protons and pions at all measured energies could be obtained.²

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Fig. 1.
The ΔE -E contour plot.

A Search for Nuclear Critical Opalescence Using the Reaction $^{40}\text{Ca}(\pi^+, 2\gamma)$ (Exp. 541)

(Los Alamos National Laboratory, Tel Aviv Univ., Louvain)

Spokesman: M. D. Cooper (Los Alamos National Laboratory)

The $^{40}\text{Ca}(\pi^+, 2\gamma)$ experiment at $T_\pi = 55$ MeV has had the need for a calculation of the expected cross sections to aid in planning the experiment, and as a first step in the data interpretation. The experiment proposed would measure the double differential cross section $d^2\sigma/dqdx$ for the process $^{40}\text{Ca}(\pi^+, 2\gamma)$ in the region of quasi-elastic dominance. The range of momentum transfer q would be from 0.5 to $2.0 m_\pi$, and the range of the photon energy-sharing parameter x would be from -0.75 to 0.75 . The reaction is hoped to be particularly sensitive to medium modifications to the pion propagators present in the matrix elements. This effect, called nuclear critical opalescence,¹ should be most dramatic for $x = 0$ and $q \approx 2.2 m_\pi$.

In response to the need for a more detailed calculation of the $^{40}\text{Ca}(\pi^+, 2\gamma)$ reaction and the medium modifications, a two-part theoretical effort has been undertaken. The goals of this effort are (1) to calculate the cross section for $^{40}\text{Ca}(\pi^+, 2\gamma)$ using the distorted wave impulse approximation (DWIA) for one-nucleon processes, and (2) to include the medium modifications to the propagators.

This report gives a summary of the formalism that has been developed to meet the first part of our efforts. It has

been incorporated into a computer program that takes a few hours to compute a cross section. Some remaining theoretical uncertainties, such as the role of the delta and the inclusion of the Pauli principle, prevent the quotation of any results.

The starting point for the calculation is the fundamental $\pi N \leftrightarrow N\gamma\gamma$ matrix element, which we denote by

$$\langle p'k' | m | pq \rangle \quad (1)$$

for incident nucleon p and pion q , outgoing nucleon p' , and photons k and k' . There are 18 one-nucleon graphs included in Eq. (1), and the direct terms are illustrated in Fig. 1. These matrix elements follow closely the development of Cammarata,² using pseudovector coupling and

Fig. 1.

The one-nucleon Feynman graphs. All except h are included in the DWIA matrix element. Each graph leads to two terms due to photon exchange.

the tree approximation. They differ in the following respects:

1. magnetic photon coupling is not included,
2. the incident particles are π^+ and neutron,
3. photons are coupled to neutrons via an effective charge, and
4. the π -nucleon vertex has a form factor $\exp(-Q^2/\Lambda^2)$ included (Q^2 is the square of the pion three momentum that attaches to the nucleon).

To imbed the matrix element in finite nuclei, we define m' as

$$\begin{aligned} \langle p'k' | m' | IK \rangle &\equiv \int \frac{d^3\vec{q}}{(2\pi)^3} \int \frac{d^3\vec{p}}{(2\pi)^3} \\ &\times \langle p'k' | m | pq \rangle \left(\frac{M}{2\epsilon_k E_p} \right)^{1/2} \\ &\times \psi_K(\vec{q}) \psi_I(\vec{p}) (2\pi)^3 \delta^{(3)}(\vec{p}' + \vec{k} + \vec{k}' - \vec{p} - \vec{q}) \quad (2) \end{aligned}$$

The kinematic variables are illustrated in Fig. 2. The initial nuclear state ψ_I is characterized by a binding energy $-\epsilon$ and momentum $\vec{p}$, and is normalized to one nucleon. The distorted pion wave $\psi_K(\vec{q})$, where K is the incident momentum, is given as

$$\begin{aligned} \psi_K(\vec{q}) &= (2\pi)^3 \delta(\vec{q} - \vec{K}) + \frac{(2\pi)^3}{q^2} \\ &\times \left\{ \delta(q - K) \sum_{\ell} P_{\ell}(\cos \theta_q) \left[\phi_{\ell}^{(0)}(K) - \frac{2\ell + 1}{4\pi} \right] \right. \\ &+ \frac{P}{q - K} \sum_{\ell} P_{\ell}(\cos \theta_q) \phi_{\ell}^{(1)}(K, q) \left. \right\} \quad (3) \end{aligned}$$

The values for $\psi_K(\vec{q})$ are obtained for the program PIPIT,³ a momentum-space optical-model program, by using the π -nucleon form factor $\exp(-Q^2/\Lambda^2)$. The parameters of the optical potential are adjusted to fit 50-MeV elastic π^+ -⁴⁰Ca scattering data.⁴ All three terms of Eq. (3) contribute substantially to m' .

Fig. 2.

The graph corresponding to m' for a nucleus, showing the distortion that puts the pion off the mass shell. The initial nucleon is also off the mass shell.

The triple differential cross section, which is needed for comparison to experiment, is given by

$$\frac{d\sigma}{d\Omega_1 d\Omega_2 dx} = \frac{(1-x^2)}{(2\pi)^8} \frac{1}{16 \beta_\pi} \sum_I \int d^3 \vec{p}' \frac{M}{E_{p'}} \times g_{p'_F}(p') \left(\frac{\omega_1}{2} \right)^3 n_I \theta(\omega_1 > 0) \times \sum_{\substack{\text{nucleon spins} \\ \text{photon polarizations}}} |\langle p' k k' | m' | I K \rangle|^2. \quad (4)$$

In Eq. (4), the symbols have the following definitions:

$$x \equiv \text{Energy-sharing parameter} \quad \frac{E_1 - E_2}{E_1 + E_2},$$

E_i are photon energies

$$\beta_\pi \equiv \text{Incident pion velocity}$$

$$g_{p'_F}(p') \equiv \text{Factor that excludes the occupied states forbidden by the Pauli principle}$$

$$\omega_I \equiv E_1 + E_2 \text{ for photons produced from an initial neutron in state } I$$

$$n_I \equiv \text{Number of neutrons in state } I$$

It is useful here to delineate the kinematics used to evaluate Eq. (4). They are

$$\vec{q}, \vec{q}' \quad \text{Arguments of integration representing the pion's off-shell momentum and the final nucleon's momentum}$$

$$E_p' = \sqrt{p'^2 + M^2} \text{ final nucleon on the mass shell}$$

$$E_\pi \quad \text{Given incident pion energy, off the mass shell}$$

$$x, \Omega_1, \Omega_2 \quad \text{Measured energy-sharing parameter and photon angles}$$

$$\omega = E + E_\pi - E_{p'}$$

$$k = \frac{1+x}{2} \omega \quad k' = \frac{1-x}{2} \omega$$

$$\vec{p} = \vec{p}' + \vec{k} + \vec{k}' - \vec{q} \text{ off the mass shell}$$

In order to make the calculation tractable, m' has been taken to be independent of I ; $\psi_I(p)$ has been chosen as the Fourier transform of a bound d-state Woods-Saxon wave function of average binding energy,

$$26 \text{ MeV} = \sum_I E_I n_I / n.$$

It is believed that the momentum composition of s- and d-state wave functions is similar enough so that this will not be a severe approximation. It can be checked for a few examples.

The integrations are done numerically using Monte Carlo techniques. With the above approximation, a cross section for one value of x , Ω_1 , and Ω_2 can be calculated to about 10% accuracy using a few hours of VAX CPU time.

There are two other approximations implicit in Eq. (4). The first is that a simple form for $g_{p'_F}(p')$ exists. In nuclear matter, it is just a theta function. In a finite nucleus, it has a diffuse edge at p'_F , which is still being

studied. The other is that plane waves are an adequate description of the final state when the integral in p' is cut off by p'_F and $\theta(\omega_i > 0)$. It is expected that it will be a good description in the region of momentum transfer where the nuclear response function, as measured in electron scattering, is dominated by quasi-free scattering. The electron-scattering data for ^{40}Ca show this to be largely true for $q > 0.5 m_\pi$, and this is where the calculation will be valid.

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Nuclear Reactions of ^{127}I with Pions (Exp. 349) (Purdue Univ., Los Alamos National Laboratory) Spokesman: N. T. Porile (Purdue Univ.)

We are in the process of measuring the excitation functions and mass-yield curves of $^{127}\text{I}(\pi^+, \pi^+ xn)^{127-x}\text{I}$ reactions ($x = 1-10$) with 60-350-MeV pions (at the P³ and LEP channels at LAMPF) by activation techniques. Comparative measurements will also be performed with ≈ 400 -MeV protons at LAMPF.

These data (Fig. 1) are from a continuing series of measurements whose results are to be compared to Monte Carlo cascade-evaporation calculations. In Fig. 1 we see the apparent variation with energy in mass-yield curves at $A \geq 123$. But at $A \leq 123$, these mass-yield curves at several energies between 100 and 350 MeV are rather similar.

Measurement of the Residual Muon Polarization in ^3He Muonic Atom (Exp. 529, Part I) (Columbia Univ., Yale Univ.) Spokespersons: G. Dugan and C. S. Wu (Columbia Univ.)

We have measured the residual muon polarization in the $(\mu^-: ^4\text{He})^+$ and $(\mu^-: ^3\text{He})^+$ atoms at 0.75-atm gas

Fig. 1.
Mass-yield curves.

pressure. These measurements were performed at the SMC at LAMPF. A longitudinally polarized muon beam

was stopped in a 4-mg/cm² gas target; a transverse field of ≈ 100 G resulted in spin precession of the polarized atoms at a frequency ≈ 1 MHz. The polarization of the atoms was determined from the amplitude of the harmonic modulation appearing in the time distribution of the decay electrons relative to the muon stop. Backgrounds from muons stopping in materials other than the gas target were suppressed by detecting the decay electrons in a series of multiwire proportional counters (MWPCs), which allowed the electron tracks to be reconstructed back to the target gas volume.

Preliminary results indicate a residual polarization of the muon, in 0.75-atm gas, of $5.2 \pm 1.7\%$ in $(\mu^-:^4\text{He})^+$ and $3.4 \pm 1.1\%$ in $(\mu^-:^3\text{He})^+$. The reduction in going from ^4He to ^3He is consistent with that expected from the additional hyperfine depolarization in the ^3He case. The result for $(\mu^-:^4\text{He})^+$ is roughly a factor of 3 lower than the prediction of the standard theory of cascade depolarization ($\approx 16\%$), indicating the presence of an anomalous depolarization in this atom. Moreover, since this result at 0.75 atm is consistent with previous measurements¹ of the residual muon polarization in $(\mu^-:^4\text{He})^+$ at higher pressures (7 and 14 atm), the anomalous depolarization appears to be roughly independent of the gas pressure in this pressure range.

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Measurement of the Cross-Section Difference for Longitudinal Polarized Beam and Target (Exp. 498) (Argonne National Laboratory, New Mexico State Univ., Los Alamos National Laboratory)

Spokesmen: Robert Wagner (Argonne National Laboratory) and George Burleson (New Mexico State Univ.)

We have measured the difference in the p-p total cross section for beam and target protons in pure parallel and antiparallel longitudinal spin states for laboratory energies between 300 and 800 MeV. For these runs the variable-energy operation of the LAMPF accelerator, with reduced duty factor, was used extensively for the first time. These measurements were carried out in the EPB area using the polarized proton beam and the HERA polarized proton target, a LAMPF facility. The 5.5-cm-long target was filled with propanediol ($\text{C}_3\text{H}_8\text{O}_2$). Typical values of the polarization of the beam and the

target were 80% or greater; both were monitored continuously during experimental runs. A conventional transmission technique was used for the total cross-section measurements, with the 10 transmission counters having radii varying between 5.1 and 22.9 cm. Counter efficiencies and accidental rates were monitored during the runs, and their measured values were used as corrections for the data. The total cross-section difference $\Delta\sigma_L \equiv \sigma(\text{antiparallel}) - \sigma(\text{parallel})$ is found from extrapolation to zero solid angle of the partial cross sections $\Delta\sigma_L(\Omega)$ obtained from each transmission counter using a least-squares method involving the full covariance error matrix. Here parallel and antiparallel refer to the laboratory orientation of the beam and target proton spins. Many systematic checks were made during the experiment; from these, the value of $\Delta\sigma_L$ was found to be insensitive to variations in beam position and intensity (for beam rates below a determined value), and it was found to go to zero as required when the beam or target polarization was reduced to zero, or when the beam was given either a vertical or a sidewise polarization. During the runs, measurements were also made of the C_{LL} parameter around 90° (center of mass) using wire chambers to detect the scattered and recoil proton. The preliminary results for $\Delta\sigma_L$ are shown in Fig. 1, along with previous results from ZGS experiments and with new results from SIN.¹ The agreement among all sets of data is seen to be very good.

The principal purpose of this experiment is to continue the investigation of evidence for dibaryon resonances. The possibility of such resonances was first noted in the initial measurements of $\Delta\sigma_L$ (Ref. 2); the present status of evidence for and against dibaryon resonances has been reviewed recently.³ The aim of these data runs was to check the previous ZGS data, to obtain new data at lower energies, and to search for new, possibly narrow, structure that might indicate additional resonances. It was important to check the previous data, since doubts on its interpretation in terms of dibaryon resonances had been raised on the basis of possible errors in the measurement of the magnitude of $\Delta\sigma_L$. It was also important to search for additional structure, since the possibility of such structure is strongly suggested by many models of dibaryon resonances and cannot be ruled out by existing data. From the results shown in Fig. 1, it can be seen that the previous data were found not to be in error. Therefore, objections to its interpretation as evidence for dibaryon resonances cannot be based on errors in the magnitude of $\Delta\sigma_L$. Also, no evidence for narrow structure has so far been found.

Fig. 1.
Total cross-section differences [$\sigma(\text{antiparallel}) - \sigma(\text{parallel})$] for p - p scattering.

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A Study of Inclusive Inelastic Pion Scattering Near the $\Delta(3/2,3/2)$ Resonance (Exp. 390)

(Argonne National Laboratory, Northwestern Univ.)

Spokesman: H. E. Jackson (Argonne National Laboratory)

We have measured the inclusive scattered pion spectra for targets of helium, carbon, oxygen, nickel, and lead resulting from incident π^+ and π^- pions with energies of 100, 160, 220, and 300 MeV. The large-acceptance spectrometer was used to obtain spectra spanning 80% of the range of momentum transfer with a resolution limited by the energy spread of the incident beam to between 1 and 2%, FWHM. Measurements were made for various combinations of angles ranging from 30 to 150°. The primary objectives were to obtain information on the gross properties of the scattered spectrum, to determine the contribution of inelastic scattering to the total reaction cross section, and to establish the extent to which the inelastic scattering can be explained in a simple impulse approximation. Estimates of quasi-free scattering obtained from these spectra would also be useful in assessing the validity of optical-model descriptions of pion-nucleus scattering.

Typical data are shown in Fig. 1 for a helium scatterer, and in Fig. 2 for carbon and nickel targets. The incident beam for these spectra is 220-MeV π^+ . The energy-integrated cross sections are in agreement with values observed in earlier measurements in which only integral spectra could be observed. Very qualitatively, the spectra show features similar to those observed earlier in measurements of inclusive charge exchange¹ (Exp. 303). At large scattering angles a broad peak is observed centered at energies near that appropriate to quasi-free scattering. However, to date we have not been able to obtain detailed agreement with quasi-free calculations.

The total inelastic-scattering cross sections obtained by integration of the spectra of Figs. 1 and 2 are 114, 256, and 506 mb for helium, carbon, and nickel, respectively. We can estimate the total pion absorption cross

Fig. 1.

Inclusive pion-scattering cross sections for helium at $T_{\pi^+}(\text{incident}) = 220 \text{ MeV}$.

section (including charge exchange) for helium by subtracting the total inelastic-scattering cross section from the estimated total nonelastic cross section measured for $\pi^- + \text{helium}$ at 220 MeV by Binon *et al.*² The resulting absorption cross section is 66 mb.

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Fig. 2.

Inclusive pion-scattering cross sections for carbon and nickel targets at $T_{\pi^+}(\text{incident}) = 220 \text{ MeV}$.

Measurement of the Angular Dependence of Tensor Polarization in the $^2\text{H}(\pi^+, \pi^+)^2\text{H}$ Reaction (Exp. 483) (Argonne National Laboratory, Los Alamos National Laboratory, Univ. of Illinois)
Spokesman: R. J. Holt (Argonne National Laboratory)

The first angular distribution for the tensor polarization (t_{20}) of the recoil deuteron in the reaction $d(\pi, \pi')d$ has been obtained on the LEP channel at LAMPF. Previously (Exp. 388), the tensor polarization was measured at 180° using the second half of the LEP channel as a spectrometer and a novel ^3He polarimeter.¹ For the recent angular distribution measurements, a quadrupole doublet focused deuterons into a new polarimeter while the scattered pions were detected in a scintillator telescope (Fig. 1). The new ^3He polarimeter was designed for sensitivity not only to t_{20} but also to other polarization moments, as well as to allow a lower energy cutoff to accept deuterons at pion angles $< 180^\circ$. Recent measurements at 140 MeV were at pion angles of

Fig. 1

Schematic diagram of the experiment to measure the angular distribution of t_{20} .

$\theta_{\pi}^{c.m.} = 100, 120, \text{ and } 145^\circ$. These data are being analyzed. As an extension of this program at LAMPF, we plan to do analogous measurements with electrons $[d(e,e')\vec{d}]$ with the same polarimeter at the Bates electron linac.²

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Measurement of the Dalitz Decay of the Neutral Pion (Exp. 221)

(Arizona State Univ., Los Alamos National Laboratory)

Spokesman: Cy Hoffman (Los Alamos National Laboratory)

This experiment, run in the P³ channel at LAMPF, is aimed at improving the accuracy of our knowledge of the rate for the decay $\pi^0 \rightarrow e^+e^-$, the Dalitz decay mode of the neutral pion. The branching ratio,

$$B = \frac{\Gamma(\pi^0 \rightarrow e^+e^-\gamma)}{\Gamma(\pi^0 \rightarrow \gamma\gamma)}$$

can be calculated in a straightforward manner using conventional quantum electrodynamic theory (QED). Lowest order QED predicts¹ $B = 1.186 \times 10^{-2}$. Higher order electrodynamic corrections and strong interaction corrections increase the prediction² to $B = 1.199 \times 10^{-2}$. The existing measurement³ is $B = (1.166 \pm 0.047) \times 10^{-2}$. B is very sensitive to the vacuum polarization contribution.

A plan view of the apparatus is shown in Fig. 1. There are two arms: a photon detector (shower counter), and a magnetic spectrometer to detect electron-positron pairs. The π^0 's were produced via the reaction $\pi^+\bar{p} \rightarrow \pi^0 n$ in polyethylene targets. The apparatus detected both Dalitz decay events and $\pi^0 \rightarrow \gamma\gamma$ events where one of the photons converts in the target; these events were indistinguishable. Data were collected for three target thicknesses, and an extrapolation of the event rate per target thickness to zero thickness eliminated the photon conversion events. Data were also collected with a copper sheet inserted in front of the spectrometer magnet to convert photons into e^+e^- pairs. After again extrapolating to zero target thickness, these events, along

Fig. 1.

Schematic view of the experimental apparatus. The MWPCs are not labeled in the figure, but they can be seen flanking the pair spectrometer magnet.

with the calculated photon conversion probability, were used for normalization. Data were collected at several beam intensities to ensure that rate-dependent corrections such as accidental coincidences, deadtime, and detector efficiency were well understood. Some typical data are shown in Fig. 2.

The data rates were compared with the results of a Monte Carlo code, which modeled the apparatus and included all physical effects such as ionization energy loss, bremsstrahlung, and energy-dependent pair production in each of the available materials. To a very good approximation, the final result depends only upon the relative acceptance for Dalitz decay and pair production events.

To extract the branching ratio B from the data, the intercepts of the event rates per target thickness were fit to linear functions of the copper converter thickness. The

Fig. 2.

The corrected number of events per target thickness per beam monitor is plotted vs target thickness for the beam intensity of $4 \times 10^6 \pi^-/s$. The three curves are least-squares fits for the no-copper, thin-copper, and thick-copper configurations of the experiment.

slope of this fit (in units of mm^{-1} of copper) was then compared with the Monte Carlo results as a function of B , as shown in Fig. 3. The result is

TABLE I

SYSTEMATIC ERRORS

Quantity	Error in Branching Ratio
Target thickness	0.002×10^{-2}
Copper converter thickness	0.004×10^{-2}
Absolute copper conversion probability	0.013×10^{-2}
Material between target and first MWPC	0.002×10^{-2}
π^0 form-factor slope	0.001×10^{-2}

Fig. 3.

The ratio R vs the Dalitz decay branching ratio B for the data and for the Monte Carlo results. The bands correspond to 1 std dev.

$$B = (1.25 \pm 0.04) \times 10^{-2} \quad ,$$

where the error is due to statistical errors in both the data and the Monte Carlo calculation.

Systematic uncertainties arise from uncertainties in the targets and converters and in the theoretical uncertainty in the photon-conversion probability in copper. These uncertainties are summarized in Table I and result in an overall systematic uncertainty of 0.014×10^{-2} in B .

A paper describing the experiment and the results has been submitted to *Physical Review*.

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A Study of the Decays $\pi^0 \rightarrow \nu \bar{\nu}'$

(Los Alamos National Laboratory)

Cy Hoffman and P. Herczeg (Los Alamos National Laboratory)

The decay $\pi^0 \rightarrow \nu \bar{\nu}'$ is interesting because momentum and angular momentum conservation admit only final states in which the helicities of ν and ν' are the same. Consequently, $\pi^0 \rightarrow \nu \bar{\nu}$ is forbidden if ν is a massless Weyl neutrino. The observation of $\pi^0 \rightarrow \nu \bar{\nu}'$ would imply either the existence of neutrino states of both helicities, or that lepton number is not conserved, or both.

An examination of existing data¹ on the process $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ yields a limit

$$B = \frac{\Gamma(\pi^0 \rightarrow \nu \bar{\nu}')}{\Gamma(\pi^0 \rightarrow \text{all})} < 2.4 \times 10^{-5} \text{ (90\% C.L.)} \quad .$$

This appears to be the best limit on B that one can extract from existing data.

Possible mechanisms that could give rise to $\pi^0 \rightarrow \nu \bar{\nu}'$ have been examined in the framework of unified gauge theories of the weak and electromagnetic interactions. Contributions due to the exchange of neutral gauge bosons and neutral Higgs mesons have been calculated. Branching ratios of the order of 10^{-7} for decays into ν_e or ν_μ are found possible. Rates comparable to the experimental limit for decays into final states involving other neutrinos cannot be ruled out.

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The Crystal Box Experiment (Exps. 400/445)

(Los Alamos National Laboratory, Stanford Univ., Univ. of Chicago)

Spokesmen: M. Duong-Van, M. D. Cooper, and C. Hoffman (Los Alamos National Laboratory)

This experiment is designed to search for the rare decay modes $\mu^+ \rightarrow e^+ e^+ e^-$, $\mu^+ \rightarrow e^+ \gamma$, and $\mu^+ \rightarrow e^+ \gamma \gamma$

using a modularized sodium-iodide (NaI) detector, a cylindrical drift chamber, and plastic scintillation counters as described in the preceding Progress Report.

Crystal Box Experiment — Data-Acquisition System. The Crystal Box is a sophisticated array of sodium-iodide crystal detectors that is necessary to carry out the LAMPF experiments searching for rare muon decays (Exps. 400 and 445). The software necessary to support these experiments is of necessity quite complex, since all 432 of the crystals, as well as a drift chamber and many scintillators, are issuing data that must be collected and processed rapidly. A schematic diagram representing the data flows that will accomplish this task is given in Fig. 1. Not shown is a specially designed hardware trigger that combines and tests the crucial signals to determine if a valid muon decay event has occurred. When such a signal is received, parallel data-acquisition sequences are begun. Each quadrant of the Crystal Box is read and compressed by a separate "intelligent multiplexer" (IM), which is a subsystem composed of an LSI-11/23 and a multiplexer that enables all crystals to be consecutively read out through a single analog digital converter (ADC). Simultaneously, the

microprogrammed branch driver (MBD), another special-purpose computer, collects data through a CAMAC system from the drift chamber and scintillators. The MBD then attaches the data from the IMs and feeds all the information to the PDP-11, which decides if the event is good enough to save on tape. Ancillary programs in the PDP-11 display data, test for hardware malfunction, and, in general, monitor and control the experiment.

Recent progress for this data-acquisition system takes the form of a more complete and detailed specification, which is based both on the established requirements for these computer codes¹ and also on design of the hardware trigger.² Separate areas of progress are detailed below.

Front-End Data-Flow Logic. We have developed a scheme³ for controlling the data flows to the MBD from the hardware and the IMs. The most important consideration in its design was to avoid having a piece of one physical event confused with data from a different event. Only slightly less important was to ensure, by selecting appropriate buffering modes, that bottlenecks in the data flow would be avoided. These two considerations and the interrelationships between them determined the signals and levels necessary between the trigger module, IMs, hardware event trigger, and CAMAC I/O registers. Since some of the signals are controlled by both the MBD and the IMs, a flow diagram of the functions that the IMs were required to perform was also included in this scheme. Detailed, annotated timing diagrams and CAMAC crate layouts were also prepared.

Drift-Chamber Readout System. In August we received, on loan, a LeCroy 4290 drift-chamber readout system for testing. Data-acquisition and support software was written and used with the prototype drift chamber in a run on the test channel at LAMPF. As a result of this run it was decided to use this system for the Crystal Box experiments, and an order was placed with LeCroy.

Computer Requirements. The specifications for both the IM computer and the main analysis computer and its peripherals was completed. The IM will be an LSI-11/23 with 96k of memory, which will communicate with the rest of the system via a BiRa auxiliary crate

Fig. 1.

Data-flow schematic for the Crystal Box experiments.

controller with a dataway access port in a CAMAC crate connected to the MBD. The actual choice for a main processor has not yet been made.

Timing Tests. One significant input to the establishment of the computer requirements was the result of timing tests. A representative event processor was written along with a routine to generate data to feed to it. This code was run on several different computers to compare their execution speeds. On the basis of these tests we were able to rule out certain CPUs as being too slow to keep up with the expected data rates.

Analysis Software Specification. The data-flow schemes for the main analysis computer have been determined and written up. The main scheme takes the data from the MBD, processes it, histograms desired quantities, examines it for acceptability, and, if it passes the test, writes the data onto tape. Provision is also made for sending the data to other tasks that will perform a more sophisticated analysis of the data, display it in one of several ways, or print it out. Other schemes address further requirements of the system, such as creating and maintaining a history of the experiment, changing constants, exercising the hardware to diagnose or discover malfunctions, monitoring and updating values that may drift during a run (like crystal gains and magnet currents), collecting statistics on event types, and examining and/or printing out values of important variables in the code.

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Asymmetries for Elastic pp Scattering in the Coulomb-Interference Region at 800 MeV (Exp. 15) (Univ. of California at Los Angeles, Univ. of Minnesota, Los Alamos National Laboratory)

Spokesmen: George J. Igo (Univ. of California, Los Angeles) and N. Tanaka (Los Alamos National Laboratory)

Small-angle asymmetries for the elastic scattering of transversely polarized protons of hydrogen have been measured at 800 MeV. These measurements are the continuation of the differential elastic cross-section measurements previously reported,¹ and are motivated by the need to determine forward p-p scattering amplitudes accurately around 1.4 GeV/c. Forward spin-orbit amplitudes, poorly known at present, are needed as input to microscopic p-nucleus calculations, while the spin-independent and double spin-flip amplitudes are relevant to the speculations concerning dibaryon resonances in this energy region.

The experiment was performed at LAMPF, using the High Resolution Spectrometer (HRS) to detect protons scattering in a forward direction from a 6-cm LH₂ target with 5-mil Kapton windows. For measurements at the smallest angles, the beam was incident on the focal plane where it passed through the insensitive region of a specially constructed set of multiwire proportional chambers (MWPCs) and was counted by means of a three-fold scintillator telescope. This permitted the beam-related background, produced by passing the beam through the bulky MWPC frames, to be virtually eliminated. A second set of chambers was sensitive to the beam and could be used to monitor eventual shifts that would produce spurious asymmetries. The spectrometer's good resolution may be relied upon to differentiate against events from inelastic scattering at all angles, and against those from elastic scattering off the heavy constituents of the target windows (carbon and oxygen) down to 1.2° (lab).

Data below 1.2° can be obtained by subtracting target-empty runs after correcting for multiple-Coulomb scattering. At small angles ($\leq 2^\circ$ lab) the yields could be normalized both to the measured beam intensity and to a set of three-fold scintillator telescopes viewing the target at $\pm 20^\circ$ (lab). At larger angles ($\geq 2^\circ$ lab), the telescopes were used, and at yet larger angles ($\leq 4^\circ$ lab) an ion chamber was introduced. In order to avoid degrading the

Fig. 1.

Analyzing powers for this experiment (Exp. 15) and data of Refs. 2 and 3 compared to the Arndt phase-shift analysis.

beam profile, the beam polarization ($\sim 80\%$) was monitored continuously by means of a polarimeter in another beam line.

Data have been analyzed down to 1.2° (lab) and are shown in Fig. 1. These agree with previous LAMPF data² and with the data from another previously reported³ experiment at the points of overlap. The solid line represents the prediction of the most recent Arndt phase shifts, which do not include our data. The data will be extended down to 0.7° (lab) as soon as yields at small angles have been corrected for multiple-Coulomb scattering. The differential cross section and asymmetries will then be analyzed in conjunction to extract 0° scattering amplitudes.

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$\bar{p}$ -Nucleus Elastic Scattering at 800 MeV (Exp. 311)
(University of Texas at Austin, Los Alamos National Laboratory, Univ. of California at Los Angeles, Univ. of Pennsylvania, Univ. of South Carolina)
Spokesman: G. W. Hoffmann (Univ. of Texas at Austin)

New and corrected angular distribution data for $\bar{p} + {}^{40,42,44,48}\text{Ca}$ at 800 MeV have been obtained and a second-order Kerman-McManus-Thaler (KMT) optical-potential analysis has been made.¹ The data and results of the analysis are shown in Figs. 1-6. The experimental differential cross sections are described extremely well by the present calculations, in contrast with previous results.^{2,3} However, the absolute magnitude of the empirically deduced ${}^{40}\text{Ca}$ neutron root-mean-square (rms) radius is not in agreement with theoretical expectations when several current N-N amplitude solutions and the impulse approximation are employed. Fortunately, the isotopic neutron density differences are insensitive to the possible theoretical and N-N amplitude uncertainties.

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Fig. 1.

Experimental and computed angular distributions for $p + {}^{40,42,44,48}\text{Ca}$ at 0.8 GeV. The two theoretical curves result from using two current sets of nucleon-nucleon amplitudes.

Fig. 2.
Experimental and computed differential cross-section ratio for $p + {}^{42}\text{Ca}$ to $p + {}^{40}\text{Ca}$ at 800 MeV. The solid and dashed curves result from using different sets of nucleon-nucleon amplitudes. The arrows denote the positions of the diffractive minima in the experimental ${}^{40}\text{Ca}$ angular distribution of Fig. 1.

Fig. 3.
Experimental and computed differential cross-section ratio for $p + {}^{44}\text{Ca}$ to $p + {}^{40}\text{Ca}$ at 800 MeV. The solid and dashed curves result from using different sets of nucleon-nucleon amplitudes. The arrows denote the positions of the diffractive minima in the experimental ${}^{40}\text{Ca}$ angular distribution of Fig. 1.

Fig. 4.
Experimental and computed differential cross-section ratio for $p + {}^{48}\text{Ca}$ to $p + {}^{40}\text{Ca}$ at 800 MeV. The solid and dashed curves result from using different sets of nucleon-nucleon amplitudes. The arrows denote the positions of the diffractive minima in the experimental ${}^{40}\text{Ca}$ angular distribution of Fig. 1.

Fig. 5.

Neutron isotopic density differences for ^{42}Ca - ^{40}Ca , ^{44}Ca - ^{40}Ca , and ^{48}Ca - ^{40}Ca deduced from the LMT analysis (cross-hatched regions) and predicted by Hartree-Fock (density-matrix-expansion) theory.

Fig. 6.

Neutron isotopic density differences for ^{42}Ca - ^{40}Ca , ^{44}Ca - ^{40}Ca , and ^{48}Ca - ^{40}Ca deduced from the KMT analysis (cross-hatched regions) and predicted by Hartree-Fock (density-matrix-expansion) theory.

Large-Angle Proton Scattering from $^{12,13}\text{C}$

(Exp. 354)

(Univ. of South Carolina, New Mexico State Univ.,
Univ. of Texas, Los Alamos National Laboratory)

Spokesman: G. S. Blanpied (Univ. of South Carolina)

The data obtained in this experiment consist of elastic and inelastic scattering of 0.8-GeV protons from ^{12}C , ^{13}C , and ^{14}N , all of which have been analyzed and tabulated.* Theoretical analyses of the ^{12}C data are complete and have been submitted to Phys. Rev. C.¹

The angular distributions for $p + ^{12}\text{C}$ were measured out to a momentum transfer, $q = 7.1 \text{ fm}^{-1}$ ($\theta_{\text{lab}} = 60^\circ$). At this q , the elastic cross section for ^{12}C is $\sim 0.02 \text{ nb/sr}$. The data have been analyzed using the distorted wave Born approximations (DWBA) and coupled-channels (CC) formalism. The multipole moments extracted from the optical potentials are found to be in good agreement with those of the charge densities as obtained from electron scattering.

The data obtained using the HRS had an energy resolution of about 100 keV for small θ , but increased to 650 keV at the largest angle. The overall experimental angular resolution ($\Delta\theta$) was determined to be $\leq 1.6 \text{ mr}$, FWHM, from the observed energy resolution for $p + p$ scattering, since, for this case, the resolution is dominated by the kinematic term $(dE/d\theta)\Delta\theta$. For example, at a lab angle of 15° , $dE/d\theta = 9.4 \text{ MeV/deg}$ while ΔE measured was 840 keV. Data were also acquired on ^{208}Pb and compared with the data of Hoffmann *et al.*² The absolute scattering angle for their data was determined to $\pm 0.02^\circ$. From this comparison, the absolute angle for the ^{12}C data should be known to $\pm 0.05^\circ$.

Clear particle identification is very important in the measurement of small cross sections, as in this experiment. The fraction of protons to the total number of events was found to be about 0.3 at 30° , 0.1 at 40° , and 0.01 at 55°_{lab} . The overall wire chamber efficiency was

85-95% for all runs. The instantaneous singles rates (due mainly to room background) in the scintillators were held to $< 0.5 \times 10^6 \text{ s}^{-1}$. This limited the proton beam to $\leq 40 \text{ nA}$ on target. The data acquired at the larger angles required runs of up to 24 h. The proton angular distributions over the entire angular range previously reported³ were extended to larger angles. The new data shown in Figs. 1 and 2 cover the range from 3.9 - 67.2° c.m.

Additional relative measurements of $p + p$ scattering using a CH target were made at angles of 15° , 20° , 25° , and 30° (lab), and compared with the data of Willard *et al.*⁴ As previously discussed,³ their point at 15° is believed to be low. When the other three points are used to compute an absolute normalization of the $p + p$ cross sections, we find agreement within $\pm 4\%$, except for the 15° point which is 6% larger than their point. When the new cross sections for elastic scattering from ^{12}C are then normalized and compared with the data of Ref. 3, which were also normalized in this manner, we find agreement to 2% in the region of the first two maxima located at ~ 17 and 29° c.m.

The small-angle data can be compared with that of Wriekat *et al.*⁵ which were measured with small absolute error over the angular range 0.5 to 3.7° c.m. The ratio of the data from this experiment matched to the extrapolation of their data is 0.97 ± 0.1 . Some of their elastic data from 1.7 to 3.7° , rebinned into larger angular steps, are shown as triangles in Fig. 1. When the ^{208}Pb cross sections obtained here are compared with those of Ref. 2 (absolute error $\pm 5\%$), one finds a ratio of 1.05 ± 0.05 .

The results of CC calculations, using JUPITER⁶ for the 0^+ , 2^+ , and 4^+ states, assuming the strict rotational model, are shown in Fig. 1. The importance of both the deformation of the optical potential and the two-step transition via the 2^+ state to the calculated 4^+ inelastic angular distribution is discussed in Ref. 7.

The comparison of the extracted multipole moments of the dominant imaginary part of the 0.8-GeV optical potential with the moments from other measurements^{8,9} and from theory¹⁰ are summarized in Table I.

The curves shown in Fig. 2 for the $(0^+, 7.655)$ and $(3^-, 9.64)$ states are the result of DWBA calculations.

*Tabulated data are available from G. S. Blanpied, Department of Physics, University of South Carolina, Columbia, South Carolina 29208.

Fig. 1.

Angular distributions for excitation of the 0^+ , 2^+ , and 4^+ ground-state rotational band in ^{12}C . Coupled-channels predictions are shown as solid curves.

Fig. 2.

Angular distributions for the $(0^+, 7.655)$ and $(3^-, 9.64)$ states in ^{12}C . The solid curves are DWBA predictions.

TABLE I

OPTICAL-POTENTIAL AND CHARGE-DENSITY MULTIPOLE MOMENTS
FOR ^{12}C IN $\text{eb}^{\lambda/2}$

M(E2)	$\Delta(2)^a$	M(E4)	$\Delta(4)^a$	Reaction	Reference
-0.0552	---	+0.0019	---	0.8-GeV (p,p')	This work
-0.0536 ^b	3%	+0.0017	11%	1.0-GeV (p,p')	9 ^c
-0.0634 ^b	15%	+0.0022	16%	(e,e')	10
-0.686 ^b	24%	+0.0029	53%	Theory, Hartree-Fock	11 ^d

^a $\Delta(\lambda) = \{|M(E\lambda) - M(E\lambda \text{ at } 800 \text{ MeV})|/M(E\lambda \text{ at } 800 \text{ MeV})\} \times 100\%$.

^bCalculated from $Q_0 = (16\pi/5)^{1/2} M(E2)$.

^cGlauber formalism.

^dDoes not reproduce the known root-mean-square (rms) charge radius of ^{12}C .

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Large-Angle $\bar{p} + {}^{208}\text{Pb}$ Elastic Scattering at 800 MeV (Exp. 355)

(Univ. of Texas at Austin, Los Alamos National Laboratory, Univ. of California at Los Angeles, Rutgers Univ., Univ. of South Carolina)
 Spokesman: G. W. Hoffmann (Univ. of Texas at Austin)

The 800-MeV $\bar{p} + {}^{208}\text{Pb}$ elastic differential cross-section data and the results of theoretical analysis have appeared in the literature.¹ The analogous analyzing-power data, $A_y(\theta)$, are shown in Fig. 1. The older $A_y(\theta)$ data² extend to about 20° c.m., while the new data,

besides being of better statistical quality, extend to about 31° and contain three additional oscillations.

Obtaining these larger-angle data was deemed necessary in order to help determine the reason for the breakdown² of the Kerman-McManus-Thaler (KMT) optical-model fits to the older data set. Difficulties existed in fitting $A_y(\theta)$ for target nuclei from ${}^{12}\text{C}$ to ${}^{208}\text{Pb}$ at around 20°; the predictions were always too large, and the slope of the analyzing powers was predicted to continue to rise while experimentally, even at 20°, it appeared that this slope was tending to become constant.

Analysis of the new data is in progress and will be reported in the next progress report.

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Fig. 1.
 Analyzing power, $A_y(\theta)$, for $\bar{p} + {}^{208}\text{Pb}$ at 800 MeV.

Forward-Angle Quasi-Free Proton-Neutron Analyzing Powers at 0.8 GeV (Exp. 385)

(Univ. of Texas at Austin, Los Alamos National Laboratory)

Spokesman: G. W. Hoffmann (Univ. of Texas at Austin)

As the first step in determining the nucleon-nucleon scattering amplitudes at small momentum transfers at 0.8 GeV, quasi-free $\bar{p} + n$ and $\bar{p} + p$ analyzing powers were obtained at laboratory scattering angles from 6 to 32.9° by scattering 800-MeV polarized protons from a liquid deuterium target. Forward-scattered protons were detected with the HRS, while recoil neutrons and protons were detected in coincidence by a 5 by 5 array of scintillators. A thin scintillator placed between the target and the array enabled discrimination of recoil particle type and facilitated the simultaneous measurement of both $\bar{p}p$ and $\bar{p}n$ analyzing powers. The results of the experiment are shown in Fig. 1 along with data obtained elsewhere.¹⁻³ The open circles for $\bar{p}p$ correspond to free $\bar{p} + p$ scattering, while the open circles for $\bar{p}n$ correspond to free $n + \bar{p}$ scattering. A comparison of the different

types of data shown in Fig. 1 suggests agreement between free and quasi-free results, which is expected since the final-state interaction should be weak at the energies involved. Arndt's phase-shift code has provided new pn amplitudes that are consistent with the new data. However, when these amplitudes are used in Kerman-McManus-Thaler (KMT) calculations, the absolute test of KMT on $p + {}^{40}\text{Ca}$ elastic scattering at 0.8 GeV "fails" in that the neutron-proton root-mean-square (rms) radius difference is found to be about -0.2 fm, in contrast to the universal result of -0.04 ± 0.01 fm predicted by all Hartree-Fock, shell-model, and other theoretical predictions. The results indicate that further nucleon-nucleon measurements are necessary in order to unambiguously determine the nucleon-nucleon amplitudes at 800 MeV.

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Fig. 1.

A comparison of the quasi-free analyzing powers obtained by Exp. 385 with previous free analyzing-power measurements.

The Reactive Content of the Optical Potential (Exp. 470)

(Univ. of Texas at Austin, Los Alamos National Laboratory, Brookhaven National Laboratory, Univ. of Maryland, Vassar)

Spokesmen: M. Barlett (Los Alamos National Laboratory), and G. W. Hoffmann (Univ. of Texas at Austin)

The purpose of Exp. 470 was to see how much of the p-nucleus total reaction cross section could be accounted for by the inclusive (p,p') cross section. The experiment was run last year and the data have been replayed and reduced to almost final form. Experiment 470 was deemed necessary in order to provide experimental data to support the assumption, implicit in all popular multiple-scattering theories, of the validity of using free nucleon-nucleon scattering amplitudes to describe p-

nucleus scattering — i.e., the impulse approximation. If the impulse approximation is valid at 800 MeV, then the p-nucleus total reaction cross section must evolve essentially from the two-nucleon quasi-elastic (e.g., $(p,2p)$ or (p,pn) and quasi-elastic delta-production $(p,N\Delta)$) doorways; only those processes which can happen between two free nucleons can lead to the p-nucleus total reaction cross section.

Shown in Fig. 1 are some of the 800-MeV ${}^1\text{H}(p,p')$ data obtained in Exp. 470. These data extend from pion production threshold to outgoing proton laboratory momenta of 350 MeV/c and represent the experimental single-arm signature of the proton + proton initiated processes. Shown in Fig. 2 are the experimental data for ${}^2\text{H}(p,p')$. A comparison of Figs. 1 and 2 indicates the same shapes for the inclusive spectra at angles between 5 and 20° and serves to indicate that the signature of the

Fig. 1.

${}^1\text{H}(p,p')$ inclusive spectra between 5 and 20°.

Fig. 2.

${}^2\text{H}(p,p')$ inclusive spectra between 5 and 20°.

Fig. 3.

$^{12}\text{C}(p,p')$ inclusive spectra between 5 and 20°.

Fig. 4.

$^{40}\text{Ca}(p,p')$ inclusive spectra between 5 and 20°.

proton + neutron initiated processes is the same as that for the proton + proton processes.

Figures 3 and 4 show some of the results for ^{12}C and ^{40}Ca . Surprisingly, the ^{12}C and ^{40}Ca data are very similar in shape to the ^1H and ^2H data and graphically suggest

that the nucleon-knockout and delta-production processes account for the observed data. Angle-integrated cross sections for ^{12}C and ^{40}Ca are given in Table I. Note that these cross sections account for over

TABLE I

ANGLE-INTEGRATED CROSS SECTIONS FOR 800-MeV $p + ^{12}\text{C}, ^{40}\text{Ca}$

Nucleus	Quasi-Elastic (mb)	Δ -Production (mb)	Sum (mb)	Reaction Cross Section ^a (mb)	Reaction Cross Section (%)
^{12}C	109	135	244	269	91
^{40}Ca	259	321	580	615	94

^aKMT prediction (the ^{12}C result agrees to a few percent with that obtained from Exp. 386).

90% of the total 800-MeV $p + {}^{12}\text{C}, {}^{40}\text{Ca}$ reaction cross sections.

Recent theoretical work¹ also supports our "empirical" conclusions. If we look for details in the inclusive spectra, we note the suggestion at forward angles of two distinct peaks in the region corresponding to pion production. These peaks appear to be of different widths, with the narrow peak (width ~ 150 MeV/c) about 350 MeV/c away from the quasi-elastic peak, while the second, broader peak (width ~ 700 MeV/c) is located about 600 MeV/c away from the quasi-elastic peak.

Figure 1 of Ref. 1 shows that in the isobar production model two diagrams contribute to pion production. One diagram leads to the "recoil" proton being detected in the experiment, while the other diagram leads to the "decay" proton being detected. The first diagram is expected, from kinematics, to produce a sharp and forward-angle proton (p') momentum spectrum, in contrast to what is expected from the other diagram. Further, simple calculations indicate that the first diagram contributes about 18% of the (p, p') total reaction cross section, whereas the other diagram contributes 82%. These statements are in qualitative agreement with the data shown here (Figs. 1-4).

Thus, we have semiquantitative experimental and theoretical evidence that quasi-elastic processes do explain 800-MeV p -nucleus reaction cross sections.

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The Analyzing Power for $p + {}^{24,26}\text{Mg}$ at 800 MeV (Exp. 476)
(Univ. of South Carolina, Univ. of Texas at Austin, Rutgers Univ., Univ. of Minnesota, New Mexico State Univ., Los Alamos National Laboratory)
Spokesman: G. S. Blanpied (Univ. of South Carolina)

This experiment consisted of scattering 0.8-GeV polarized protons from ${}^{24,26}\text{Mg}$. About half of the data for this experiment have been acquired (July 1980). These measurements complement those of Exp. 178 in which unpolarized angular distributions were measured. On-line measurements ($\sim 20\%$ of the taped events) for the elastic analyzing powers are given in Fig. 1. While most of the states in ${}^{24}\text{Mg}$ up to about 10 MeV can be grouped into rotational bands, the members of the different bands in ${}^{26}\text{Mg}$ are less certain. Seven 4^+ states and several 3^- states in ${}^{26}\text{Mg}$ have been observed in the unpolarized measurements.

Fig. 1.
Elastic analyzing powers for 0.8-GeV $p + {}^{24,26}\text{Mg}$ from 5.1 to 25.5°.

Measurement of the Spin-Rotation Parameter "Q" in Scattering of 0.5-GeV Polarized Protons From ^{40}Ca (Exp. 479)

(Univ. of California at Los Angeles, Univ. of Texas, Univ. of Minnesota, Rutgers University, Los Alamos National Laboratory)

Spokesman: G. J. Igo (Univ. of California, Los Angeles)

In the first experiment to use the HRS focal-plane polarimeter, the triple-scattering parameters R , A , R' , and A' were measured for the ground-state, the 3^- (3.74-MeV), and the 4^- (4.49-MeV) states of ^{40}Ca . The experiment used 497-MeV protons, polarized in the $\pm S$ and $\pm L$ directions (S : transverse, horizontal; L : longitudinal). Data were taken at scattering angles between 5° and 20° in the laboratory frame.

A and R (or A' and R') can be combined to form^{1,2*} $Q = A \cos \theta + R \sin \theta$ (θ = scattering angle). Figure 1

shows preliminary results from this experiment. For elastic scattering, Q , together with earlier measurements of the scattering cross section, $d\sigma/d\Omega$, and the analyzing power, A_y (Ref. 3), yield (except for a phase factor) complete information on the scattering amplitude of the reaction.² The data, which will be analyzed in the Glauber formalism, will considerably reduce the uncertainties in the knowledge of the neutron-density distribution of the nucleus.⁴

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*Figure 1 shows preliminary results from the experiment.

Fig. 1.
The quantity "Q" for elastic scattering of 497-MeV protons on ^{40}Ca .

Inelastic Proton Scattering at 800 MeV to the ^{12}C 15.11-MeV State: A Search for Nuclear Critical Opalescence (Exp. 486)

(Univ. of California at Los Angeles, Rutgers Univ., Los Alamos National Laboratory, Univ. of Minnesota)

Spokesmen: G. J. Igo (Univ. of California, Los Angeles), C. Glashauser (Rutgers Univ.), and J. M. Moss (Los Alamos National Laboratory)

The angular distributions for $^{12}\text{C}(p,p')^{12}\text{C}$ to the states (12.71 MeV, 1^+ , $T=0$), (15.11 MeV, 1^+ , $T=1$), (16.1 MeV, 2^+ , $T=1$), and (16.58 MeV, 2^+ , $T=1$) have been measured at 800 MeV for laboratory angles ranging between 6.5 and 18.5°. Theoretical analysis has thus far been completed for the 15.11-MeV state, and the calculations for the other states are in progress.

Cross sections were measured in HRS at LAMPF. The energy range of the HRS was confined to excitation energies from about 7 to 17 MeV by adding an extra scintillator to the event trigger. Included in this range are the 7.65- and 9.64-MeV states of ^{12}C , which by comparison with previous data of Blanpied *et al.*¹ provided the absolute normalization at each angle. The target was a strip of natural graphite, 50 mg/cm² thick, and narrow enough to improve the energy resolution by intercepting only about 25% of the incident beam in the dispersion

direction. The overall energy resolution varied between 110 and 160 keV as the kinematic contribution increased to about 100 keV at the largest angle.

An energy spectrum at a laboratory angle of 13.95° is shown in Fig. 1. This corresponds to a momentum transfer of 1.8 fm⁻¹, where the maximum cross section has been predicted if critical opalescence occurs.² The insert shows the region around 15 MeV of the excitation on an expanded scale with a computer fit to the 15.11-MeV state. The 15.11-MeV state is only weakly excited, with a cross section somewhat smaller than the cross section for the 12.71-MeV, 1^+ , $T=0$ state, which is not expected to be enhanced.

The angular distribution for the 15.11-MeV state over the region from 3 to 22° (c.m.) is plotted in Fig. 2. Forward-angle data are taken from Ref. 3. Although there is a hint of a shoulder around 1.6 fm⁻¹, there is certainly no pronounced maximum in this region. In Fig. 2, the solid and dashed curves show Glauber-model calculations by Toki and Weise (Ref. 2) with ($g'=0.5$) and without nuclear critical-opalescence effects, respectively. The third curve in Fig. 2 is probably a better estimate of the scattering with pure Cohen-Kurath (CK) wave functions. This is a distorted wave impulse approximation (DWIA) calculation using a two-body force determined by Franey and Love⁴ on the basis of the Arndt phase shift. Thus, independent of theoretical

Fig. 1.

Energy spectrum of the $^{12}\text{C}(p,p')^{12}\text{C}$ reaction at 800 MeV taken at a laboratory angle of 13.95°. The insert shows the excitation energy region around 15 MeV on an expanded scale. The solid line is a computer fit to these data.

Fig. 2.

Experimental angular distributions and theoretical calculations for the $^{12}\text{C}(p,p')^{12}\text{C}$ reaction to the 15-MeV state. The solid and dashed curves show Glauber-model calculations by Toki and Weise (Ref. 2) with ($g' = 0.5$) and without nuclear critical-opalescence effects, respectively. The dash-dot curve is a distorted wave impulse approximation (DWIA) calculation without opalescence effects.

calculations, the absence of a secondary maximum at large angles shows that no large precursor effects are present for this state with 800-MeV protons.

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Pion-Induced Double Charge Exchange on Helium Isotopes (Exp. 74)

(Oregon State Univ., Univ. of Oregon, Univ. of Virginia, Lawrence Berkeley Laboratory, Univ. of California at Los Angeles, Los Alamos National Laboratory)

Spokesmen: V. Perez-Mendez (Lawrence Berkeley Laboratory) and A. Stetz (Oregon State Univ.)

We have measured the double differential cross section, $d\sigma/d\Omega dT$, for the double-charge-exchange reactions $^3\text{He}(\pi^-, \pi^+)3n$, $^4\text{He}(\pi^-, \pi^+)4n$, and $^4\text{He}(\pi^+, \pi^-)4p$. Data were taken at three incident pion energies — 140, 200, and 295 MeV — and at a range of scattering angles. The EPICS spectrometer facility was used with its scattering stand modified to accommodate the University of Virginia's cryogenic ^3He - ^4He target. The experiment was run for 350 h during Cycle 24.

Our aim in the experiment was to provide a reliable data set for comparison with recent theoretical models of double charge exchange (DCX), as well as to settle an old question regarding the existence of a resonance near threshold in the three-neutron system.

One feature that has clearly emerged from our data is that the differential cross section for $^4\text{He}(\pi^-, \pi^+)$ measured at Berkeley¹ during the 1960s is too low by a factor of 10^2 ! These anomalous results, which made the ^4He DCX cross section appear enormously suppressed relative to that of ^3He , have, over the last 10 years, frustrated theoretical attempts to explain double charge exchange in terms of some underlying reaction mechanism.

Our data, samples of which are shown in Figs. 1 and 2, span the region of the 3-3 resonance. Two sets of calculations have been carried out for the reaction $^4\text{He}(\pi^-, \pi^+)$ in this region: one by Germond and Wilkin² assumes that double charge exchange arises from scattering from pion exchange currents, and the other by the Los Alamos theory group³ assumes that double charge

Fig. 1.

The three-neutron missing mass at an incident π^- energy of 140 MeV and a laboratory scattering angle of 30° .

Fig. 2.

The four-neutron missing mass at an incident π^- energy of 295 MeV and a laboratory scattering angle of 30° .

exchange comes from two separate pion-nucleon single-charge-exchange events. The two theories predict widely different cross sections, which can be systematically compared with our data.

An important feature of the DCX experiments done during the 1960s was a prominent peak near threshold in the energy spectrum for $^3\text{He}(\pi^-, \pi^+)$ at 140 MeV (see Fig. 1), and only at small forward-scattering angles. Moreover, the enhancement does not yield consistent values for either the position or the width of the putative resonance.⁴ Our tentative conclusion is that these enhancements are due to reaction mechanism effects, but of course the possibility that a small resonant amplitude might still be present cannot be ruled out.

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Pion Scattering From $^3,^4\text{He}$ (Exp. 87)

(Univ. of Virginia, Los Alamos National Laboratory, Oregon State Univ., Univ. of California at Los Angeles)

Spokesman: J. S. McCarthy (Univ. of Virginia)

Most of the data from this EPICS experiment have been analyzed since the previous LAMPF progress report.

The $\pi^\pm$ elastic scattering was measured at $T_\pi = 50, 100, 200,$ and 295 MeV, covering the angular range $20-120^\circ$, while partial angular distributions were obtained at 260 and 310 MeV. The high-energy data ($T_\pi > 200$ MeV) have been published¹ and the rest will be published soon. Data were also obtained for quasi-free $\pi + N$ scattering at $100, 200,$ and 295 MeV at $\theta = 120^\circ$, and at 200 MeV at 60° .

We also have data for $^3,^4\text{He}(\pi^+, p)X$, recorded at incident energy intervals of 50 MeV, between 50 and 295 MeV at $\theta = 20^\circ$ (see Fig. 1.) We find enhancements in these spectra due to quasi-free proton knockout reactions and pion absorption on a quasi-free nucleon pair; $\pi NN \rightarrow Np$ results have already been published,² and the $\pi^- pp \rightarrow pn$ results will soon be published. One interesting result of (π^-, p) is the ratio between the (π^-, p) to (π^+, p) yields. At 200 MeV, for instance, the observed ratio is $1:20$ and $1:30$ for ^3He and ^4He . The isobar model

Fig. 1.

Number of counts vs outgoing proton momentum for an incident pion energy of 200 MeV.

for $\pi NN \rightarrow Np$ (i.e., the sequential process $\pi + N_1 \rightarrow \Delta$ and $\Delta + N_2 \rightarrow Np$) predicts 1:10 and 1:20. Another finding is that (π^-, p) is smaller for ${}^3\text{He}$ than for ${}^4\text{He}$.

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Inelastic Pion Scattering From Light Nuclei: ${}^{10}\text{B}$, ${}^{11}\text{B}$, ${}^{14}\text{N}$ (Exp. 389)

(Argonne National Laboratory, Los Alamos National Laboratory, Indiana Univ., New Mexico State Univ., Northwestern Univ., Oregon State Univ., Univ. of South Carolina, Univ. of Birmingham)

Spokesmen: G. C. Morrison (Univ. of Birmingham) and B. Zeidman, (Argonne National Laboratory)

Angular distributions for both π^+ and π^- scattering by ${}^{10}\text{B}$, ${}^{11}\text{B}$, and ${}^{14}\text{N}$ have been obtained for an incident pion kinetic energy of 162 MeV, approximately the (3,3) resonance energy in nuclei. The basic aim of the experiment is to investigate nuclear structure in light nuclei where the wave functions for low-lying states are reasonably well known and comparisons between experi-

ment and theory are relatively direct. These comparisons can then be used to extract new structure information for higher lying states that involve excitation of particles into higher shell-model orbitals, i.e., the 2s-1d shell.

The data for ${}^{14}\text{N}$ have been analyzed and have yielded some unexpected results. In particular, at large angles the strongest peak in the spectra corresponds to a hitherto unidentified state at about 14.7-MeV excitation. From the magnitude of the cross section, together with theoretical calculations, we propose that $5^-, T=0$ be assigned to this state, so that this is the yrast 5^- . Other 5^- states at higher excitations are also present. All of these states arise from $1p_{3/2}^{-1}1d_{5/2}$ configurations coupled to 4^- , the stretched configuration, which then couples to the 1^+ ground-state spin and parity. In the region above 16-MeV excitation, sizable differences between π^+ and π^- data are observed. For a $T=0$ nucleus such as ${}^{14}\text{N}$, these differences must arise from isospin mixing. Additional analysis is under way in an effort to extract as complete information as possible. This effort has been hindered by statistical errors that arise from the need to subtract contributions from carbon and hydrogen which are present in the melamine ($\text{C}_3\text{H}_6\text{N}_6$) target.

Data for π^+ and π^- scattering by ${}^{10}\text{B}$ and ${}^{11}\text{B}$ were obtained during Cycle 28, so that there has been no opportunity to analyze the data. During data acquisition, however, several salient features were apparent. In ${}^{10}\text{B}$, excitation of the $0^+, T=1$ state at 1.74 MeV was observed. Formation of this state required both spin- and isospin-flip, so that the predicted cross section was $<10 \mu\text{b/sr}$ at its maximum. In ${}^{11}\text{B}$, substantial differences between the spectra for π^+ and π^- scattering at the same angle are observed, as can be seen from Fig. 1. In particular, excitation of the $11/2^+$ state at 14.04 MeV is constrained to be a pure neutron excitation if the simplest model of ${}^{11}\text{B}$ is considered. In Fig. 1, no evidence for this broad (~ 400 -keV-wide) state is observed in the π^+ data, whereas it is prominent in the π^- spectrum. A similar π^- enhancement is seen for the $9/2^+$ state at ~ 11.3 MeV and also, possibly, the $7/2^+$ at ~ 9.2 MeV. Although the excitation of the $11/2^+$ state must be M4, transitions to the lower spin positive-parity states involve both magnetic and electric components. Completed calculations for the negative-parity states predict large π^+/π^- differences, as are seen in the data.

Fig. 1.

Excitation energy spectra for 162-MeV π^+ and π^- incident on ^{11}B at a laboratory angle of 70° .

Elastic and Inelastic π^+, π^- Scattering on ^7Li
(Exp. 391)
(Univ. of Colorado, Los Alamos National Laboratory)
Spokesman: R. J. Peterson (Univ. of Colorado)

Data were taken in February 1980 on the ^7Li ($\pi^\pm, \pi^\pm$) reaction at 143 MeV using the EPICS facility. The angular range of 22 to 120° was covered with good statistics for the ground, 0.478-, 4.630-, and 6.68-MeV states, and with usable data on the states at 7.456 and 9.67 MeV.

Two ^7Li targets were used: a thin target (90 mg/cm^2) for the small angles, and a thicker (251 mg/cm^2) target for the larger angles. Cross sections for the elastic scattering of $\pi^\pm$ on ^2H and ^1H were measured at a number of angles during the experiment as a means of normalizing the data. The ^7Li experiment directly followed the $\pi^\pm + ^2\text{H}$ experiment, where careful procedures for normalizing the data to $\pi^\pm + ^1\text{H}$ cross sections were worked out. This is discussed elsewhere in this progress report (Exp. 478).

The magnetic tapes for the ^7Li experiment have all been played back with a 3° acceptance angle chosen in the reaction plane, and cross sections obtained. Figure 1 shows a π^+ spectrum at a lab angle of 100° . The 0.478-MeV state is seen to be clearly resolved from the ground

Fig. 1.

Inelastic π^+ spectrum at a scattering angle of 100° and 143 MeV.

state. The elastic angular distributions are shown in Figs. 2 and 3 for π^+ and π^- , respectively. The optical-model codes in use, such as DUMIT,¹ do not include contribu-

tions from the quadrupole interaction. Since the ground state of ${}^7\text{Li}$ has a spin of $3/2$, it is necessary to correct the elastic cross sections for the contribution of the

Fig. 2.

The elastic angular distributions for π^+ scattered from ${}^7\text{Li}$. The data in the lower part of the figure had the first excited-state cross sections subtracted. The solid line is an optical-model calculation as described in the text.

Fig. 3.

The elastic angular distributions for π^- scattered from ${}^7\text{Li}$. The data in the lower part of the figure had the first excited-state cross sections subtracted. The solid line is an optical-model calculation as described in the text.

quadrupole interaction. The nearby 0.478-MeV state would be expected to be excited primarily by the quadrupole interaction, and calculations have shown that it would be a reasonable approximation to use the cross section for the excitation of that state as a close estimate of the contribution of the quadrupole interaction. In the bottom half of Figs. 2 and 3, the elastic cross sections are

Fig. 4.

Inelastic cross sections for the excitation of the 0.478-MeV state by 143-MeV π^- and π^+ .

shown with the cross section for the 0.478-MeV state (see Fig. 4) subtracted. A variety of optical-model calculations were carried out to try to obtain an adequate description of this corrected elastic data. The LOFIT² π -N phase shifts were finally used, with the s- and p-wave absorption from the thesis of Rosenthal,³ the Pauli blocking value from Thies,⁴ and the Lorentz-Lorenz parameter set equal to 1. It was found that the second-order terms that went as ρ^2 ($\rho \equiv$ nuclear density) had very little effect on the calculated cross section. The proton density distribution was taken from electron elastic-scattering measurements. It was in the form given by a modified harmonic oscillator with parameters $a = 1.77$ and $\alpha = 0.327$. This corresponds to a root-mean-square (rms) charge radius of 2.39 fm for ${}^7\text{Li}$. The DUMIT program was modified so that a search could be performed for the best values of a and α for the neutron distribution to give a minimum χ^2 for the ratio of π^- to π^+ . The data and the resulting optical-potential fit to the ratio are shown in Fig. 5. While the general shape of the

Fig. 5.

The ratio of the cross sections for π^+ to π^- elastic scattering after the subtraction of the cross sections for the first excited state. The solid line represents the ratio of optical-model calculations with a , the neutron radius, adjusted for a best fit.

Fig. 6.

Inelastic cross sections for the excitation of the 4.63-MeV state by 143-MeV π^- and π^+ .

ratio of angular distributions is obtained, there are detailed differences, particularly at the forward angles. The dashed curves on either side of the solid line represent calculations for neutron radii where the value of χ^2 is 1 greater than the minimum. The value of a for the neutron distribution was determined to be 1.85 ± 0.02 and $\alpha = 0.282$. These correspond to an rms matter radius of 2.60 ± 0.02 fm for the neutrons. The corresponding optical-potential calculations are shown in Figs. 2 and 3 for the individual π^+ and π^- elastic angular distributions. The fact that the calculations in both cases are somewhat below the data has been of some concern.

Fig. 7.

Inelastic cross sections for the excitation of the 6.68-MeV state by 143-MeV π^- and π^+ .

At this time there appears to be no valid reason to question the normalization of the data, and there has been no reasonable variation in any of the optical-model parameters that affects the forward-angle behavior of the calculations to any degree.

Fig. 8.

Inelastic cross sections for the excitation of the 7.47-MeV state by 143-MeV π^- and π^+ .

Figures 4 through 9 show the inelastic angular distributions for the 0.478-, 4.63-, 6.68-, 7.47-, and 9.61-MeV states for both π^- and π^+ . As yet no detailed theoretical calculations have been performed, but some preliminary collective model ($l = 2$ distorted wave Born

Fig. 9.

Inelastic cross sections for the excitation of the 9.61-MeV state by 143-MeV π^- and π^+ .

approximations (DWBA) results obtained using the program CHOPIN and the potentials previously discussed are shown as the solid lines in the various figures. The deformation parameters, β_2 , were extracted from these calculations for the first four states, and these are shown in Table I. The values of β_2 are consistently larger for π^- than for π^+ scattering. The calculations were

TABLE I

DEFORMATION PARAMETERS, β_2 , FOR THE EXCITATION OF THE EXCITED STATES OF ${}^7\text{Li}$ USING 143-MeV π^+ AND π^-

E_x	J^π	π^-	π^+
0.478	$1/2^-$	1.26 ± 0.17	1.21 ± 0.15
4.63	$7/2^-$	1.05 ± 0.23	0.95 ± 0.17
6.68	$5/2^-$	0.49 ± 0.09	0.48 ± 0.08
7.46	$5/2^-$	0.27 ± 0.05	0.21 ± 0.05

repeated using coupled channels, and the effects on either the shapes of the angular distributions or the values of β_2 were quite small.

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Study of the Inclusive Double-Charge-Exchange Reaction (Exp. 442)
(Univ. of Virginia, Los Alamos National Laboratory)
Spokesman: J. Källne (Univ. of Virginia)

Using EPICS, we have measured (π^+, π^-) and (π^-, π^+) spectra for ${}^{12,13}\text{C}$, ${}^{40,44,48}\text{Ca}$, ${}^{52}\text{Cr}$, and ${}^{56}\text{Fe}$ targets bombarded with pions of energies between 175 and 310 MeV. The charge-exchanged pions were generally detected at $\theta = 20, 70$, and 116° . In several spectrometer settings we could scan the exit particle spectrum down to about $P_\pi = 120$ MeV/c or $T_\pi \approx 50$ MeV. An example of such a spectrum is shown in Fig. 1. With these data we hope to shed some light on the reaction mechanism of the double-charge-exchange reaction and examine to what extent the (π^+, π^-) and (π^-, π^+) reflect the variation in N and Z of the target nuclei.

Fig. 1.

Double differential cross sections composed from several spectrometer settings and an incident pion energy of 295 MeV.

$\pi^\pm\text{D}$ Comparison at 143 MeV (Exp. 478)
(Los Alamos National Laboratory, Univ. of Colorado)
Spokesman: T. G. Masterson (Univ. of Colorado)

Charge symmetry implies that the nuclear interaction should be unchanged by the inversion of the T_3 component of the isospin of every part of the system. Thus the n-n and p-p nuclear interactions should be identical. This classical example is plagued by a Coulomb correction of more than a factor of 2, which changes the p-p scattering length from -7.8 to -17.2 fm. The comparison n-n system is still unavailable to the experimenter and must be deduced from n-D scattering, resulting in a large experimental error (16.1 ± 1.0 fm).

The intermediate-energy πD system minimizes these problems. The inversion of the T_3 component of the isospin of the $\pi^+\text{D}$ system gives the $\pi^-\text{D}$ system, and both are experimentally available. The Coulomb corrections are small ($\approx 2\%$). A $\pi^\pm\text{D}$ comparison provides a direct test of charge symmetry.

Fig. 1.

The π^+D differential cross section at 143 MeV. The 0 and 180° data points are from Refs. 1 and 3, respectively. The three-body calculation is from Ref. 7 and includes all πN s- and p-wave channels.

Fig. 2.

The π^-D differential cross section at 143 MeV. The 0 and 180° data points are from Refs. 1 and 6, respectively.

A comparison¹ of the total cross sections for $\pi^\pm D$ has indicated possible charge-symmetry violations at the several-percent level even after electromagnetic corrections.² If this effect occurred entirely in the elastic channel, the effect would be enhanced by the ratio of the total to the elastic cross sections (183 mb/47 mb) and would be seen as a 10-25% difference between π^+D and π^-D differential cross sections.

This experiment was carried out on EPICS to look for possible violations of charge symmetry and to obtain the first π^-D differential cross sections. The target was 194-mg/cm² CD₂. Background subtraction was made with a 131.5-mg/cm² carbon target, while a 152.7-mg/cm² CH₂ target provided a reference to the πp cross sections.³ The π^+ and π^- cross sections were measured sequentially at each angle.

The measured π^+D and π^-D differential cross sections are shown in Figs. 1 and 2. The angles at which forward-angle data were measured were selected to minimize interference from inelastic scattering from ¹²C. The resolution of EPICS was a crucial factor in allowing us to do this. The angles were also selected to match those at which Bussey *et al.*³ have measured the π^+p differential cross section. This gave us two independent reference cross sections: (1) the experimental πp data, and (2) the theoretical calculations of the πp differential cross section. Three different sets of theoretical πp cross sections

were available to us: the Dodder⁴, SCATPI⁵, and CROSS phase-shift codes. For most angles these codes agreed with each other and with the Bussey data to within $\pm 2\%$. We used the reference cross section calculated from the CROSS computer code. Statistical errors were usually $< 1.5\%$. The 0° points shown in Figs. 1 and 2 are determined from the total cross-section data. The 180° data are from Holt *et al.*⁶ at 140 MeV. Systematic errors associated with μ and e contamination of the pion beam, the absolute pion flux, the spectrometer acceptance, and electronic dead times were minimized by using the πp reference cross section.

The π^+D cross sections agree very well with the three-body Faddeev calculations of Girraud *et al.*⁷ when all s- and p-wave πN channels are included. Their calculations would be identical for both π^+D and π^-D as charge symmetry is assumed. Our π^+D cross sections also agree very well with the preliminary SIN data of Gabathuler *et al.*⁸

The π^-D data shown in Fig. 2 represent the first accurate π^-D measurements between 100 and 300 MeV. The only previous data were the bubble chamber data of Pewitt *et al.*,⁹ which had large angular bins and poor statistics.

The difference between π^-D and π^+D divided by their sum is shown in Fig. 3. This ratio method is a very powerful tool for reducing systematic uncertainties. Effects of chamber inefficiencies and different possible πp

Fig. 3.

The ratio $[\sigma_{\pi^-}(\theta) - \sigma_{\pi^+}(\theta)] / [\sigma_{\pi^-}(\theta) + \sigma_{\pi^+}(\theta)]$ at $T_{\pi} = 143$ MeV. Coulomb connections, which would lower the first three points, have not been included. The use of different $\pi^{\pm}p$ calculations could raise the back two points by as much as 0.02.

phase shifts were also reduced by this procedure. All πp calculations and data ratios agree well in the medium-angle range. A maximum difference occurs at far backward angles where the SCATPI π^-p calculation differs from the CROSS π^-p calculation by enough to raise the last two points by ≈ 0.02 .

No Coulomb corrections have been included in the data shown in Fig. 3. These calculations are in progress and their net effect will be to lower the first three points to about +0.01. The errors shown are statistical and work is continuing to deduce realistic systematic errors.

The median charge-symmetry deviation as shown here corresponds to $\sigma_{e1}(\pi^-) - \sigma_{e1}(\pi^+) = +0.5 \pm 1.0$ mb and is consistent with no violation of charge symmetry. This is to be compared with a difference of approximately -3 ± 2 mb seen in the total cross-section measurements of Pedroni *et al.*¹ The difference in sign of the two measurements puts them outside of each other's uncertainties. There are at present no calculations of the effect on the differential cross section of any of the electromagnetic charge symmetry-violating terms. The effect should,

however, change sign at energies above the resonance, and an experiment at higher energy is part of our continuing investigation of the $\pi^{\pm}D$ system.

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Excitation of High-Spin States in ^{28}Si by Pion Inelastic Scattering (Exp. 481)

(Argonne National Laboratory, Los Alamos National Laboratory, New Mexico State Univ., Northwestern Univ., Oregon State Univ., Univ. of South Carolina, Indiana Univ.)

Spokesman: D. F. Geesaman (Argonne National Laboratory)

The excitation of high-spin particle-hole states in ^{28}Si was studied at $E_{\pi^{\pm}} = 116$ MeV using EPICS. In previous work at $E_{\pi} = 162$ MeV, two 6^{-} states at 11.58 MeV, $T = 0$ and 14.36 MeV, $T = 1$ were observed to be prominent in the inelastic spectra.¹ These states have also been observed in inelastic scattering of other medium-energy probes.^{2,3} The ratio of the cross sections of the two states at 162 MeV,

$$R \equiv \frac{\sigma_{T=0}}{\sigma_{T=1}} = 1.5^{+0.4}_{-0.2} \text{ for } \pi^{+} \text{ scattering}$$

$$= 1.7 \pm 0.4 \text{ for } \pi^{-} \text{ scattering} ,$$

Fig. 1.

Excitation spectrum resulting from 116-MeV π^+ incident on ^{28}Si at a lab angle of 100° .

is significantly lower than the value of 3.6 expected from distorted wave impulse approximation (DWIA) calculations. The measurement of these cross sections at other energies should help determine whether this discrepancy is due to nuclear structure effects or a lack of understanding of the reaction mechanism.

The present experiment consisted of measuring inelastic spectra from a natural silicon target at 65, 80, and 100° with a π^+ beam, and at 90° with a π^- beam. The 100° spectrum is illustrated in Fig. 1. Data analysis is presently under way to extract the inelastic cross sections. Preliminary analysis reveals that the ratio, R , is somewhat larger at 116 MeV than at 162 MeV, but the analysis is complicated by the observation that at the same momentum transfer, more states are strongly populated at 116 MeV than at 162 MeV. In particular, the 14.36-MeV, $6^-, T=1$ state is not resolved from several nearby states.

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Strong Cancellations of Proton and Neutron Transition Amplitudes Observed in Pion Inelastic Scattering from ^{14}C (Exp. 539)

(Univ. of Minnesota, Los Alamos National Laboratory, New Mexico State Univ., Univ. of Texas, Oak Ridge National Laboratory)

Spokesmen: H. W. Baer and D. B. Holtkamp (Los Alamos National Laboratory)

Experiment 539, "Search for Pure Neutron/Proton Transitions in ^{14}C ," has been successfully completed. The data from this experiment have proved to be quite surprising. Large π^+/π^- asymmetries have been observed for numerous states, and these have created much theoretical interest.

Figure 1 shows π^+ and π^- spectra for ^{14}C at a laboratory angle of 66° and an incident pion energy of 164 MeV. Among other states that exhibit asymmetries, there are two states, at 11.67 and 17.23 MeV, that are strongly excited at this momentum transfer. Each of these states appears to be excited by either π^+ or π^- , but weakly, if at all, by the conjugate probe. The π^+/π^- cross-section ratios at 66° , which are near the maximum

Fig. 1.

Inelastic-scattering spectra from ^{14}C at an incident energy of 164 MeV and an angle of 66° .

Fig. 2.

Inelastic-scattering spectra from ^{14}C at an incident energy of 164 MeV and an angle of 42° .

for these states, are 0.06 ± 0.03 and 12.83 ± 4.41 for the 11.67- and the 17.23-MeV states, respectively. Because these states peak at large q (≈ 275 MeV/c), we believe they are high-spin states, probably first observed in pion scattering.

The other surprising result in ^{14}C is shown in Fig. 2. A known state at 8.32-MeV (2_2^+ , $T=1$) is excited by π^+ and not by π^- at 42° , which is near the $\Delta\ell=2$ maximum. Our analysis indicates that the π^+/π^- cross-section ratio at 42° is 33_{-10}^{+20} , with the large errors reflecting the fact that we can determine only an upper limit for the π^- yield for this state. The ratio is surprising because it seems to be the first example of a π^+/π^- ratio in excess of the free π -N (pion-nucleon) ratio of 9:1. To

understand this we make use of the simple impulse approximation result that $\sigma(\pi^+) \propto (3 \cdot A_\pi + A_v)^2$ and $\sigma(\pi^-) \propto (A_\pi + 3 \cdot A_v)^2$, where $A_\pi(A_v)$ is the proton (neutron) component of the transition amplitude. For $\sigma(\pi^-)$ to be zero [or at least $\ll \sigma(\pi^+)$] as observed for the 2_2^+ state, it is required that $A_v = -1/3 A_\pi$.

Study of (π^-,n) Reactions in ^3He and $^3\text{He}(\pi^-, \pi^0)t$ (Exp. 248)

(Univ. of Virginia, Los Alamos National Laboratory, College of William and Mary)

Spokesman: Jan Källne

We have measured spectra of charged particles from pion reactions in ^3He . The experiment was done with the p^3 beam, and the ejected protons, deuterons, and tritons were measured with a detector of plastic scintillators and wire chambers. We used liquid targets of ^3He and ^4He , which were kept in a cryostat operated at superfluid temperatures.

So far we have analyzed the data for the two-body reactions $\pi^- + ^3\text{He} \rightarrow d + n$ and $\pi^- + ^4\text{He} \rightarrow t + n$, which were measured at $T_\pi = 285, 428, 525$, and 575 MeV. The differential cross-section results are shown in Fig. 1, where comparison is made with calculations of Fearing.¹ These calculations are based on a two-nucleon reaction mechanism in which the pion is assumed to be absorbed by a quasi-deuteron in the target nucleus. It is interesting to observe that the prediction falls below the data, and gradually more so the higher the incident energy — i.e., the renormalization factors needed increase with energy. By comparison with (π^-,n) data from a previous EPICS experiment,² we find that this trend starts at around 100 MeV, so altogether the model prediction is a factor of 6 too low at 575 MeV. Among other things, the energy dependence of (π, N) is influenced by the resonances in the $\pi + N$ system; this is well established by the analysis of the $\pi d \rightarrow pp$ reaction. It is worth noting, however, that the $T=1/2$ πN resonances are strongly suppressed as contributors to $\pi d \rightarrow pp$ because of the $T=0$ NN ground state of the deuteron. Models based on using $\pi d \rightarrow pp$ as input run the risk of missing some portion of $A(\pi, n)A-1$ reactions (particularly at energies above the $T=3/2$ Δ resonance) unless the isospin conditions happen to be the same.

We also have results on the pion single-charge-exchange reaction $\pi + ^3\text{He} \rightarrow t + \pi^0$ at $T_\pi = 285, 428$,

Fig. 1.

Differential cross sections for ${}^3\text{He}(\pi^-, n)d$ and ${}^4\text{He}(\pi^-, n)t$. Curves are theoretical results from Ref. 1.

and 525 MeV at large pion angles. The preliminary cross sections are shown in Fig. 2 together with data from a previous EPICS experiment³ ($T_\pi = 200, 250, 275$, and 295 MeV) and other data.⁴ The results of Landau's optical-model calculations are also shown.⁵

Fig. 2.

Differential cross section for ${}^3\text{He}(\pi^-, \pi^0)t$ at $\theta = 120^\circ$ (Los Alamos National Laboratory data from Ref. 3 and University of California at Los Angeles data from Ref. 4). Curve is theoretical result from Ref. 5.

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Nonresonant Pion Production in $np \rightarrow pp\pi^-$
 (Exp. 366)
 (Rice Univ., Univ. of Houston, Los Alamos National Laboratory)
Spokesman: G. C. Phillips (Rice Univ.)

Peripheral model calculations, which are dominated by the Δ resonance, are able to predict the pion production differential cross section in regions of phase space where the Δ is produced. However, in regions of phase space not dominated by the Δ , the differential cross section is much larger than predicted with present models.

To learn more about nonresonant pion production, the reaction $np \rightarrow pp\pi^-$ has been measured in a kinematically complete experiment at LAMPF's 790-MeV (nominal beam energy) neutron beam.¹ The differential cross section for this reaction contains explicitly both resonant and nonresonant partial cross sections,² allowing the nonresonant terms to be extracted.

A schematic of the experimental configuration is shown in Fig. 1. Since the beam was not monoenergetic, six quantities were measured to determine completely the kinematics of the final state. The three momenta (P_1, θ_1, ϕ_1 and P_2, θ_2, ϕ_2) of two of the three charged particles were measured using two spectrometer arms, the first time a two-spectrometer experiment has been performed

by this group. All data were written onto magnetic tape, while a portion of the data was analyzed on-line using a DEC PDP-11/34 to monitor the data quality.

This experiment was performed during February and March 1980, and is presently being analyzed. To date all of the data have been converted from multiwire-proportional-chamber (MWPC) coordinates to the measured three-momenta P_1 and P_2 . In addition, some preliminary work has been done on the theory to extract the nonresonant contributions to the differential cross sections.

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Measurement of $\Delta\sigma_T$ in p-p Scattering (Exp. 504)
 (Rice Univ., Univ. of Houston)
Spokesman: G. C. Phillips (Rice Univ.)

The total cross-section difference for proton-proton scattering in pure transverse spin states, $\Delta\sigma_T = (\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow})$, has been measured from 300 to 800 MeV (0.84-1.46 GeV/c) in 50-MeV steps. The measurements were made using the LAMPF polarized proton beam and the Argonne-Rice polarized proton target (PPT-VI). Data were taken using new high-precision integrating ion chambers rather than digital counting techniques. The preliminary on-line results indicate that $\Delta\sigma_T$ rises to about 10-12 mb at 600 MeV in rough agreement with the TRIUMF results,¹ then drops abruptly to 4-5 mb by 650 MeV in agreement with past Argonne National Laboratory Zero-Gradient Synchrotron (ZGS) measurements by this group.² However, the final results will require considerably more analysis, as significant corrections due to beam intensity, position, and structure remain.

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Fig. 1.
 Experimental setup for Exp. 366.

Energy Dependence of $A_{nn}(90^\circ)$ in p-p Elastic Scattering from 0.84 to 1.45 GeV/c (Exps. 504/505)
(Rice Univ., Univ. of Houston)
Spokesman: G. C. Phillips (Rice Univ.)

As a parasitic experiment to Exp. 504 from July to November 1980, the spin correlation parameter A_{nn} was measured at $\theta_{c.m.} = 90^\circ$ at 13 momenta between 0.84 and 1.46 GeV/c. The measurements were made using the LAMPF polarized proton beam and the portable Argonne-Rice polarized proton target (PPT-VI). Elastic events were detected with a double-arm spectrometer. The scattering angles of the forward-scattered and recoil proton were measured by multiwire proportional chambers. Both the forward scattered proton and the recoil proton were momentum analyzed, thus providing a "clean" elastic signal with only negligible quasi-elastic background.

The analysis of these data is now in progress. Our previous measurement of $A_{nn}(90^\circ)$ in this energy region showed a dramatic peak centered around $p_{lab} = 1.34$ GeV/c.¹ Our more recent measurements at additional momenta should further resolve this interesting structure as well as provide actual new input for N-N phase-shift analyses. We expect our final results to shed more light on the controversy of whether there are pp resonances near the $N\Delta$ threshold.

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Transverse Spin-Spin Asymmetry in the Reaction $pp \rightarrow d\pi^+$ (Exps. 504/505)
(Rice Univ., Univ. of Houston)
Spokesman: G. C. Phillips (Rice Univ.)

During the LAMPF variable-energy polarized beam run in the summer of 1980, Exp. 505, the measurement of the transverse spin-spin asymmetry in the reaction $pp \rightarrow d\pi^+$ in the 500- to 800-MeV region, was approved to run parasitically to Exp. 504 (see preceding section, p.44). The experimental setup consisted of two magnet spectrometer arms instrumented with four multiwire proportional chambers each, viewing the N-type Argonne-Rice polarized proton target (PPT-VI).

The $pp \rightarrow d\pi^+$ is the only two-body inelastic reaction in this energy range where the two-body kinematics allow easy identification of events originating from un-

bound (polarized) protons in the target, which may not be the case for the dominant inelastic channel $pp \rightarrow p\pi^+n$. Thus, measurement at double-spin symmetries from 500-800 MeV, where the total cross section is still >1 mb, is also proposed to test models of inelastic nucleon-nucleon scattering (i.e., those of Green, Siano, Niskanen, Duck, Verwest, Amado, Silbar, Biggs, Riska, and others).^{*} Proper development of such models is very important, since a phase-shift analysis at this high energy is very difficult to perform.

Due to several difficulties with beam lines, machine operation, debugging at the new ion chamber, technology used in Exp. 504, data were taken at $\theta_{c.m.} = 90^\circ$ for only three energies — 500, 580, and 800 MeV. When analyzed, these data will be compared to the complete set of data from SIN at 515 and 575 MeV.¹

^{*} See proposal supplement to LAMPF Exp. 505, Los Alamos National Laboratory report LA-7444-SR.

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Analyzing Power Measurement for the Reaction $\bar{p} + d \rightarrow {}^3\text{He} + \text{mm}$

(Univ. of Minnesota, Univ. of California at Los Angeles, Los Alamos National Laboratory)
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The reaction $p + d \rightarrow {}^3\text{He} + \text{mm}$ was studied extensively during the period of 1960-1973. An enhancement in the multipion production near the $2\pi^0$ missing mass in the isospin singlet channel, which seemed to be inconsistent with the π - π scattering length, was observed. This enhancement, better known as the ABC anomaly,¹⁻³ was investigated by several authors.⁴⁻¹¹ The numerous reaction mechanisms proposed to account for this anomaly covered a wide range of phenomenology. Amongst these reaction mechanisms are the following: (1) multistep processes,⁷ (2) the Δ -isobar model,⁸ (3) intermediate d^* resonance formation,¹¹ and (4) modification of phase space due to the dependence of the production mechanism on the ${}^3\text{He}$ form factor.⁴ In spite of the fact

Fig. 1.
Momentum distribution of ${}^3\text{He}$ from the reaction $\bar{p} + d \rightarrow {}^3\text{He} + mm$.

that each of these reaction mechanisms succeeded in explaining one or more aspects of this anomaly, the anomaly still remained without satisfactory explanation.² However, after the comparative success of Brody's model,⁴ both theoretical and experimental work on this anomaly stopped.

Here we present new data which should serve to impose further constraints on the theory.

The experiment was performed at LAMPF, using the High Resolution Spectrometer (HRS) to detect ${}^3\text{He}$ produced by the incidence of 800-MeV transversely polarized protons on a 2.5-cm LD_2 target. The ${}^3\text{He}$ was separated from background by momentum analysis and

by a combination of pulse-height and time-of-flight information from a set of focal-plane scintillators comprising the event trigger. Scattering angles were determined by a set of multiwire proportional chambers (MWPCs) situated at the focal plane. Absolute cross sections were obtained by normalizing our yield to Banaigs' data.^{3*}

The differential cross sections as a function of the ${}^3\text{He}$ momentum divided by its charge are presented in Fig. 1. The momentum distribution exhibits the enhancement observed earlier.

* The range of missing mass spanned during the measurement was $\approx 100\text{--}400 \text{ MeV}/c^2$.

Fig. 2.
Analyzing powers of the ${}^3\text{He}$ from the reaction $\bar{p} + d \rightarrow {}^3\text{He} + mm$.

From inspection, the analyzing powers (Fig. 2) seem to be inconsistent with the Brody's model, since one would expect to see the influence of the ^3He vertex in the analyzing powers as one seems to see it in the cross sections. It would be interesting to see the theory extended to include predictions for the analyzing power.

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Nuclear Chemistry

Medical Radioisotope Production (Exps. 106 and 267) (Los Alamos National Laboratory)

Spokesman: H. O'Brien (Los Alamos National Laboratory)

The objective of this experimental program is to investigate spallation processes at LAMPF as a means of providing radionuclides of known or potential value in the biosciences. During the past 6-month period, we have continued to provide ^{82}Sr and ^{77}Br to collaborating institutions; 11 shipments of ^{82}Sr totaling 3.2 Ci and 36 shipments of ^{77}Br amounting to 3.0 Ci were made to 13 institutions.

Significant advances have been achieved in the production and processing of 36.4-day ^{127}Xe . A remotely operated vacuum chamber and cold trap were constructed and installed in the dispensing hot cell at the Los Alamos Radiochemistry Site (TA-48), thus permitting the recovery of released xenon gas when the target container is opened. Subsequently the target (La_2O_3) is transferred to a dissolving pot, which is coupled to a gas-line system where the material is dissolved and the remaining xenon is recovered. Three lanthanum-oxide targets have been processed to date, and a total of 3.2 Ci of ^{127}Xe was delivered to Brookhaven National Laboratory for commercial sale.

Radioiron has been shown to be useful as an *in vivo* imaging agent for erythropoietic bone marrow and is believed to be of greater value than ^{111}In -transferrin in following the course of radiation/chemotherapy in cancer patients. Iron-52 ($T_{1/2} = 8.28 \text{ h}$) decays by electron capture and positron emission, and emits a 168-keV photon. In addition, ^{52m}Mn , which decays 98% by positron emission, is useful for emission-computed tomography. Atcher *et al.*¹ have shown that Mn(II) is cleared rapidly from the blood with a high uptake in the myocardium in <5 min following intravenous (iv) injection. Both Atcher *et al.*¹ and Ku *et al.*² have reported on the development of a successful $^{52}\text{Fe}/^{52m}\text{Mn}$ biomedical generator. Recently we reported on a chemical procedure for recovery of radioiron from a nickel target.³ Just before shutdown in November, a nickel target was irradiated and the isolated ^{52}Fe was sent to Massachusetts General Hospital in Boston where myocardial metabolism studies in animals were conducted.

Radiochemical procedures for the recoveries of germanium and copper from a rubidium-bromide target have been completed, and a long-term irradiation was carried out. Processing of this target for ^{68}Ge is expected soon.

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Materials Science

Isotopic Discrimination Between Plutonium Isotopes Using Muonic X Rays (Exp. 51)

(Los Alamos National Laboratory)

Spokesman: J. Malanify (Los Alamos National Laboratory)

The goal of this experiment is to investigate the feasibility of detecting small amounts of ^{240}Pu in the presence of large amounts of ^{239}Pu . This capability would offer a new avenue of approach to the problem of nuclear materials analysis.

During the past six-month period, significant progress has been made toward the completion of data analysis. Because of the inherent difficulty of identifying relatively weak ^{240}Pu muonic x-ray lines lying between more intense and closely spaced ^{239}Pu lines, it was necessary to estimate and make corrections for time-dependent gain shifts in the energy analysis electronics. This was done for the nine successive spectra that we measured. These nine spectra, after gain corrections, were combined into a composite spectrum. Now that an effective technique has been developed for making gain corrections to a selected part of a spectrum, the method will be applied to the remaining interesting regions of the measured spectra. Afterwards, the final stage of analysis, that of locating and making fits to spectral peaks, will be done.

Muon-Spin-Rotation Study of Diffusion in Metals in the Presence of Paramagnetic Ions (Exp. 375)

(Los Alamos National Laboratory, Rice Univ.)

Spokesman: M. E. Schillaci (Los Alamos National Laboratory)

The principal objective of this experiment has been to study muon diffusion in metals having negligible nuclear moments or at temperatures such that the muon motion is so rapid that field inhomogeneities due to nuclear moments average to zero. Muon depolarization is affected by paramagnetic impurities randomly dispersed throughout the host lattice. Considerations of impurity solubility and sample characterizability have led us to study rare earths dissolved in noble metal hosts — primarily gadolinium and erbium in gold and silver.

For both gadolinium and erbium in gold, we observe a rapid rise in muon depolarization (Λ) at about 120 K (Fig. 1). A similar behavior of Λ is observed for silver

Fig. 1.

Temperature dependence of the depolarization rate of AuGd and AuEr at 80-Oe applied field.

(Fig. 2) near room temperature, leading to the qualitative conclusion that the muon diffuses more rapidly in gold than in silver, and more rapidly in silver than in copper (measured in the pure host¹). Comparison of different concentrations of rare-earth ions shows $\Lambda(T)$ to be linearly proportional to the concentration. Diffusion parameters have been obtained from a model fit² of the AuGd (300-ppm-atomic) data, for which we obtain an activation energy of ~ 1500 K and an attempt frequency of $\sim 2 \times 10^{14} \text{ s}^{-1}$. These parameters can be compared with 560 K and $3.2 \times 10^7 \text{ s}^{-1}$, respectively, for copper,¹ indicating different diffusion mechanisms for the muon in gold and copper (see Ref. 2).

Fig. 2.
Temperature dependence of the depolarization rate for AgGd and AgEr at 80-Oe applied field.

Our model fits also indicate that in the region of the peak in $\Lambda(T)$ for AuGd_x and AuEr_x the long-range (dipolar, RKKY) muon-impurity interactions are inadequate to fit the data and that a much stronger short-range interaction is necessary. The dipolar interaction can be calculated exactly, and was checked at low temperatures and high fields where the muon is stationary in the lattice. In this region the data and theory³ were in excellent agreement (Fig. 3). The RKKY strength was estimated to be an order of magnitude lower than the dipolar. Using an isotropic contact interaction of strength 35 kOe, the model fit is in excellent agreement with the peak in $\Lambda(T)$ for AuGd (300-ppm-atomic) data at 80-Oe external field. This assumed short-range interaction contributes almost an order of magnitude more than the dipolar at these temperatures. Thus as the muon diffuses closer to the rare earths, the dominant interaction mechanism appears to change from dipolar to some kind of short-range contact interaction. Using the same model parameters, but at an external field of 5 kOe, the

Fig. 3.
Temperature and field dependence of the depolarization rate for AuGd at low temperatures and high fields. The solid line is calculated from Ref. 3 assuming a dipolar interaction.

fit falls about 15% below the high-field data for the same sample. Further studies are planned to elucidate the exact nature of this short-range interaction.

For AuGd, on the high-temperature side of the peak, $\Lambda(T)$ falls exponentially, indicating that the muon hop time (τ_h) is much less than the impurity-spin relaxation time (τ_s) (Ref. 2). For AuEr, $\Lambda(T)$ falls off like T^{-1} , indicating $\tau_s \ll \tau_h$; this temperature dependence is consistent with impurity-spin relaxation via conduction electrons (Korringa) or via direct phonon processes. Our result, $\tau_s[\text{Er}] \ll \tau_s(\text{Gd})$, is what one would expect since erbium in gold is a crystal-field split system in contrast to the Gd^{3+} , which is in an S-state.

In addition to the principal features described above, our data show secondary peak structure at higher temperatures (Fig. 1). For the primary peaks, $\Lambda(T)$ scales linearly with impurity concentration, as might be expected for a single-impurity magnetic interaction. However, such a concentration dependence is not found for the secondary peak. This may indicate that clustering of the impurity ions is responsible for the second peak. Resistivity measurements, however, would seem to limit this clustering to $\lesssim 5\%$. This secondary structure certainly merits further study; however, our principal conclusions regarding muon diffusion rates and muon single-ion interactions remain intact.

In addition to the experimental measurements described above, a technique was developed for calculating muon depolarization rates in metals containing dilute concentrations of paramagnetic impurity atoms. The technique is applicable to the model in which muons are described as hopping from interstitial site-to-interstitial site while being depolarized by long-range dipolar and contact interactions with an impurity. A depolarizing, diffusing ensemble of muons is described in terms of a system of ordinary differential equations in such a way that the depolarization rate of interest is just equal to the smallest eigenvalue of the solution of the system of equations.

Thus far the technique has only been applied to the analysis of data obtained for the AuGd (300 ppm). By assuming a contact interaction field of 27 kOe for the gadolinium, an excellent fit is obtained to the major, low-temperature peak in the measured depolarization rate vs temperature curve. The weaker, high-temperature peak is not predicted.

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Muon Longitudinal and Transverse Relaxation Studies in Spin-Glass Systems (Exp. 499)

(Los Alamos National Laboratory, Rice Univ., Univ. of California at Riverside)

Spokesmen: S. A. Dodds (Rice Univ.), R. H. Heffner (Los Alamos National Laboratory), and D. E. MacLaughlin (Univ. of California at Riverside)

We have recently taken μSR data in both zero and finite fields for AgMn (1.6 at%) and AgMn (3 at%) spin-glass samples. The data allow us to determine, in the context of a particular model, the fluctuation rate of the manganese ions as a function of temperature. This rate decreases smoothly, but very rapidly, near the glass temperature, T_g . The corresponding behavior in CuMn is more gradual.¹

The samples were prepared by arc melting and then annealing at 800°C for 1 hour. Low-field alternating-current susceptibility measurements for these samples show a sharp cusp at the expected glass temperatures ($T_g = 7.6$ K for 1.6 at%). A conventional time-differential technique was used to obtain transverse depolarization rates at several fields and temperatures. Zero field data were obtained with a pair of counter telescopes along the beam direction. The effects of counter efficiency, solid angle, and beam polarization were estimated by using the same counters to measure a μSR spectrum in a small transverse field. The zero field data were thereby analyzed to yield the muon polarization as a function of time. All measurements below T_g were made by cooling the sample in an external field of < 1 G. The measurements reported here were taken on the 1.6-at% sample.

The transverse field data are summarized in Fig. 1 in which exponential depolarization rate is plotted against temperature. The measured rates show a rapid increase as T_g is approached from above. Below T_g , the rate appears to saturate at $(12 \pm 2) \mu\text{s}^{-1}$, which is rather close to the expected² value of $11 \mu\text{s}^{-1}$ for a randomly frozen array, assuming a dipolar coupling between the muon and the impurity. The functional dependence of the linewidths at these temperatures is Lorentzian, indicating that the depolarization mechanism is due to inhomogeneous broadening. A further observation is that the measured λ values are always larger than expected for a random distribution of noninteracting manganese spins, assuming a dipolar manganese-muon interaction.

Well below T_g , the zero field polarization function shows a rapid drop to one-third of its zero time value, followed by a slower decrease to zero. A finite depolarization rate persists to 2 K, indicating that fluctuations in the local field are present down to $0.27 T_g$. At temperatures well above T_g , a smooth but nonexponen-

tial decay is seen. More complex behavior occurs at intermediate temperatures.

In order to extract quantitative information from our zero field depolarization curves, we use the weak collision model of Leon.³ The model assumes that each stopped muon sees a magnetic field of fixed strength but time-varying direction. The field strength at the various muon sites is assumed to follow a Lorentzian distribution with half-width σ . The fluctuations of the field direction are characterized by a single correlation time τ , although recent neutron-scattering results⁴ indicate this may be an oversimplification.

The results of fitting this model to our zero field data are shown in Fig. 2, where we plot the manganese correlation time τ against temperature. The low-temperature data require $\sigma = 18 \mu\text{s}^{-1}$ (210 G), which is somewhat larger than the value observed for small transverse fields. This value of σ is held fixed in the higher temperature fits.

The variation of τ with temperature is obviously rapid, but still smooth on the scale of the susceptibility cusp width. It is interesting to note that the measured τ reaches an apparent saturation at a value near the observed⁵ Korringa rate for free manganese at only $1.3 T_g$.

Fig. 1.

Relaxation rate λ , for an assumed exponential depolarization, vs temperature. The error bars are approximately the size of the plot symbol. A point at 8 K and 1 kG lies between the plotted values for 150 G and 5 kG. The arrow indicates T_g .

Fig. 2.

Manganese spin-correlation time, in the weak collision model, vs temperature. The size of the dots represents the error in τ . The solid line indicates the Korringa rate for an isolated manganese ion in silver, and the arrow denotes T_g .

The data do not follow an Arrhenius law over the full temperature range, as is clearly shown by the persistence of fluctuations to very low temperatures. If data between 6 and 10 K ($0.7 - 1.3 T_g$) are fit to an Arrhenius law, a barrier energy of $E_b = 30 k_B T_g$ is found, together with an attempt frequency ν of $2 \times 10^{20} \text{ s}^{-1}$. These results are to be compared with values of $E_b = 10.5 k_B T_g$ and $\nu = 2 \times 10^{12}$ previously found¹ for CuMn (0.7%), which has $T_g = 7.5 \text{ K}$. In addition to the obvious lack of scaling between the two systems, the attempt frequency in AgMn is unphysically large.

Future work will deal with a wider range of temperatures and concentrations to test the scaling of the results presented here. It will also be necessary to construct more complete models that allow for a distribution of correlation times and for temperature variation of a .

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The Effect of Dislocation Vibration on Void Growth in Metals During Irradiation (Exp. 407)

(Swiss Reactor Institute, Univ. of Illinois, Northwestern Univ., Case Western Reserve Univ., Los Alamos National Laboratory)

Spokesman: W. Sommer (Los Alamos National Laboratory)

A major contribution to the analysis capability for small defects such as cavities in metals has been made.¹

The quality of transmission-electron-microscope (TEM) plates is enhanced through a digital computer-based system. This process has allowed unambiguous identification of small cavities, imaged on TEM plates in aluminum material from our recent irradiation, and substantially increases our ability to study cavity nucleation and growth.

In addition, an automated system that both counts and sizes cavities on TEM plates has been developed. This system has been applied to a "round-robin" TEM plate that was used in a study aimed at determining the analysis quality of reported cavity volume and number density in irradiation studies on metal swelling. The results are shown in Fig. 1.

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Fig. 1.

The above graph shows the Los Alamos National Laboratory void-size histogram (determined automatically), superimposed upon that of Naval Research Laboratory (NRL), which was calculated using conventional methods. The swelling fractions derived from the two histograms are nearly identical.

Biomed

Computerized Treatment Planning Development (Los Alamos National Laboratory)

Spokesman: P. Berardo (Los Alamos National Laboratory)

The treatment planning code PIPLAN uses a pencil-beam or ray-tracing method of dose calculation. A fundamental problem with this approach is the computer time required to calculate the dose obtained from enough rays to reduce the statistical uncertainty to clinically acceptable levels. The nearly monoenergetic pion beams used for clinical treatment result in a peak dose spread of only about 3 cm in depth, FWHM, which is too small for most treatments. A mechanical device is placed in the beam that varies the amount of degrader the beam must pass through before entering the patient, and yields a spread-out stopping distribution in depth. PIPLAN then must obtain a high-confidence result throughout the spread-peak region with fewer stopping pions per unit volume, or increase the number of rays to be calculated. For example, if 25 000 rays produce an acceptable answer for an unmodulated beam, about 75 000 rays are required for a 10-cm-spread peak, and three times as much calculation time.

If one neglects multiple scattering, the pencil-beam library dose distribution can be folded with the range-modulation function to yield a composite library depth-dose distribution. This library can then be used to describe the distribution for each ray as if it experienced the full range-modulation function. The number of rays required for a given statistical uncertainty is then independent of the modulation function.

However, multiple scattering is a serious problem for pions, especially in clinical situations where inhomogeneities, appliances, and large air gaps between appliances are common. The problem is compounded when using folded library distributions, since the multiple scattering at a given depth in the patient is, to first order, given by the sum of Gaussian radial distributions where the addends are weighted by the range-modulation function. The resultant pencil-beam width due to multiple scattering is no longer conveniently analytic, and the time required to individually keep track of Gaussians at each point in depth for each ray and directly calculate the width at that point essentially offsets the time gained by folding (even if computer memory is unlimited).

We have found, for several typical range-modulation functions, beam momenta, and clinical geometries, that

the radial spread of a pencil beam at various depths in a phantom can be reasonably approximated (to within ~3% in relative probability amplitude) with either a Gaussian or an exponential function. Since normalization is required, only one variable is needed to describe the composite radial distribution at each depth for a given modulation function, beam momentum, and geometry. Since modulation functions are designed for each momentum and since the geometry for a given momentum is dominated by a collimator thickness and opening (air gaps), a one-dimensional table of distribution parameters can be precalculated and saved with each modulation function. The net effect of the procedure is to maintain a constant statistical uncertainty and calculation time for all modulation functions and spread-peak widths.

Of the nine beam tunes used for treatments, all but three tunes (12A, 12B, 23A) have gone through the complete sequence of (1) a measured air scan, (2) production of a smoothed beam input tape (from the air scan) for PIPLAN, and (3) parameterization of the depth-dose curve in a PIPLAN calculation to match experimental measurement.

The PIPLAN code was used successfully on an actual case, a patient who received treatments from two parallel, opposed ports. The anterior-posterior port results are displayed in Fig. 1 with the 80, 50, and 20%

CASE #145 - AP PORT

Fig. 1.

PIPLAN calculation of dose distribution in a patient for an anterior-posterior port.

isodose contours. This case used new features in PIPLAN that allow a calculation requiring two different beam tunes and two different range-shifter functions in the same patient. The results of Fig. 1 are in satisfactory agreement with the current treatment planning methods, which use simpler models for the dose calculation and which cannot take into account the effects of neighboring tissues in adjacent slices.

Therapy Beam Development — Dosimetry

(Exp. 271)

(Univ. of New Mexico)

Spokesman: Alfred R. Smith (Univ. of New Mexico)

A new computer code has been written to calculate the range-modulating function needed to produce a variety of depth-dose distributions for stopping pions. For example, pion-stopping distributions can be shaped to produce flat physical dose, flat high-LET dose, or flat dose equivalent (biological effect). The function describes the variation in the thickness of a column of oil with time. The distribution of stopping pions in tissue must be altered during a treatment in order to extend the 2- to 3-cm stopping region of the unmodulated beam to the thickness of the target volume. Currently functions are being used at LAMPF that produce extended peaks from 3- to 14-cm thick. The criterion for designing these functions is that one must have a flat biological effect over the intended treatment region. To calculate the RBE at any point a simple biological model with experimental parameters is used.

The program reads in total and high-LET depth-dose curves and, applying various weights, offsets each curve by different amounts in Z, adds all the contributions at each position, and renormalizes to produce the resultant modulated total and high-LET depth-dose curves. A long time is spent at minimum range-shifter thickness, and then a series of four small steps of increasing size and decreasing times are taken in moving away from minimum thickness. The center section is composed of a set of positions evenly spaced 0.5 cm apart, whose times decrease linearly with distance from minimum thickness. Finally, the pions are stopped for a relatively long time at a position ~1 cm shallower than the desired proximal edge of the spread peak.

The dose equivalent is calculated from a simple biological model: the relative biological effectiveness (RBE) is assumed to be a linear function of the fraction of dose delivered at high LET (> 50 keV/μ),

$$\text{RBE} = 1.0 + a D_H$$

where D_H is the ratio of high-LET dose to low-LET dose normalized to unity at the position of the highest fraction of high-LET dose. The RBE equals 1.0 when all the dose is delivered at low LET. The values of the constant, a , are determined from radiobiological data. Presently a number is chosen to make the RBE = 1.6 at the maximum of D_H in a 10-cm-spread peak.

Figure 1 shows examples of physical dose, high-LET dose, and dose equivalent curves calculated with the new code. The uniformity of the dose equivalent curves have recently been verified by radiobiological data.

Therapy Beam Development — Microdosimetry

(Exp. 272)

(Los Alamos National Laboratory)

Spokesman: J. Picello (Los Alamos National Laboratory)

Previous results of Exp. 272 showed that in therapeutically relevant volumes, ~50% of the high-LET dose from pion stars is a result of interactions by the neutrons from pion stars. The neutron dose results in an increased RBE and a decreased variation in the biological response throughout the treatment volume because of the long mean-free path of the neutrons. It is therefore necessary to take into account the effects of

Fig. 2.

Calculated range-shifted depth-dose distributions illustrating physical dose, high-LET dose, and equivalent dose.

neutrons both in treatment planning and in radiobiological experiments.

Until now, the only experimental methods for the determination of the neutron dose in a pion beam relied on the measurement of the neutron dose outside of the treatment volume with an extrapolation into the volume itself. A method has been devised which directly measures in the stopping region that portion of the neutron dose which results from hydrogen recoils. Dose distributions are obtained in both a carbon and a polyethylene phantom with carbon and polyethylene ion chambers, respectively. Because polyethylene is composed of hydrogen and carbon $(C_2H_4)_n$, the difference between the two measurements is a measure of the neutron dose from hydrogen recoils. The technique is analogous to a method used to obtain the gamma dose in neutron beams.

Experimental data have been obtained for a variety of treatment volumes for both π^+ and π^- beams. Typically the neutron dose is 15% of the total dose in a 1-cm stopping volume. Results of Monte Carlo calculations for the same geometries are in close agreement with the measured data.

Secondary particle production spectra due to neutrons incident on carbon and oxygen have been calculated using an intranuclear cascade code that takes into account specific nuclear properties of carbon and oxygen (in particular, α -particle clustering). It also allows excited nuclei to deexcite by Fermi breakup rather than the more frequently used statistical evaporation mechanism, which is not applicable to low-mass nuclei. The code yields double-differential secondary particle spectra in energy and angle, which show good agreement with the experimental data from the University of California at Davis at 27, 40, and 61 MeV.

The use of these complete theoretical cross-sectional data allow

- (1) the calculation of absolute depth-dose curves for particular beams, as opposed to depth-kerma curves that are less sensitive to secondary particle distributions. These calculations are performed with a Monte Carlo neutron transport code; build-up curves that are sensitive to secondary charged-particle distributions are calculated for high-energy neutron beams, such as those produced by 65-MeV protons on beryllium $[p(65)\text{-Be}]$;
- (2) the calculation of energy-deposition distributions in small sites, these distributions being even more sensitive to the secondary particle spectra. Microdosimetric lineal-energy spectra are

calculated with Monte Carlo techniques reported previously, using as input measured neutron energy spectra. As an example, the lineal-energy spectrum from $p(65)\text{-Be}$ neutrons in a 2- μm site size shows excellent agreement with experimental data obtained with a walled detector. In addition, these calculations can predict lineal-energy distributions and averages in much smaller site sizes than can be routinely obtained experimentally. Results in the nanometer region have been obtained for low-energy protons.

Biological Intercomparisons of High-LET Beams Used for Radiation Therapy* (Exp. 384)

(Los Alamos National Laboratory, Univ. of Washington)

Spokesman: J. P. Geraci (Univ. of Washington)

We have biologically intercompared negative pion beams at Los Alamos with cyclotron-produced neutron beams, ^{137}Cs gamma rays, and 300-kVp x rays. For this purpose the testes of three hundred B6DF1 mice were exposed to graded single doses of pions in the plateau and peak regions of a 3-cm-modulated pion peak beam. At the same time these irradiations were taking place, mice testes were also exposed to either an 8-MeV mean-energy cyclotron-produced neutron beam, ^{137}Cs gamma rays, or 300-kVp x rays. The biological endpoints of decrease in testes weight¹ 28 days after exposure, and spermatogenic activity² 35 days after exposure, were used to determine the relative biological potency of pion, neutron, and photon beams.

The predominant response of testes weight and spermatogenic cell survival to different LET radiations was a change in the slope of the dose-response curves (Figs. 1 and 2). The relative change of the slopes of the dose-response curves at different LET radiations was similar for both endpoints, resulting in a similar estimate of the relative potency factors. The results indicate that neutrons, peak pions, and plateau pions are respectively 2.8, 1.5, and 1.2 times more effective per rad than photons in producing testicular damage. Similar studies done at TRIUMF indicate that both TRIUMF and LAMPF pions are equally effective per rad in producing testicular damage.

*Part of this work has been published in *Radiat. Res.* 82, 579-587 (1980).

Fig. 1.

Testes weight dose-response curves for cyclotron neutrons, $\diamond$; π^- peak radiation, $\times$; π^- plateau radiation, $\square$; ^{137}Cs gamma rays, $\circ$; and 300-kVp x rays, $\triangle$. Testes weight losses have been normalized to the zero dose value. Each data point represents the mean testes weight of six mice. Error bars are omitted for clarity. Standard errors were 2-11% of the mean values.

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Fig. 2.

Dose-response curves for decrease in spermatogenic colonies per tubule cross section following cyclotron neutron, $\triangle$; negative pion, $\square$; and ^{137}Cs gamma irradiation, $\circ$. Each data point represents the mean number of spermatogenic colonies per tubule cross section. Six to eighteen mice were used for each data point. Bar symbols indicate the standard errors.

Biomedical Instrumentation

(Los Alamos National Laboratory)

Spokesman: J. D. Doss (Los Alamos National Laboratory)

Recent efforts have been concentrated on designing improved probes and electronics for the corneal shape-modification program that is being carried on jointly by the University of Oklahoma and Los Alamos National Laboratory, since expanded research efforts and commercial development appear likely. A staff member at the

University of New Mexico (UNM) School of Medicine plans to initiate a corneal shape-modification program in collaboration with a Los Alamos Medical Center ophthalmologist; they have requested that the Laboratory loan appropriate instruments to UNM for this work.

The electronics has been completely redesigned, with primary changes including the addition of circuitry for monitoring a rotating paddlewheel flowmeter that measures saline flow across the cornea, and a digital readout of flow on the front panel. Several changes have been made to improve safety, including fault-sensing circuitry and audible signals to assist the ophthalmologist during treatment procedures. Radio-frequency current-sensing circuitry with front-panel and audible readout has been added to assist the physician in determining whether good electrical contact has been made with the tissue. Circuitry has been added to interrupt treatment if certain types of errors are sensed in the closed-loop rf-voltage level feedback control system. The first chassis representing these changes is currently about 80% complete.

New circulating-saline electrodes and related devices are being designed. Electric field intensity distributions have been calculated for a variety of "bipolar" probes; these would have both electrodes near the cornea, rather

than only one as in the earlier work with monopolar electrodes. It appears that the bipolar designs have the advantage of concentrating the highest current density at the locations where coolant-flow velocity is also maximum, but that current densities at corneal endothelium (the inner surface of the cornea) will be increased. No bipolar probes have been constructed, but construction and testing is expected during the next 3 months. An apparent major improvement in the probes that have been tested on phantoms involves the use of vacuum-driven rather than pressure-driven flow. This approach, with a flexible gasket at the cornea-probe interface, allows the probe to be easily "attached" to the cornea rather than requiring considerable pressure by the physician to hold the probe on the cornea. This method should greatly simplify the mechanics of the treatment and thereby improve safety and repeatability.

The computer code, which was developed at Los Alamos for calculation of corneal shape, has been improved significantly during the past few months. It continues to be used at the University of Oklahoma for the evaluation of various corneal modification procedures, and is an essential element in a National Eye Institute funded grant for the evaluation of the controversial "radial keratotomy" surgical techniques.

Theory

On Regularities Observed in Pion Elastic, Single, and Double Charge Exchange in the Resonance Region (Los Alamos National Laboratory)

Mikkel B. Johnson

Pion elastic and charge exchange scattering to the single and double analogs of the nuclear ground state are related at a fundamental level by isospin invariance of the strong interaction. A unified treatment of these reactions is possible in an optical potential approach which makes manifest the isotopic spin symmetry of the pion-nucleus interaction,

$$U = u_0 + u_1(\phi_\pi \cdot T) + u_2(\phi_\pi \cdot T)^2 \quad (1)$$

Here T is the nuclear and ϕ_π the pion isotopic spin operator. In the simpler models of pion-nucleus

scattering,¹ the functions u_0 , u_1 , and u_2 are expressed as a function of the nuclear density and its derivatives. The lowest order term is determined from free pion-nucleon scattering, and the higher order terms are determined by the interaction of the pion with several nucleons.

Recent elastic, single-, and double-charge-exchange data analyzed within models of the type just described have yielded a number of interesting regularities. Some confirm elementary ideas about pion-nucleus interactions, and others suggest that these experiments permit a direct, sensitive determination of the higher order (in density) terms in U . This information is interesting because it is related to fundamental aspects of nuclear structure and pion and isobar interaction dynamics.

Two of the most striking recent results are shown in Figs. 1 and 2. In Fig. 1 the results of zero-degree measurements of angular distributions to the analog state are plotted for pions of 100-MeV incident energy. The data were taken with the LAMPF π^0 spectrometer.² The results are well described by the formula

Fig. 1.

The A dependence of the 0° differential cross sections for (π^+, π^0) reactions to the IAS. The error bars reflect the relative errors only. The solid line represents the function $13.4(N-Z)A^{-4/3}$ fitted to the data. Also shown are the results of first-order optical-model calculations with use of realistic densities (dashed line) and N/Z scaled neutron densities (dot-dashed line) with proton densities determined from electron scattering.

Fig. 2.

A dependence of all of the measured 5° cross sections for DCX transitions to DIAS at 292 MeV. The solid curve is a prediction based on the semiclassical approximation as given in Eq. (3).

$$\frac{d\sigma}{d\Omega} \text{SCX}(0^\circ) = \sigma_1(N-Z)A^{-4/3} \quad (2)$$

The factor of $N-Z$ is simply the number of valence neutrons, and the factor $A^{-4/3}$ is understood in terms of a diffractive eikonal model analysis.³ The same model predicts a simple dependence on N and Z for the zero-degree double-charge-exchange cross section

$$\frac{d\sigma}{d\Omega} \text{DCX}(0^\circ) = \sigma_2 \frac{(N-Z)(N-Z-1)}{A^{10/3}} \quad (3)$$

The factor of $(N-Z)(N-Z-1)$ is proportional to the number of pairs of valence neutrons, and $A^{-10/3}$ is again understood in terms of the details of diffractive scattering. Figure 2 shows the results of a fit of Eq. (3) to double-charge-exchange data for 292-MeV pions, which were measured at the LAMPF EPICS spectrometer.⁴ The values of σ_1 and σ_2 are $\sigma_1 = 13$ and $\sigma_2 = 20$ mb/sr.

Learning new physics begins when one tries to understand the size of σ_1 and σ_2 in Eqs. (2) and (3). Detailed calculations show that these quantities are very sensitive to higher order terms in u_0 and u_1 but not u_2 . For 100-MeV pion single charge exchange, at least, a sizable enhancement in σ_1 can be attributed to these terms.²

Fluctuations about the predictions in Eqs. (2) and (3) carry significant information about the details of the valence neutron wave functions. This can be seen explicitly in the eikonal theory by retaining the distinction between the shape of the neutron and proton densities and ignoring the higher order terms.³ If the valence neutron density $\Delta\rho$ and the total density ρ are assumed to have the same diffuseness a , then

$$\frac{d\sigma}{d\Omega} \text{SCX}(0^\circ) \simeq \frac{k^2 \bar{R}^2 a^2}{2(N-Z)} \left[\frac{\Delta\rho(\bar{R})}{\rho(\bar{R})} \right]^2 \quad (4)$$

and

$$\frac{d\sigma}{d\Omega} \text{DCX}(0^\circ) \simeq \frac{N-Z-1}{(N-Z)} \frac{k^2 \bar{R}^2 a^2}{16} \times \left[\frac{\Delta\rho(\bar{R})}{\rho(\bar{R})} \right]^4 \quad (5)$$

The quantity $\bar{R}$ is given approximately by $\bar{R} = (\sigma_{\text{tot}}/2\pi)^{1/2}$, where σ_{tot} is the total pion-nucleus cross section. Equations (2) and (3) result by taking ρ and $\Delta\rho$ to be proportional; in realistic models of nuclear densities this is not the case, and one looks forward to the time when charge exchange can be used to study the systematics of the "neutron halo" of nuclei throughout the periodic table.

Some of the most interesting experimental double-charge-exchange results are the data at 164 MeV on ^{18}O (Refs. 5-7) and ^{42}Ca and ^{48}Ca (Ref. 8). The puzzling features are:

- (1) the location of the first minimum in the double-charge-exchange angular distribution on ^{18}O occurs at about 22° , whereas most theoretical calculations give a first minimum at $35\text{-}40^\circ$; and
- (2) the simple explanation [Eq. (3)] of the 292-MeV data does not work at this energy, as emphasized by K. Seth.⁸

Using the results of Refs. 5-8 the $T=1$ nuclei ^{18}O and ^{42}Ca are found to nearly follow the prediction of Eq. (3), but ^{48}Ca falls an order of magnitude below where it should. Why does the simple theory appear to work at 292 MeV but not 164 MeV?

The double-charge-exchange measurements are difficult to perform, but if they are correct a simple theoretical interpretation, which explains both the anomaly of the shape of the ^{18}O angular distribution and the relative magnitude of the 5° ^{42}Ca - ^{42}Ca measurement, becomes possible. To do this, a new element must be added to the theory, namely the isotensor term in Eq. (1). The isotensor term is interesting because in *leading* order it requires a collision between the pion and two nucleons.

The effect of the isotensor term can be seen easily in the extended analytical theory developed recently by M. Johnson and E. Siciliano.⁹ In this work the general form of the second-order terms in U are worked out in a model which assumes that U can be expressed as a power series

in density. We then find analytical approximations which explicate the dependence of the cross section on the strength of the higher order terms. The result for double charge exchange is, close to resonance,

$$\frac{d\sigma}{d\Omega} \text{DCX}(\theta) \simeq \frac{2T-1}{T^3} \frac{k^2 \bar{R} a^2}{64} \left(\frac{\Delta \rho}{\rho} \right)^4 \times \left\{ J_0(q\bar{R}) \left[c_3 - \frac{8T}{2T-1} c_2 \frac{\rho}{\rho_0} \right] - \left[J_0(q\bar{R}) - q\bar{R} J_1(q\bar{R}) \right] \frac{ac_1^2}{\bar{R}} \right\}^2, \quad (6)$$

where c_1 and c_3 are coefficients directly related to the strength of the second-order terms in u_0 , u_1 of Eq. (1). The coefficient c_2 is proportional to the strength of u_2 , which is assumed here to be purely imaginary. According to Ref. 9, c_1 , c_2 , and c_3 are nearly independent of N and Z but they may depend strongly on the incident pion energy.

It is clear from Eq. (6) that the isotensor interaction interferes with the iterated isovector interaction,¹⁰ which is contained in c_3 . The term u_2 can therefore cause a dramatic change in both the shape and magnitude of the double-charge-exchange angular distribution. The theory of Ref. 9 shows how even a moderately sized isotensor strength can lead to the result

$$c_3 < \frac{8T}{2T-1} c_2 \frac{\rho}{\rho_0}. \quad (7)$$

If this inequality holds, then the leading term $J_0(q\bar{R})$ in Eq. (6) is allowed to interfere constructively with the term $J_0(q\bar{R}) - q\bar{R} J_1(q\bar{R})$ at 0° but *destructively* in the angular range between the first zero of these terms. One possible result of this destructive interference is to move the first minimum of the angular distribution to substantially smaller angles than can occur in the absence of the isotensor interaction.

In order to determine phenomenologically the strength of the isotensor term in U , a detailed numerical solution of the Klein-Gordon equation is required. The optical potential should include the second-order terms in u_0 and

u_1 as well as u_2 . Theorists will find it very exciting to have a measurement of the second-order terms in U . To determine a unique parameter set it will probably be necessary to fit the parameters to the elastic, single-, and double-charge-exchange angular distributions. The prospects for a unique solution for ^{18}O at 164 MeV appear to be good¹¹ because data have been taken for all three experiments.

A second interesting consequence of the isotensor term is that the simple result in Eq. (3) may be strongly violated. Dropping the small term in Eq. (6) proportional to $a/\bar{R}$ and assuming $\Delta\rho$ to be proportional to ρ , we find^{9,12} a correction to Eq. (3).

$$\frac{d\sigma}{d\Omega} \text{DCX}(0^\circ) = \sigma_2 \frac{(N-Z)(N-Z-1)}{A^{10/3}} \quad (8)$$

$$\times \left[1 - \frac{4\gamma(N-Z)}{N-Z-1} \right]^2,$$

where $\gamma = c_2/c_3 \rho/\rho_0$ is smoothly dependent on A . Fitting Eq. (8) to the ^{18}O , ^{26}Mg , ^{42}Ca , and ^{48}Ca results⁵⁻⁸ we find $\gamma = 0.175$ and $\sigma_2 = 47.7 \text{ mb/sr}$ at 164 MeV with $\chi^2 = 2$. The success of Eq. (3) at 292 MeV implies $\gamma \simeq 0$ at that energy. A value of γ as large as $\gamma = 0.175$ is consistent with moving the first minimum of the angular distribution of ^{18}O at 164 MeV to smaller angles.

In the near future it would be of interest to explore experimentally the systematics of double charge exchange on nuclei having a variety of values of T and A . More measurements at 164 MeV would be interesting, because it is at this energy that the available data show the isotensor interaction to be strongest. Additional data would make it possible to corroborate the results of the analysis of Ref. 11.

Finally, there are interesting, recent elastic-scattering results related to the position of the (3,3) nuclear resonance. The nuclear resonance is defined to be the energy at which the real part of the forward elastic-scattering amplitude vanishes. The simpler optical models predict the resonance to occur at $\sim 160 \text{ MeV}$, whereas the elastic-scattering data shows it to lie at $\sim 178 \text{ MeV}$.¹³ A shift of 20 MeV is difficult to achieve by the addition of second-order terms in U ,^{14,15} but a result compatible with experiment and theoretically

motivated¹⁶ can be obtained by evaluating the pion-nucleon scattering amplitude in the optical potential at an energy lower than the incident pion energy. A variation of this idea has been recently¹⁷ employed by W. Cottingham and D. Holtkamp and applied to ^{12}C , ^{16}O , ^{40}Ca , and ^{208}Pb over an energy range extending from 100 to 300 MeV. Their results are strikingly good reproductions of the data and set a standard for numerical fits that will be hard to match by any theorist, given only one parameter (an energy shift) to adjust!

The results of Cottingham and Holtkamp lend strong empirical support to ideas that are central to modern developments in pion-nucleus scattering theory.^{18,19} They serve to underline the need in the near future for the development of codes which are both quickly solved by the computer and which correctly handle the kinematical aspects of pion-nucleus scattering. Extension of these ideas to include single- and double-charge-exchange analog-state physics, with an appropriate phenomenological treatment of the higher order terms in U , would undoubtedly lead to a vast expansion of our knowledge of pion and isobar-nucleus reaction dynamics and their interplay with nuclear structure.

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II. FACILITY AND EXPERIMENTAL DEVELOPMENTS

Low-Energy Instrumentation

Recent instrumentation development in the low-energy portion of the linac has resulted in several improved devices for beam profile measurements: the double-card harp, the solid beam-scanner, and the sandwich collector.¹ The sandwich collector is also used for emittance measurements. A substantial increase in life expectancy was attained with the new devices, even at higher beam currents.

The double-card harp, shown in Fig. 1, consists of two printed-circuit cards mounted on a 3.2-mm-thick stainless steel plate. The cards are fabricated from a 1.6-mm-thick, fiber-glass-base epoxy sheet in the shape of a U. The stainless steel mounting plate is also U-shaped and is positioned upstream to shield the fiber glass cards from the beam. The printed circuits accommodate forty 33- μ m carbon wires soldered across the opening of the U.

Fig. 1.
Double-card harp.

The spacing of the wires on each card is 1.0 mm, but the cards are mounted very close together (distances between wire planes < 0.75 mm), and offset to produce an effective projected wire spacing of 0.5 mm. Figure 2 shows the details. The choice of wire size and material resulted in increased beam-handling capability over the larger tungsten and silicon-carbide wires used previously. Although the beam-handling ability is much better than with the old harps and printed-circuit models, the device is still vulnerable. One full-duty macropulse will sever the center wires if the harp is at a focus. Presently only the central 40 of the 80 wires per plane are used due to the limited capacity of the data-acquisition system.

Two complete assemblies are required to obtain data in both X and Y directions. At this time the double-card harp is used primarily for steering.

The solid beam-scanner (Fig. 3) was designed for a single location between Tanks 1 and 2 of the Alvarez section of the accelerator. This is a one-of-a-kind application and access is very difficult, as can be seen in Fig. 4. Complicating the actuator design problem further was the need for a vacuum lock feature to eliminate the necessity of letting Tanks 1 and 2 up to air every time the scanner required maintenance.

The actuator has a 8-cm stroke along a line 30° above horizontal. The scanner is shaped (Fig. 5) so that its preceding edge and trailing edge traverse the beam first vertically and then horizontally in a single stroke. The vertical and horizontal beam profiles are obtained by differentiating the scanner signal.

The scanner material is graphite, which is very durable under beam heating. The original graphite scanner is still in use after 12 months and a recent inspection revealed very little erosion. Previously used wire scanners of tungsten, silicon carbide, and carbon wires often didn't make it through a single beam-tuneup procedure. The solid-graphite scanner is threaded onto an 8-mm stainless steel cooling tube to carry away the 2-kW beam heating. The 8-mm cooling tube is electrically isolated from ground with a piece of Envex (polyimide) so that it is also used as the signal lead. A further improvement will be to clamp a 5-MeV absorber-collector to the cooling tube just behind the scanner so that phase-scan measurements can also be made at this position.

The sandwich collector (shown in Fig. 6) was designed primarily as an emittance-measuring collector to

Fig. 2.
Double-card harp assembly details.

Fig. 3.
Solid-beam-scanner.

be used as close to full beam intensity as beam size would permit. (We have not yet been able to build a collector or beam scanner that will withstand the full beam intensity for more than a few minutes in the transport region unless the beam size is > 1 cm.) The collector consists of a stack of up to 80 copper foils, 0.4-mm thick, separated by 0.1-mm-thick mica foils. The foils are 1.1-cm wide and 4.4-cm long. The assembled stack is clamped in a cooling fixture threaded to the end of a standard LAMPF actuator. The cooling fixture is a complex structure that allows water to flow all the way around the assembly. The cooling water enters and leaves the fixture through the standard concentric actuator cooling tubes. The assembly is drawn in Fig. 7. The tab pattern allows foil assembly in groups of 10 with uniform tab spacing across the width of the stack. Eight of these substacks are then stacked to produce the 80-foil collector. This arrangement leaves enough room to connect a signal wire (with a small tab receptacle attached), to each foil tab, as shown in Fig. 8.

This device is the sturdiest collector yet made and tested at LAMPF. It has been in use for 6 months and shows little or no beam erosion. The only problem so far encountered was a leak in a cooling fixture braze joint.

(R. K.)

Fig. 4.
Actuator access between Tanks 1 and 2.

Fig. 6.
Sandwich collector.

Fig. 5.
Solid beam-scanner details.

Fig. 7.
Collector details.

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Module 5 Move

To make space available to permit modification of the transition region, the first 805-MHz accelerator module has been moved downstream a distance 0.457 m. This was accomplished by jacking the entire module 13 mm off the floor and positioning roller assemblies under the support rails, as shown in Fig. 1. Dial indicators were used to gauge uniform lift of all 100 hydraulic jacks. The module was moved downstream using the hydraulic pull assembly, as shown in Fig. 2. Alignment measurements were made of each tank section and magnet prior to the move so that the module could be repositioned in its new location. The move was concluded successfully.

(V. H.)

Fig. 8.
Signal wiring to collector tabs.

Fig. 1.

Module 5 with rails lifted on rollers, ready to move.

Fig. 2.

Hydraulic pull assembly to move Module 5.

VAX Conversion in CCR

The LAMPF central control computer is a Systems Engineering Laboratory SEL-840, delivered on-site in December 1969. The original control system design was based upon a distributed data-acquisition system (RICE), which was (1) modular, to be parallel to the linac structure, and (2) closely integrated into the 840 architecture. Work load increases, especially in the experimental areas, were met by adding a satellite computer network which now includes seven small PDP-11's. Four of these computers are interfaced through CAMAC to beamline instrumentation and controls. The other three computers serve special functions on the 840 and have custom-built interfaces.

The capabilities of the 840 are rather limited when measured against the requirements of the expanded system. Furthermore, the 840, because of its age and design, is a maintenance liability. For these reasons it is necessary to replace the 840 with a more versatile and modern computer. A Digital Equipment (DEC) VAX 11/780 was chosen because of its advanced hardware design, wide range of software, excellent maintainability, and the extensive array of peripherals and communications equipment available.

The replacement plans are based on three constraints:

1. Full control functions must continue during the changeover period.

2. The existing RICE and CAMAC data system interfaces to the accelerator hardware must be used.
3. The operator consoles must not change radically.

The Hardware Plan

The steps in the changeover of the system are summarized in Figs. 1, 2, and 3. Figure 1 shows the connections between the SEL 840, the support devices, and the accelerator in early 1980 before the replacement project began. Figure 2 shows the connections between the SEL 840, the support devices, the VAX, and the accelerator at the present time. Figure 3 shows the connections between the VAX 11/780, the support devices, and the accelerator after the conversion is completed but before the 840 removal.

Fig. 1.

Control system before start of changeover.

Fig. 2.

Control system after Summer 1980 shutdown.

In all three figures, the paired rectangular boxes on the right represent PDP-11 computers interfaced to CAMAC. CAMAC is also used to provide the link to the control computing system. The "DIVA-11" is a PDP-11 that is interfaced to a number of disk drives and was incorporated into the system some time ago to expand disk storage and to replace some of the old disks on the SEL 840. The newer operator consoles make use of the standard CAMAC-driven GPIB bus. The Serial CAMAC Highway goes to two CAMAC crates (without remote computers) along the linac. The Status Display provides information in TV format about the current state of the accelerator.

To insure that there are no interruptions in accelerator control functions, we decided to dual-port all parts of the LAMPF data system to the SEL 840 and the VAX. As a first step, the "RIU-11" computer was added to the RICE interface system in the summer of 1980. The RIU-11 is a standard PDP-11/34. Custom-built interfaces connect the RICE Interface Unit (RIU, see Fig. 4) and the SEL 840 to the RIU-11. The link between the VAX and the RIU-11, on the other hand, is a standard DEC interface.

The SEL 840 now takes RICE data, gives RICE commands, and reads and sets the Master Timer by sending messages to the RIU-11. Through its port to the RIU-11, the VAX will be able to do the same. A secondary function of the RIU-11 is to reduce the number of interrupts that the control computer needs to handle. The RIU-11 processes 120 interrupts per second from each of the

Fig. 3.

Control system just before changeover is complete.

three timing signals (pre-T-zero, RIU trigger, and post-RF) needed to synchronize RICE data taking. The SEL 840 is no longer burdened with these interrupts and, of course, the VAX will not have to process them either. At the same time that the Master Timer function was moved to the RIU-11, a new Master Timer with additional timing features (e.g., dual energy) was also included.

The next step is to functionally duplicate the console devices on the VAX. On the SEL 840, a special Computer Interface Unit handles the color CRTs, knobs, keyboard, trackball, and buttons. On the VAX, these devices will be interfaced using a standard and more

Fig. 4.

RIU-11 Hardware configuration.

maintainable CAMAC-based interface. We have already tested a standard color CRT CAMAC interface module and we will test a CAMAC/GPIB keyboard module in December.

The addition of the NET-11 computer is the last major step in the hardware changeover and is needed to dual-port the CAMAC-based remote PDP-11 data systems. The NET-11 will have the same standard hardware, operating system, and basic control program as the RIU-11.

The Software Plan

Just as the hardware plan takes into account the existing facility, the software plan is also based on the existing functions and experience.

The standard VAX/VMS operating system will be used, making it unnecessary to write a new operating system for LAMPF use. In the 10-15 years since the original control system was first developed, the methodology of software system development has changed a great deal. These changes have paralleled the hardware advances from RTL/DTL to LSI and Gate Array technology. The most significant new approach (as far as the VAX control system is concerned) is to consider the total life-cycle cost of a piece of software. In the past, the development cost was the primary consideration. Maintenance cost and costs to upgrade were usually not considered. The software development methodologies that we are using in this project include requirements specification, system design, modular programming, standard documentation, and walk-throughs at each step.

Many of these new software techniques have already been used in the RIU-11 development. Here, the standard RSX-11M operating system is used, reducing development time and maintenance costs. Since all software was developed within the RSX-11M framework, no modifications will be required when the operating system is upgraded. The RIU-11 software is written almost entirely in modular FORTRAN which also simplifies maintenance and changes.

We have learned four basic lessons while operating the accelerator with the SEL 840 Control System. They are:

1. Change is the rule in the accelerator hardware and operation. New devices are added and old ones are changed or removed.

2. There are certain common functions performed by many different applications.
3. Operators and users prefer standard interfaces to programs.
4. Equipment fails frequently. Hence, troubleshooting is often required.

The VAX-based LAMPF Control System will use generalized interfaces so that changes are easier to accommodate. For example, device access will be by device name rather than by channel address. All information about the characteristics of a device will be filed under device name in the Device Table, which will be an expanded version of the Channel Tables on the SEL 840. The application program will not have to know how the device is attached to the system.

Many programs have common requirements which are now supplied by special in-line code in each program. To reduce the burden on the application programmer and improve maintainability, a number of these common requirements have been identified and will be met by general routines. For example, the Automatic Data Taker will provide periodic data and the Automatic Display Updater will provide periodically refreshed output.

The VAX-based LAMPF Control System will also be easier to use because of standardized operator interfaces. Color and control (what actions are taken to select an option) will be used consistently. The Automatic Display Updater will make it easier to use the standard colors.

Another feature of the VAX Control System is that more emphasis is being given to error handling. Items will be checked and cross-checked to insure that bad data do not slip through. For example, all messages between the RIU-11 and the VAX are checked for early identification of errors on the communication link. This emphasis on error handling will help us to troubleshoot problems that may originate from any point in the system.

The first major software application to be developed on the VAX is a subset of the Line-by-Line program. Work is in progress on the required software support for the console devices, Device Table, Data System, Automatic Data Taker, Automatic Display Updater, and a Job Controller. When the RIU-11 software is adapted for the NET-11, CAMAC and remote devices will also be available to Line-by-Line. Once the basic parts of the VAX-based LAMPF Control System are working, the task of converting the library of some 2000 application programs can begin.

(S. B.)

Quench Ratio Calibrations

The beam line polarimeters for EPB (EPPO) and Line B (LBPO) were calibrated at 13 energies between 315 and 800 MeV during Cycles 27 and 28. The polarimeter asymmetry was divided by the beam polarization as measured by the ion source quench ratio to give the analyzing power for each energy. By interpolating from Exp. 27 measurements of the ratio of analyzing powers for $pp \rightarrow pp$ and for EPPO (1.022-1.025), it was possible to extract the analyzing power for $pp \rightarrow pp$ at 17° lab at each energy. Results are shown in Fig. 1, in comparison with selected data. (For selection criteria and references see Ref. 1.) The data are listed in Ref. 2.

(M. M.)

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Fig. 1.

Analyzing power for $pp \rightarrow pp$ at 17° lab (solid squares). Except where otherwise shown, the uncertainties are the size of the square. The line is to guide the eye.

Spectrometer Systems Development

HRS Detectors, Scattering Chamber

A completely new detector system was installed at the focal plane of the spectrometer. The arrangement was outlined in the last progress report and a photo of the completed work is shown in Fig. 1. The new large multiwire chambers were also installed and tested and all the scintillation counters were tested in place.

The small-angle ion chambers were installed in the scattering chamber. The spectrometer can now be placed at $\sim 4^\circ$ without seeing the ion chambers. The two chambers are of similar design and are filled with Ar-CO₂ but operate at different gas pressure, one at 50 torr, the other at 200 torr. The ion chambers have 0.12-mm-titanium windows and were pressure tested to 2 atm. A secondary emission monitor (SEM) was also installed in the scattering chamber. This SEM can only be used for relative beam monitoring since the vacuum of the scattering chamber ($\sim 10^{-4}$ - 10^{-5} torr) is rather poor. Also the scattering chamber often goes up to air for target changes and other services, so the secondary emission efficiency will change. The large SEM outside the scattering chamber

Fig. 1.
HRS detector area.

was completely rebuilt along with its pumping system. It is kept under good vacuum all the time. This SEM can be used if the spectrometer is at an angle larger than 10° .

The environmental glove box for work on reactive targets has been completed. This box can be filled with any inert gas to approximately atmospheric pressure. The new vacuum target storage system is being built with 35 small vacuum compartments. Each compartment can be let up under argon separately so that targets in the other compartments are not disturbed. The main vacuum is maintained by an ion pump. The operation of this target storage system will be assigned to MP-10 personnel.

A new scattering chamber will be installed during the winter shutdown. This chamber will be much like the one recently installed at EPICS. The chamber will rotate with the spectrometer while a 24-cm-i.d. welded bellows will couple the beam line to the chamber. The bellows is designed to accommodate $\pm 25^\circ$ rotation; there are also coupling ports every 20° . Various parts have been designed and fabricated. The main cylinder has been welded and is presently being vacuum leak checked. The remaining parts have all been designed and should be ready for installation during the shutdown.

(N. T. & R. B.)

Line C Polarimeter

A redesigned beam-line polarimeter was installed in June 1980. The new polarimeter contains detectors for

up-down as well as left-right scattering and can therefore simultaneously analyze both components of transverse polarization. The final configuration represents a compromise in achieving maximum analyzing power within the physical restrictions of the existing hardware. The polarimeter uses a CH_2 target and detects both the forward and the recoil protons in coincidence. The forward detectors are 2.5-cm-square by 1.27-cm-thick pilot-F scintillator plastic glued directly onto EMI 9813 photomultiplier tubes. Recoil protons are partially blocked by the target ladder at angles $> 70^\circ$; consequently, the conjugate arm is centered on 61° . The forward arm is then constrained to be centered on 23° (cf. typically 17° on the other beamlines). Maintaining symmetry between the left-right and the up-down scattering systems reduces the number of polarimeter calibrations needed.

To eliminate the time-consuming and error-prone repositioning of the detectors with each energy change, the conjugate detectors were designed large enough (6.4 by 7.6 by 1.0 cm) to intercept recoil protons for incident beam energies between 400 and 800 MeV. Beam energies as low as 300 MeV can be run with little loss in elastic acceptance.

Calibration of the effective polarimeter analyzing power is accomplished via the "quench-ratio" method.¹ The ratio of the beam currents with the injector spin-filter quench field on and off gives the beam polarization with accuracy $\sim 0.5\%$. The asymmetry measured in the polarimeter divided by this beam polarization then yields the polarimeter analyzing power. The polarimeter has been calibrated at several energies between 400 and 800 MeV, and the results (Table I) are compared to proton-proton analyzing-power data in Fig. 1. An effective

TABLE I

RESULTS OF THE LINE C POLARIMETER CALIBRATION

Beam Energy	Effective Analyzing Power
398	0.378 ± 0.010
497	0.387 ± 0.006
530	0.426 ± 0.009
547	0.442 ± 0.007
597	0.462 ± 0.007
647	0.484 ± 0.007
699	0.493 ± 0.010
800	0.454 ± 0.009

Fig. 1.

Comparison of the Line C polarimeter effective analyzing power (heavy dots) to existing proton-analyzing power data.

analyzing power of a few percent less than the proton-proton value can be expected because of dilution of the p-p events by inelastic events from the carbon in the CH_2 target. The p-2p events typically have half the analyzing power of proton-proton events.

Because the conjugate detectors are larger than necessary for any single energy, some consideration was given to reducing accidental coincidences and backgrounds. The scintillators were made relatively thick to improve proton pulse-height separation from low-energy gammas. At 800 MeV, both forward and recoil protons deposit ~ 3 MeV in the respective detectors. The phototubes are run at a reduced voltage (1600 V compared to the 2100 V typical of the other phototubes in the HRS system). At this voltage, protons yield significant pulse heights while gamma rays are not detected.

Figure 2 shows how the effective analyzing power is affected by accidental coincidences. Below $\sim 12\%$ ac-

cidental coincidence rate, simply subtracting the accidentals from the total adequately corrects for accidental coincidences. For accidental rates $> 12\%$, an empirical correction factor obtained from Fig. 2 can be used to correct the polarization.

In general the Line C polarimeter has performed very well. At first a few angle positioning problems were noted, but now an alignment jig has been constructed and should eliminate any further alignment problems. A few of the data points in Table I have been calibrated more than once and the results are self-consistent. Best performance is realized with accidental coincident rate below 12% and a beam properly centered on target.

(W. C.)

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Fig. 2.

Ratio of the effective analyzing power to the mean analyzing power as a function of percent accidentals. The figure shows the total data accumulated at all calibration energies.

HRS Focal Plane Polarimeter

During Cycles 27 and 28 the focal plane polarimeter (FPP) was debugged and used in Exps. 479 and 411 with encouraging results. The buffered CAMAC permits the acquisition of up to 32 events/macropulse. The events are then examined in the MBD to select out only those which appear to have all necessary chamber information and which appear to have scattered at larger than a specified angle in the graphite slabs. Using the raw TDC information the apparent angular resolution for either horizontal or vertical scattering angle in the carbon is ~ 25 mr or 1.4° (FWHM). With full chamber information (and carbon blocks removed), the apparent angular resolution is ~ 7 mr or 0.4° (FWHM).

Since the chambers behind the carbon block are larger than the normal focal plane chambers, they count at higher rates due to room background. While these high count rates do not damage the chambers they do lower the overall system efficiency quite a bit, since all 16 planes must have a single good event in the present analysis scheme. Chamber efficiencies at low count rates are typically 75% overall. These efficiencies can drop very low if singles rates in the chambers rise. A good rule of thumb is to keep the chamber current below $3 \mu\text{A}$ to have overall efficiencies above 50%.

Except at very small angles or with very thick targets the singles rates in the chambers are not target related. Maximum allowable beam currents appear to be ~ 100 pA at spectrometer angles $< 8^\circ$ where the beam is striking the post, and $\sim 2\text{--}3$ nA at angles $> 12.5^\circ$ with the downstream beam pipe inserted.

To date the characteristics of the FPP have been studied in a rather limited set of circumstances. We know from studies with unpolarized beam that false asymmetries are $< 1\%$ for any polarization if one takes care to align the chambers in the software so as to keep the unscattered particles at zero apparent scattering angle within an error of ± 0.5 mr.

The analyzing power of the carbon block has been measured with an in-beam run using S-type beam at an incident energy of 497 MeV. For this run, four graphite slabs having a total thickness of 11.9 cm were used as the analyzer and the beam was centered in the focal plane. The results of this measurement as a function of the scattering angle in the carbon block are shown in Fig. 1. Also shown for comparison are best-fit curves through the SIN data of Besset *et al.*¹ for several time-of-flight (i.e., outgoing particle energy) cuts. In general, our data is in reasonably good agreement with the SIN data,

Fig. 1.

A comparison of carbon analyzing power as measured at HRS and SIN.

although our apparent analyzing powers are consistently higher than the SIN data with no time-of-flight cut. A

possible explanation for this difference might lie in the fact that the SIN data were taken using only 5 cm of graphite as an analyzer, whereas the HRS data were taken using a 12-cm analyzing block. The thicker analyzer used at HRS may have ranged out lower energy particles so that they did not contribute to the trigger. This would have an effect similar to the inclusion of a time-of-flight cut in the SIN data. A weighted average of HRS data over the angular range ~ 5 - 20° yields an average analyzing power of 0.322 compared to a value of 0.295 for the SIN data with no time-of-flight cut.

It is interesting to note that the apparent analyzing power at 4.0° is substantially less than that at 5.0° . Since the multiple Coulomb scattering in 12 cm of carbon is only $\sim 1.4^\circ$ (FWHM), it may be useful to attempt running with a thicker analyzer (~ 30 cm is available). This might result in an increase from $\sim 10\%$ to $\sim 25\%$ in the fraction of events usefully scattered, with little or no apparent loss in the average analyzing power.

To test the entire system under actual experimental conditions, some data were taken for Exp. 479, the so-called Q experiment. As a by-product of the measurement of R, A, R', A' for elastic scattering on ^{40}Ca it was also possible to extract the apparent polarization of the scattered protons. By time-reversal invariance this polarization should be equal to the asymmetry A_y measured for elastic scattering with a polarized beam. A

Fig. 2.

A comparison of P_n and A_y for elastic scattering on ^{40}Ca at 500 MeV.

comparison of a smooth curve for A_y as measured in Exps. 425/433 and the values of P_n as determined in Exp. 479 is shown in Fig. 2.

It can be seen that for both L- and S-type beam, agreement between the P and A_y measurements is excellent, giving us confidence that the system as a whole is operating correctly.

During the shutdown a number of steps will be taken to improve our understanding and hopefully also the operation of the FPP. The buffered CAMAC TDCs, which have shown some reliability and stability problems, will undergo extensive testing. The small amount of existing data taken with 10 graphite slabs will be analyzed to see if this could become our standard mode of running for energies >500 MeV. Finally, the possibility of making use of events in which one of the planes in either X or Y has bad information due to a random singles event will be investigated. If this proves fruitful, a substantial increase in allowable beam currents or a corresponding increase in chamber efficiency would be possible.

(J. A. & J. M.)

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EPICS Development

With the vacuum-coupled scattering chamber in operation, the energy resolution is no longer limited by straggling and multiple scattering in the old chamber vacuum windows. An energy resolution of 140 keV has been obtained at forward-scattering angles near 30° and on heavy targets where the kinematic shift is minimized. The initial software optimization to obtain this resolution went smoothly and quickly, with previously developed techniques and programs used. However, 4 days after the start of Cycle 27, EPICS was given 12 h of experimental area development time to optimize resolution. With 100 nA of primary proton beam and the spectrometer at 0° , the channel multipoles were tuned by directly looking at the incident pion beam. A resolution of 95 keV was seen in this configuration. This same resolution was seen with targets in place in the scattering chamber, when contributions from energy straggling in such targets were subtracted. Work is continuing to see why only 140 keV of energy resolution can be seen with

production beams and moderate spectrometer scattering angles.

The angle resolution as determined in the front chambers is presently limited by the spacing between the wire chamber planes. The distance between the front four planes and the rear four planes will be increased by 3.8 cm before the start of Cycle 29. This should improve angle and position resolution at the target, especially in the horizontal scattering plane.

The trigger inefficiencies as seen in Cycles 25 and 26 have been eliminated during the Cycle 27 startup. Improved shielding along the primary beam line near large spectrometer angles has greatly reduced the high neutron fluxes. The phototube bases for the focal plane scintillators were replaced with bases specially designed for high count rates. The last five dynodes have transistor circuits to insure no voltage sags at high tube currents. In addition, all the logic pulses in the scintillator trigger coincidence circuits were reduced in width from 40 ns to 15 ns.

At the beginning of Cycle 27 and at the end of Cycle 28, a π^+p angular distribution from forward to back angles was taken. When the yield was compared to the known cross sections, no fall off was seen outside the errors of the known cross sections. In addition, at the end of Cycle 28 the same angular distribution was taken for π^-p , where the signal to noise is much worse due to a factor of 9 decrease in the πp cross section. No fall off was seen in this case either. This lack of fall off confirms that the trigger inefficiency problem has been eliminated.

Recently progress was made in rejecting muons in the focal plane trigger. The method uses π/μ differential absorption and range, and was developed during low-intensity chopped beam studies. With this beam, the spectrometer was put at 0° and timing with respect to the accelerator rf gave good π , μ , e separation, even at pion energies of 300 MeV. The effective flight path was nearly 29 m, and a time resolution of 0.6 ns was obtained.

The muon filter consists of a graphite absorber and veto counter added on past the usual focal plane detectors. The graphite thickness is adjusted for energy.

With 61 cm of graphite and pion energies between 230 and 300 MeV, most of the pions interact in the carbon and the noninteracting muons are vetoed after passing through the scintillator. Over 97% of the muons are rejected this way whereas only $\sim 20\%$ of the pions do not interact and are thus also vetoed.

For pion energies between 100 and 230 MeV, π - μ separation occurs principally by the range difference of a

few centimeters. Figure 1 shows the rejected and accepted time-of-flight spectra at a pion energy of 165 MeV with 38.1 cm of graphite range absorber. The muon rejection efficiency is extremely good and the pion inefficiency is quite tolerable. The large tail on the muon peak is from π - μ decay. Electrons will not pose a problem since they will not be present for scattering angles outside a few degrees; also, a threshold Cerenkov counter is available.

The present plan is to build a permanent range absorber in the focal plane. It will consist of a series of carbon blocks and scintillators, each designed to optimally reject muons in 20-MeV steps of the pion energy. The graphite will be tapered along the length of the focal plane to account for momentum shift. For energies between these 20-MeV step sizes, a variable graphite thickness can be added in front. This particular arrangement will involve minimal user rearrangement of the muon filter.

(R. B.)

Fig. 1.

Time-of-flight spectra at a pion energy of 165 MeV for those particles rejected by the veto scintillator and those accepted.

EPICS Engineering

A new scattering chamber for EPICS has been installed (see Fig. 1). The scattering chamber is designed so that it rotates with the spectrometer and the connection between the beam channel and the scattering chamber uses a 40.6-cm-diam welded bellow consisting of two sections. The spectrometer can move $\pm 20^\circ$ without changing the port between the scattering chamber and the spectrometer. All the connections between the scattering chamber, the channel, and the spectrometer are vacuum tight and no windows are required. Two windows remain in the EPICS system: one 0.12-mm-thick stainless steel window at the A-1 target box and one 0.25-mm Mylar window immediately after EA-BM-06. This new system has been dependable and many users have successfully made port changes; however, the alignment of this system has posed some small problems.

In conjunction with the installation of the new scattering chamber, new vacuum systems have been installed (one each in the channel, scattering chamber, and spectrometer) (Fig. 1). The new vacuum pump package eliminates the old pump package on top of the Line A shielding, which caused high neutron flux around the balcony. During the next shutdown this pump will be removed and a revised shielding arrangement will be installed to reduce the neutron flux.

Fig. 1.

New EPICS scattering chamber and vacuum pump system.

The double-charge-exchange setup with the new welded bellows and wedged insertable piece between the channel and the scattering chamber was installed during Cycle 28 for Exp. 549. By rotating the wedge 180° it is possible for the spectrometer to cover an angular range from -3.0 to 43.0° . With these improvements the double-charge-exchange setup ran during the whole month of September without any problems.

(N. T. & R. B.)

Data-Acquisition Systems

Recent major software changes have been directed towards the focal plane polarimeter at HRS. The HRS analyzer has been completely rewritten to make full use of the buffering capability of the CAMAC electronics at HRS. This now makes it possible to acquire as many as 32 events/macropulse into the MBD, although not nearly this many events/second may be taped. An upper limit on the number of events/second that may be written to tape is set by the tape-writing speed. This is presently ~ 600 events/second for the standard analyzer and 400 events/second for the FPP analyzer. These data rates fill a standard tape in <10 min.

An important accessory to this ability to accept data at an order of magnitude higher rate than previously is the ability to reject certain classes of events through testing in the MBD before the data get written to tape. This facility has proved useful not only with the FPP for rejecting events that do not scatter in the carbon analyzer, but also with the more customary class of experiments as an elastic event rejector.

Another useful tool added recently is the ability to reorder the sequence of data words read in from CAMAC into any order desired by the experimenter. This capability has two useful functions. First, it allows data words to occupy the same locations in the data array independent of whether or not the FPP (which requires additional data words compared to the normal style analyzer) is being used. This means that software for the two versions is more nearly compatible than would otherwise be the case. The second useful function is that of substituting a spare ADC or TDC channel in case one should go bad during the course of an experiment. If spare channels are read in, the cables from the malfunctioning channel may be switched to the spare, and the only required change to the software is changing a data file to reflect the new location of the information. This feature allows rapid recovery from a hardware failure with a minimum amount of recalibration.

(J. A.)

III. ACCELERATOR OPERATIONS

This period covers operating Cycles 27 and 28 in their entirety. The accelerator was in operation for almost the entire period, providing beams for research use for 114 days and for facility development for 24 days. A summary of information on beams provided for experimental use is given in Table I.

A shared-time dual-energy mode of operation was introduced and used throughout the period. Negative ion beams were delivered to HRS, Line B, and EPB at 3% duty factor with the beam energy varied between 300 and 800 MeV. The H^+ beam ran at 800 MeV and 6% duty factor. Machine operation continued to be reliable and stable. The major portion of unscheduled downtime for the H^+ beam was attributable to vacuum leaks and overheating in production target boxes, and overheating in target cell quadrupole magnets. Polarized beam operation suffered from injector problems and difficulties in meeting requirements for three experiments simultaneously. A summary of unscheduled facility downtime during research shifts is given in Table II. Because some of the outages were concurrent, the total is greater than the beam downtime.

Accelerator development efforts continued to address various aspects of the transverse phase space tuning problem. Measurements were made to support the continuing development of the PARMILA beam dynamics simulation code. New 0.75-MeV emittance-measurement hardware was tested successfully in the full-duty H^+ beam. A search for sextupole effects from quadrupole

TABLE I
BEAM STATISTICS FOR CYCLES 27 AND 28

	Cycle 27	Cycle 28
No. of experiments served	47	40
H^+ scheduled beam hours	1260	1304
H^- scheduled beam hours	380	232
P^- scheduled beam hours	860	1220
H^+ beam availability, %	81	87
H^- beam availability, %	75	68
P^- beam availability, %	78	70
H^+ average current, μA	530	530
H^- average current, μA	<1	<1
P^- average current, nA	~ 5	~ 5
H^+ beam duty factor, %	6	6
H^- , P^- beam duty factor, %	3	3

steering yielded negative results. A preliminary look at the dual-beam steering problem as it relates to the proposed future operation of PSR confirmed the anticipated complexity of that problem.

(J. B. & R. H.)

TABLE II
UNSCHEDULED MACHINE DOWNTIME

	Downtime (h)	Percent of Total
RF amplifier systems	140	18
Production target cells	215	28
Magnets	100	13
Cooling water systems	33	4
Injectors	149	19
Interlock systems	20	3
Computer control and data acquisition	24	3
Magnet power supplies	19	2
Miscellaneous (utilities, etc.)	75	10
TOTAL	775	

IV. EXPERIMENTS RUN

Exp. No.	Experiment Title	Channel	Beam Hours
32	Precision Measurement of the Processes $\pi^+ \rightarrow \pi^0 + e^+ + \nu$	P ³	1092.0
106	Proton-Induced Spallation Reactions Related to the Isotope Production Program at LAMPF	AB-Nucchem	3.0
120	Measurement of the Polarization Asymmetry and the Differential Cross Section of Pion-Nucleon Charge Exchange From 160 to 500 MeV	P ³	90.0
161	The Microdistribution of Thorium in Meteorites	BSA-RAD	Short Exposure
191	π^+ Nucleus Inelastic Scattering to Giant Resonances	LEP	284.0
217	π^- Production Cross Sections	Biomed	6.0
235	Radiation Repair of Normal Mammalian Tissues	Biomed	42.0
236	Biological Effects of Negative Pions	Biomed	126.0
257	Preparation of Radioisotopes for Medicine and the Physical Sciences Using the LAMPF Isotope Production Facility	ISORAD	2145.0
270	Therapy Beam Development — Biomedical Channel Tuning	Biomed	81.0
271	Therapy Beam Development — Dosimetry	Biomed	395.0
272	Therapy Beam Development — Microdosimetry	Biomed	28.0
274	Pion Radiobiology	Biomed	119.0
275	Pion Clinical Trials	Biomed	1079.0
294	High-Energy Nuclear Reactions	AB-Nucchem	Short Exposure
299	An Investigation of the Reaction ($\pi^+, \pi^+ + p$)	LEP	365.0

308	An Attempt to Make Direct Atomic Mass Measurements in the Thin Target Area	TTA	599.0
315	High Resolution Study of the $(\pi^+, 2p)$ Reaction	LEP	233.4
316	π^- Nucleus Elastic Scattering Between 20 and 50 MeV	LEP	318.0
320	A Comparison of (π^+, xn) and (π^-, xn) Reactions	LEP	33.0
349	Nuclear Reactions of ^{127}I with Pions	LEP P^3	25.0 55.0
371	Muonic X-Ray Spectra of Gases 2. Capture Probabilities in Mixtures	SMC	69.0
382	μSR Investigation of the Effects of Impurities on the Trapping and Diffusion of μ^+ Particles in BCC Metals	SMC	42.0
384	PF Using Mouse Testes as a Biological Test System	Biomed	8.0
389	Inelastic Pion Scattering from Light Nuclei ^{10}B , ^{11}B , ^{14}N , ^{15}N	EPICS	405.0
400	Search for the Rare Decay $\mu^+ \rightarrow e^+e^+e^-$	P^3 SMC	157.0 54.0
406	Neutron Flux Characterization at A-6 Radiation Effects Facility	BSA-RAD	378.0
411	Measurement of Spin-Flip Probabilities in Proton Inelastic Scattering at 800 MeV and Search for Collective Spin-Flip Modes, Preliminary Survey	HRS	120.0
414	Bone Calcium Assay with Muonic X Rays — Signal/Noise and Reproducibility Studies	SMC	83.0
416	Study of Fast Pion-Induced Fission of Uranium	LEP P^3	15.0 11.0
419	π^+ vs π^- Inelastic Excitation of Single Particle and Core-Coupled States in ^{207}Pb and ^{209}Bi	EPICS	25.0
421	Sensitive Search for $\mu^- \rightarrow e$ Conversion	SMC	6.0

425	Proton Elastic Scattering at ~600 MeV by $^{40,46}\text{Ca}$, ^{90}Zr , ^{208}Pb	HRS	283.1
427	Magnet Resonance Studies of μ^+ Electron Defect Complexes in Nonmetals	SMC	44.0
432	Cross Section for Excitation of Unnatural Parity States in ^{12}C at $E_p < 800$ MeV	HRS	149.0
438	The (p,d) Reactions on $^{12,13}\text{C}$, ^7Li , ^{16}O , TSUPic ^{25}Mg , ^{28}Si , and ^{40}Cu Between 650 and 800 MeV	HRS	163.0
439	Particle Gamma-Ray Coincidence Studies From π^- Nuclear Reactions	P ³	239.0
442	Study of the Inclusive Pion Double-Charge- Exchange Reaction	EPICS	125.0
445	Search for the Lepton Flavor Violating Decay $\mu^+ \rightarrow e^+ \gamma \gamma$	SMC	54.4
451	Inelastic Proton Scattering in the Range 300 to 500 MeV	HRS	221.0
465	Radiochemical Study of Pion Single Charge Exchange	P ³	32.0
466	Nuclear Configuration of Individual Core- Coupled States in ^{209}Bi from Inelastic $\pi^\pm$ Scattering	P ³	220.0
473	Study of Giant Multipole Resonances with 800-MeV Protons	HRS	100.0
476	The Analyzing Power for Polarized Protons + $^{24,26}\text{Mg}$ at 500 and 800 MeV	HRS	83.0
479	Measurement of R, A, R', and A' in Elastic and Inelastic Scattering of 800-MeV Protons from Light Nuclei — Revised Version of Q Proposal	HRS	106.0
481	Excitation of High-Spin States in Tz = 0 s-d Shell Nuclei by Pion Elastic Scattering	EPICS	135.0
483	Measurement of the Angular Dependence of Tensor Polarization in the $2\text{H}(\pi^+, \pi^+)2\text{H}$ Reaction	LEP	478.0

487	Measurement of the Nuclear Resonance Effect in Some Pionic Atoms	LEP	203.0
491	Experimental Determination of the Strong Interaction Shift in the 2p-1s Transition of Pionic Deuterium and Hydrogen Atoms	SMC	441.0
492	Polarimeter Calibrations and Search for Energy Dependent Structure in pp Elastic Scattering Via Cross Section, Analyzing Power, and Wolfenstein Parameter Measurements	AB	Parasite
494	Nuclear Charge Parameters of the Stable Ruthenium and Palladium Isotopes	SMC	51.0
495/506	Isospin Mixing in ^{12}C	EPICS	340.0
498	Measurements of Longitudinal Cross-Section Difference for Longitudinal Polarized Beam and Targets (pp, pd, np)	EPB	1665.0
499	Muon Longitudinal and Transverse Relaxation Studies in Spin-Glass Systems	SMC	162.0
500	Fission Fragment Distributions in Fast Pion-Induced Fission of ^{238}U	P ³	51.0
504	Measurement of the Total Cross Section Difference for Proton-Proton and Proton-Neutron Scattering in Pure Transverse Initial Spin States in the 400-800-MeV Region	AB	1568.0
505	Measurement of the Transverse Spin-Spin Asymmetry in the Reaction $pp \rightarrow d\pi^+$ in the 500-800-MeV Region	AB	Parasite
506	Inelastic Pion Scattering to the Unnatural Parity Levels in ^{12}C and ^6Li	EPICS	Ran With 495
508	Dibaryon Resonances in Pion Production	HRS	178.0
510	Energy Dependence of Elastic and Inelastic Scattering of $\pi^\pm$ by ^{13}C and 116 and 280 MeV	EPICS	61.0
531	Excitation of Unnatural Parity States in ^{12}C at 500 MeV	HRS	101.0

539	Search for Pure Neutron/Proton Transitions in ^{14}C	EPICS	346.0
542	Feasibility Study — Using an Existing Neutron Beam Pipe at LAMPF Beam Stop for Crystal Diffraction Spectrometer Experiments	BSA-RAD	700.0
543	A Product Recoil Study of the $(\pi^{\pm}, \pi^{\pm}, \text{N})$ Reaction	LEP P ³	7.8 25.0
544	Search for a Fast Fission Process	LEP	48.0
547	Search for Fast Muonium in Vacuum	SMC	231.0
549	A Study of the DCX Reaction Mechanism — the $^{42}\text{Ca}(\pi^+, \pi^-)^{42}\text{Ti}$ Reaction	EPICS	349.0
553	Study of Target Thickness Effects in the Cross-Section Measurement of the Pion Single-Charge-Exchange Reaction $^{13}\text{C}(\pi^+, \pi^0)^{13}\text{N}(\text{G.S.})$ from 50 to 350 MeV	P ³ LEP	61.0 44.0
555	Total Cross-Section Measurements of the Single-Charge-Exchange Reaction $^{12}\text{C}(\pi^+, \pi^0)^{12}\text{N}(\text{G.S.})$	P ³	139.0
556	A Proposal to Study the (p, p') Process Leading to π -Atomic States	HRS	53.0
560	Study of Neutron-Irradiation-Induced Growth of Metals at Radiation Effects Facility	BSA-RAD	63.0
571	Muon Spin Rotation Studies of Dilute Magnetic Alloys	SMC	209.0
579	A Radiochemical Study of Neutron-Deficient Products From 500 MeV and ^{238}U	AB-Nucchem	Short Exposure
580	Cross Sections and Analyzing Powers for Elastic and Inelastic Scattering of 515-MeV Protons From ^{13}C	HRS	44.0

V. NEW PROPOSALS

Proposal No.	Title	Spokesmen	Institution
610	Use of LAMPF Beam Stop to Obtain ^{60}Fe	W. Henning W. Kutschera	ANL ANL
611	Excitation Functions of the Four Reactions $^{130}\text{Te}(\pi^{\pm}, \pi^{\pm}\text{N})$	J. J. Hogan	McGill Univ.
612	Mass of ^{14}Be	K. K. Seth H. Nann	Northwestern IN Univ.
613	Study of Deeply Bound Hole States in the Tin Isotopes via the $(\bar{p}, d)$ Reaction	A. Saha K. K. Seth	Northwestern Northwestern
614	Studies of Scalar and Vector Parts of the π -N Interaction by Measuring Nuclear Deexcitation Gamma-Ray Correlation Following Inelastic Pion Scattering	H. O. Funsten	College of William & Mary
616	Nuclear Information From the Spin Rotation and Depolarization Parameters in the $^{12}\text{C}(p, p')$ Reaction to the $1^+ 12.72$ MeV $T = 0$ and to the $1^+ 15.11$ MeV $T = 1$ Levels	M. Bleszynski J. B. McClelland J. Moss N. M. Hintz	UCLA Los Alamos Los Alamos Univ. of MN
617	A Study of the $(3/2, 3/2)$ Resonance in Light Nuclei	K.O.H. Ziock	Univ. of VA
618	Inelastic $\pi^{\pm}$ Scattering From the $N = 28$ Isotones	C. L. Morris C. Fred Moore	Los Alamos Univ. of TX
619	Inelastic Pion Scattering to 0^+ and 2^+ States in ^{40}Ca and ^{42}Ca	C. F. Moore H. T. Fortune C. L. Morris	Univ. of TX Univ. of PA Los Alamos
620	The Nuclear Reaction π^+ vs π^- Inelastic Scattering on ^{40}Ca	C. F. Moore C. L. Morris	Univ. of TX Los Alamos
621	Good Resolution Study of $^{16}\text{O}(\pi, \pi')$	D. Dehnhard H. T. Fortune	Univ. of MN Univ. of PA
622	Investigation of the Strong Cancellations of Neutron/Proton Transition Amplitudes in ^{14}C	D. B. Holtkamp H. W. Baer	Univ. of MN Los Alamos

623	Measurement of Cross Section, Analyzing Power and Depolarization Parameters in the $^{28}\text{Si}(p,p')^{28}\text{Si}^*$ (6° $T = 0$ and $T = 1$) Reaction at 400 MeV	C. Glashausser	Rutgers Univ.
624	An Attempt to Observe Directly the Coupling of Particle-Hole States to Δ -Hole States	C. D. Goodman	IN Univ.
625	Inelastic Scattering of Pions to Giant Resonances	N.S.P. King R. E. Anderson R. J. Peterson	Los Alamos Univ. of NC Univ. of CO
626	Measurement of the Depolarization Parameters D_{nn}' , D_{ss}' , and D_{ss}' in Proton-Nucleus Scattering at Very High Excitation Energies	C. Glashausser J. McGill	Rutgers Univ. Univ. of TX
627	Measurement of the Relative Sign of Neutron and Proton Transition Matrix Elements in (p,p') Reactions	M. V. Hynes A. M. Bernstein	Los Alamos MIT
628	Study of the $(\pi,\pi p)$ Reaction and Quasifree Scattering in ^4He	D. Ashery P.A.M. Gram	ANL Los Alamos
629	Feasibility of He-JET Techniques for Studying Short-Lived Nuclei Produced at LAMPF	R. C. Greenwood M. E. Bunker W. L. Talbert, Jr.	Idaho Nat. Eng. Lab. Los Alamos Los Alamos
630	A Study of Proton Inelastic Scattering at Zero Degrees and a Search for Giant Monopole and Giant Magnetic Dipole Excitations	J. B. McClelland J. M. Moss N. M. Hintz	Los Alamos Los Alamos Univ. of MN
631	Study of the Spin-Flip Probability for Elastic and Inelastic Scattering From Odd-Mass Nuclei	S. J. Seestrom-Morris T. A. Carey J. M. Moss D. Dehnhard	Los Alamos Los Alamos Los Alamos Univ. of MN
632	Can Proton Density Differences Be Extracted From Medium- Energy p -Nucleus Elastic Scattering Data?	M. Barlett G. W. Hoffmann	Univ. of TX Univ. of TX

633	Measurement of p-p Scattering in the Coulomb Interference Region Between 300 and 800 MeV	F. Irom G. Pauletta	UCLA UCLA
634	Measurement of Parity Violations in the p-Nucleon Total Cross Sections at 800 MeV	R. Carlini R. L. Talaga V. Yuan	Los Alamos Los Alamos Univ. of IL
635	Spin Measurements in pd Elastic Scattering	B. E. Bonner G. J. Igo M. Bleszynski	Los Alamos UCLA UCLA
636	A Measurement of the Wolfenstein Polarization Parameters D_{LL} , D_{SL} , K_{LL} , and K_{SL} for p-p Elastic Scattering	C. L. Hollas	Univ. of TX
637	A Measurement of the Vector Polarization of the Deuteron in the Reaction $pp \rightarrow d\pi^+$	B. E. Bonner	Los Alamos
638	A Search for Oscillations Using Muon-Neutrinos	T. W. Dombeck	Univ. of MD
639	Muon Spin Rotation Study of Muon Bonding and Motion in Selected Magnetic Oxides	C. Boekema A. B. Denison	Los Alamos Univ. of WY
640	Transverse and Longitudinal Field μ SR Measurements in Selected Ternary Metallic Compounds	S. A. Dodds R. H. Heffner D. E. MacLaughlin	Rice Univ. Los Alamos UC, Riverside
641	Measurement of Cross Section and Analyzing Powers for Elastic and Inelastic Scattering of 400 to 500 Protons From ^{14}C	C. J. Harvey S. J. Seestrom-Morris	Univ. of TX Los Alamos
642	Reactive Content of the Optical Potential — Phase II	G. W. Hoffmann T. McGill	Univ. of TX Univ. of TX
643	Structure of States in the Oxygen Isotopes Via Measurements of the Spin Depolarization and Spin Rotation Observables	B. Aas M. V. Hynes	UCLA Los Alamos
644	Tests of the Polarization-Analyzing Power Equality in Elastic Scattering of Intermediate-Energy Protons From Nuclei	G. J. Igo	Univ. of CA

645	A Search for Neutrino Oscillations at LAMPF	T. Y. Ling T. A. Romanowski	OH State Univ. OH State Univ.
646	Hyperfine Structure of Muonic ^3He and Muonic ^4He Atoms	V. W. Hughes P. O. Egan	Yale Univ. Yale Univ.

VI. MEETINGS

LAMPF Users Group, Inc.

Linda Tyra

Fourteenth LAMPF Users Group Annual Meeting

The LAMPF Users Fourteenth Annual Meeting held in Los Alamos on October 27-28, 1980, was attended by 185 members of the LAMPF Users Group. Chairman Robert Eisenstein (Carnegie-Mellon Univ.) presided at the opening session, which included a welcoming address by Los Alamos National Laboratory Director Donald M. Kerr. A safety award plaque was presented to the LAMPF Users Group by Kerr in recognition of one million man hours of experimental effort without a disabling injury. An Annual Status Report by LAMPF Director Louis Rosen and a LAMPF Operations Report by Donald Hagerman were also presented. Leonard Kisslinger (Carnegie-Mellon Univ.) addressed the group on "The Structure of Nuclei and Hadrons at Medium Energies."

The afternoon session included the Chairman's Annual Users Group Report and the announcement of the election results of three board members: Harold Jackson (ANL) as Chairman-Elect for 1981, and two new members, Ernest J. Moniz (MIT), and L. Wayne Swenson (Oregon State Univ.). Other members whose terms continue in 1981 are: Chairman, Felix H. Boehm, (Cal. Tech.) serving a two-year term (first year as Chairman, second year as Past-Chairman); Robert Eisenstein,

Cyrus M. Hoffman (Los Alamos), George J. Igo (UCLA), Anthony L. Turkevich (Univ. of Chicago), and Donald K.F. Cochran (Los Alamos), Secretary/Treasurer. Eisenstein proposed an amendment, recommended by the Board of Directors, to the LAMPF Users Group Bylaws that the terms of Technical Advisory Panel members be increased to three years with one-third of the members elected each year.

Future Directions in Nuclear Physics was the theme of the afternoon session, and the following speakers were featured: Douglas Bryman (TRIUMF, Univ. of British Columbia), "Some Physics Possibilities for the Kaon Factories"; Howel G. Pugh (LBL), "Ultra Relativistic Heavy Ions"; William Bertozzi (MIT), "A View of the Future in Electromagnetic Nuclear Physics"; and Kurt Kilian (Max Planck Institut für Kernphysik, Heidelberg), "Antiproton Physics with LEAR".

The Tuesday morning session was a LAMPF Retrospective Review, featuring the following speakers: Benjamin Zeidman (ANL), "Pion Scattering Research at LAMPF"; Norton M. Hintz (Univ. of Minnesota), "HRS, Was It Worth \$5 Million?"; Cyrus M. Hoffman (Los Alamos), "Weak Interactions at Intermediate Energies"; Billy E. Bonner (Los Alamos), "Nucleon-Nucleon Physics During the 70s"; and James N. Bradbury (Los Alamos), "Recent Results in LAMPF Biomedical Research."

The afternoon session was devoted to Working Group meetings. New Chairmen elected for 1981 are:

Stopped Muon Channel	Howard Matis	Los Alamos
Solid State Physics and Materials Science	Robert Brown	Los Alamos
Neutrino Facilities	Herbert Chen	UC, Irvine
Muon Spin Rotation	D. E. MacLaughlin	UC, Riverside
Nuclear Chemistry	Lon-Chang Liu	Los Alamos
Biomed	James Bradbury	Los Alamos
Nucleon Physics Laboratory	Lawrence Pinsky	University of Houston
Polarized Facilities	Michael McNaughton	Los Alamos
EPICS	David B. Holtkamp	University of Minnesota
Computer Facilities	Dennis Perry	Los Alamos
p ³	William J. Briscoe	UC, Los Angeles
LEP	Felix E. Obenshain	ORNL
HRS	Gary S. Blanpied	University of South Carolina
Graduate Student/Postdoc	John Faucett	Oregon State University
π^0 Spectrometer	Helmut Baer	Los Alamos

Technical Advisory Panel

The Technical Advisory Panel (TAP) met October 29, 1980, and discussed medium-term objectives. Careful planning is of the utmost importance if LAMPF is to continue to operate productively and to make the most of its future opportunities. Eleven subcommittees of TAP made in-depth studies of the needs and opinions of the User Community. A questionnaire had been circulated to all spokesmen of experiments that ran during Cycles 25 and 26 in order to assess their needs at LAMPF in the short- to medium-range future, and thereby to complement the work of the Long-Range Planning Committee in addressing possible future options for LAMPF. The following studies are outlined in a lengthy report compiled by the TAP:

Polarized Ion Sources	P ³
Nuclear Chemistry	HRS
Finances	LEP
Proton Storage Ring	Stopped Muon Channel
Nucleon Physics Lab	Kaon Factories
EPICS	

In regard to long-term, large-budget development projects, the TAP enthusiastically supports LAMPF's continued efforts to investigate projects for the future that are important not only for good physics but also for the continued viability of LAMPF. The TAP would like to extend its support to the proposed construction of a kaon factory at LAMPF and to the study of the kind of physics that might be accomplished. The TAP is also strongly in favor of continued studies of the possible neutrino program at the new Proton Storage Ring.

The TAP is in support of most current LAMPF plans for the near and intermediate future. There is already extensive communication between the Users and the LAMPF management by which the Users have the opportunity to provide input. In addition, the TAP feels that management has been wise in its direction of the facility and in the allocation of resources.

Most problems that exist at present can be linked to a shortage of money and/or manpower, which causes their solution to be delayed. Selection of priorities then becomes more important and difficult. The TAP has attempted in its 1980 study to identify projects that the User Community feels are important and deserving of attention in the near future.

The TAP did not attempt to give a ranking to all the many items mentioned in the report, but instead focused

on some of the larger issues. Among these, progress toward larger duty factor and full intensity are accorded high priority, as is the development of large impact technology, such as the optically pumped polarized ion source. Improvements that add to the flexibility of LAMPF are also applauded, such as the construction of "Caboose Caves" at SMC, spin precessors for Lines B and C, and development of surface μ beams. Better reliability of LAMPF can be achieved by improvement of equipment such as the front-end magnets at the various channels and replacement of the accelerator control computer. The development of new facilities at LAMPF, such as the neutrino area at the beam stop or at the PSR, are especially encouraged because of the opportunities they represent for important basic research. Finally, the TAP feels that it is essential that LAMPF be active in developing options for the long-range future in order to continue its enviable record of research accomplishments.

Board of Directors

The Board of Directors of the LAMPF Users Group, Inc. met on October 29, 1980, and accepted the recommendations of the TAP as outlined in their report.

The Board of Directors established that the ballots for the proposed amendment to the LAMPF Users Group Bylaws, which increases the term of office for TAP members to three years, should be immediately circulated to the membership and submitted by November 25, 1981. The proposed amendment was approved by 95% of those voting.

New TAP members appointed to three-year terms ending December 21, 1983, are:

James F. Amann (Los Alamos)
Robert H. Heffner (Los Alamos)
Paul J. Karol (Carnegie-Mellon Univ.)
Michael A. Paciotti (Los Alamos)

TAP members whose terms were extended one year following the bylaw amendment with terms ending as indicated are:

Herbert H. Chen (UC, Irvine) 1982
Kenneth M. Crowe (LBL) 1981
Daniel H. Fitzgerald (UCLA) 1982
Robert P. Redwine (MIT) 1981
William R. Wharton (Carnegie-Mellon Univ.) 1982
Benjamin Zeidman (ANL) 1982

TAP members whose terms end December 21, 1981, are:

Billy E. Bonner (Los Alamos)

E. Brooks Shera (Los Alamos)

The date for the Fifteenth Annual LAMPF Users Meeting was set for November 2-3, 1981.

Visitors Center

During this report period, 435 research guests working on LAMPF-related activities or participating in ex-

periments visited LAMPF. Eighty-eight were foreign visitors. A total of 392 visitors checked in and 411 visitors checked out of the Visitors Center. A complete list is attached in Appendix C.

Housing requirements for 1980 increased approximately 15% over the previous year. Families housed in LAMPF apartments totalled 34, students housed totalled 49 in efficiency units, and townsite sublets totalled 47. The number of Users in LAMPF efficiency (short-term) units was well over 550 for the year.

A breakdown of user statistics is set forth in Table I.

TABLE I
STATISTICS

●MEMBERSHIP

Non-Los Alamos National Laboratory	760
Los Alamos National Laboratory	196
TOTAL	956

●FIELDS OF INTEREST

Nuclear and Particle Physics	736
Nuclear Chemistry	148
Solid State Physics & Materials Science	192
Theory	173
Biomedical and Biological Applications	269
Weapons Neutron Research	98
Data Acquisition	169
Administration, Coordination, Facilities, Operations, Practical Applications, etc.	159
Isotope Production	98

(Note: These numbers do not add to total membership because of duplicate interests.)

●INSTITUTIONAL DISTRIBUTION

<i>Membership by Institutions</i>	
Los Alamos National Laboratory	196
National or Government Labs	98
U.S. Universities	365
Industry	53
Foreign	170
Hospitals	58
Non-Affiliated	16
TOTAL	956

<i>Number of Institutions</i>	
National or Government Labs	24
U.S. Universities	112
Industry	39
Foreign	84
Hospitals	42
Non-Affiliated	7
TOTAL	308

●REGIONAL BREAKDOWN

<i>East</i> (PA, NJ, DE, WASH DC, MA, NY, CT, VT, RI, NH, ME)	141
<i>Midwest</i> (OH, MO, KS, IN, WI, MI, IL, ND, SD, NB, IA, MN)	99
<i>South</i> (MD, VA, TN, AR, WV, KY, NC, SC, AL, MS, LA, GA, FL)	83
<i>SW Mountain</i> (MT, ID, UT, WY, AZ, CO, NM, OK, TX)(excluding Los Alamos)	142
<i>West</i> (AK, HI, NV, WA, OR, CA)	125
<i>Foreign</i>	170
<i>Los Alamos National Laboratory</i>	196
TOTAL	956

Intermediate-Energy Nuclear Chemistry Workshop
B. J. Dropesky (Los Alamos National Laboratory)

During the week of June 23-27, 1980 many representatives of the nuclear chemistry and nuclear physics community met in Los Alamos and participated in a stimulating and fruitful Intermediate-Energy Nuclear Chemistry Workshop. Of the 97 participants at the Workshop, 14 were from abroad (Japan, Switzerland, West Germany, France, Israel, and Canada), 38 were from numerous U.S. laboratories and universities, 11 were graduate students, and 34 were Los Alamos National Laboratory scientists. The three "meson factories," LAMPF, TRIUMF (Canada), and SIN (Switzerland), plus the other accelerator laboratories having intermediate-energy nuclear science research programs, were represented.

The major objectives of the Workshop were to review the current status of nuclear chemistry and physics programs at the forefront research facilities and, based on extensive discussions of present deficiencies in our knowledge, to arrive at some recommendations for future directions for these programs. The Workshop was organized by the following people:

P. J. Karol (Carnegie-Mellon University), Chairman;
B. J. Dropesky (Los Alamos National Laboratory),
Co-Chairman;
D. J. Vieira (Los Alamos National Laboratory), Administrative Assistant;
M. M. Sternheim (University of Massachusetts);
L.-C. Liu (Los Alamos National Laboratory);
E. P. Steinberg (ANL);
C. J. Orth (Los Alamos National Laboratory);
R. A. Naumann (Princeton University);
J. D. Knight (Los Alamos National Laboratory);
R. G. Korteling (Simon Fraser University);
G. W. Butler (Los Alamos National Laboratory);
A. L. Turkevich (University of Chicago);
N. Imanishi (Kyoto University/Los Alamos National Laboratory);
T. Nishi (Kyoto University); and
H. S. Pruyss (SIN).

Following welcoming remarks by G. A. Cowan, Los Alamos National Laboratory's Associate Director for Chemistry, Earth, and Life Sciences, and by D. C. Hoffman, CNC-Division Leader, Chairman Karol set down the basic concerns of this nuclear science meeting with the two questions, "Where are we now?" and "Where

Nobu Imanishi and Bruce Dropesky

should we be going?" The first two days of the Workshop were devoted to the first question with a group of review talks, both experimental and theoretical, on the contributions of the international nuclear science community to our understanding of the properties and structure of nuclei and also of the complex nuclear interactions that occur at intermediate energies. The next two days of the meeting consisted of the informal discussions and deliberations of six working panels devoted to timely preselected topics, concluding on the fifth day with summary reports and recommendations for future research. Below is an outline of the formal proceedings of the Workshop, and lists the invited review talks and the topics covered by the working panels.

A broad spectrum of material was covered in this Workshop, as illustrated by the variety of topic areas covered by the invited talks and the working panels. The weaknesses in our understanding of the phenomena discussed were examined, and specific recommendations were made regarding directions and strategies for future

research, both experimental and theoretical. These observations are too numerous to summarize here, but they are spelled out in the forthcoming Proceedings of the

Workshop. Requests for copies of the Proceedings should be addressed to B. J. Dropesky, MS 824, Los Alamos National Laboratory, Los Alamos, NM 87545.

Bill Gibbs and Ellis Steinberg

Henk Pruys and Jörg Hüfner

Hans Walter

Tomota Nishi

INTERMEDIATE-ENERGY NUCLEAR CHEMISTRY WORKSHOP

Ed Remler and Mort Sternheim

OUTLINE OF PROCEEDINGS

INTERMEDIATE-ENERGY NUCLEAR CHEMISTRY WORKSHOP

WELCOMING REMARKS

- G. A. Cowan, Los Alamos National Laboratory, Associate Director for Chemistry, Earth, and Life Sciences
D. C. Hoffman, Los Alamos National Laboratory, CNC-Division Leader

INTRODUCTION TO THE WORKSHOP

- P. Karol, Carnegie-Mellon University, Pennsylvania

INVITED TALKS

- H. K. Walter, Swiss Federal Institute of Technology (ETH), Zürich, Switzerland
"Pion Reactions in Complex Nuclei"
- H. Daniel, Technical University of Munich, West Germany
"Formation and Properties of Mesonic Atoms"
- W. R. Gibbs, Los Alamos National Laboratory
"Theories of the Pion-Nucleus Interaction"
- J. Hüfner, University of Heidelberg, West Germany
"Theory of Precompound Reactions and Nucleon Spectra after Pion Absorption"
- T. Nishi, Kyoto University, Japan
"Current Nuclear Reaction Studies in Japan"
- D. H. Boal, Simon Fraser University, Vancouver
"Clusters, Nucleons, and Quarks in Intermediate-Energy Reactions"
- M. Epherre, Orsay, France
"Nuclei Far from β -Stability"
- E. A. Remler, College of William & Mary, Virginia
"Intranuclear Cascade Theory as a Quantum Mechanical Approximation"
- H. A. Thiessen, Los Alamos National Laboratory
"Some Strange Reactions with Nuclei"

SUMMARY REPORTS AND RECOMMENDATIONS FROM THE PANELS

- NC-1: Pion-Nucleus Reactions
E. P. Steinberg, Argonne National Laboratory, Chairman
C. J. Orth, Los Alamos National Laboratory, Co-Chairman
- NC-2: Nucleon-Nucleus Reactions and Nuclei Far from Stability
R. G. Korteling, Simon Fraser University, Chairman
G. W. Butler, Los Alamos National Laboratory, Co-Chairman
- NC-3: Mesonic Atoms
R. A. Naumann, Princeton University, Chairman
J. D. Knight, Los Alamos National Laboratory, Co-Chairman
- NC-4: Exotic Interactions -
A. Antiproton Nucleus Interactions
B. Role of Mesons in Nuclei
C. Neutrino Properties and Nucleon Decay
D. Interactions of Kaons with Nuclei
A. L. Turkevich, University of Chicago, Chairman
E. V. Hungerford, University of Houston, Co-Chairman

(Continued on next page)

NC-5: New Theoretical Approaches

M. M. Sternheim, University of Massachusetts, Chairman

L.-C. Liu, Los Alamos National Laboratory, Co-Chairman

NC-6: New Experimental Techniques and New Nuclear Chemistry Facilities

J. Hudis, Brookhaven National Laboratory, Chairman

D. J. Vieira, Los Alamos National Laboratory, Co-Chairman

CLOSING COMMENTS

D. Nagle, Los Alamos National Laboratory, Alternate MP-Division Leader

ROUNDUP OF WORKSHOP

P. Karol, Carnegie-Mellon University

VII. LAMPF NEWS

James D. Doss, MP-3, continues to earn recognition for his pioneering work in heating of tissue by localized current fields to produce hyperthermic treatment of tumors and, more recently, thermokeratoplasty, a technique for altering corneal curvature for the treatment of severe visual problems.

Danny Doss joined MP-Division in 1964. He made contributions to the design of the LAMPF accelerator in amplifier design and fault protection and was granted a U.S. patent (with D. C. Hagerman) for a high-voltage regenerative pulse modulator in 1971. Beginning in 1972 he turned his attention to biomedical engineering. Since

that time he has published in numerous fields of biomedical engineering, including electrosurgery, ECG techniques, radiation source implantation, hyperthermia, and thermokeratoplasty. He is inventor or co-inventor on four patents and two patents pending in biomedical engineering.

Danny recently received recognition by Laboratory Director Donald M. Kerr, together with other inventors in the Laboratory. He recently received the Engineer of the Year Award for 1980 from the Los Alamos Section of IEEE.

Progress at LAMPF congratulates Danny Doss for his accomplishments and well-earned honors.

Danny Doss

M. M. Kligerman, M.D., resigned September 1, 1980, to take up new duties at the University of Pennsylvania. Dr. Kligerman was the leader of the pion radiotherapy group at LAMPF from the beginning of experimental work here, and is due credit for much of the

important progress which this new modality of cancer therapy has made. Klig remains a member of the LAMPF Users' Group; we wish him continued success in his new position and hope to see him again at LAMPF from time to time.

Giorgio Giacomelli of the University of Bologna and CERN lectured at LAMPF on July 30, 1980, on recent results in neutrino research at CERN. Professor Giacomelli is shown below with Minh Duong-Van and Helmut Baer, Chairman of the LAMPF Colloquium.

*Giorgio Giacomelli,
Minh Duong-Van,
Helmut Baer*

Prof. Emilio Segrè of the University of California at Berkeley lectured at the LUGI Young Scientists' Invited Lecture Series on September 19, 1980. He is shown here at the lectern in the LAMPF Auditorium.

Emilio Segrè

(Photo credit — Patti Wolf, Los Alamos Monitor)

Prof. Hans A. Bethe of Cornell University lectured on "Supernova Theory" at the LAMPF Colloquium on September 24, 1980. Prof. Bethe is shown during this lecture.

Hans Bethe

(Photo credit — Al Gibes, Los Alamos Monitor)

Louis Rosen, Director, LAMPF, attended the Fourth Session of the Joint Coordinating Committee on Research in the Fundamental Properties of Matter held in Moscow, December 9-10, 1980. James E. Leiss, Deputy Director of the Office of High Energy and Nuclear Physics, USDOE, headed the delegation. Other members were: J. Ballam, SLAC; D. Allan Bromley, Yale; Leon Lederman, FNAL; George Vineyard, BNL; Fredrik Zachariasen, Caltech/Los Alamos; Bernard Hildebrand, DOE; S. Kish, US Embassy, Moscow; and T. Toohig, FNAL. The delegation met with a counterpart delegation from the USSR headed by I. V. Chuvilo. The agenda of the Joint Committee, as approved, included topics of interest to LAMPF Users as follows:

visits to laboratories for planning and preparation of experimental proposals in neutrino and pion-nucleus experiments and facilities for biomedical research on accelerators, and particle and nuclear theory collaboration. Interested Users may obtain further information by contacting MP-Division Office, Los Alamos National Laboratory MS-850, Los Alamos, NM 87545.

Effective January 1, 1981, the Los Alamos Scientific Laboratory became known as the Los Alamos National Laboratory. The Laboratory continues to be operated by the University of California for the Department of Energy. The name change is consistent with the Laboratory's leading role in the national interest and with the will of Congress.

SEMIANNUAL PROGRAM ADVISORY COMMITTEE (PAC) MEETING

Meeting of PAC Subcommittee on Low-Energy Pion Channel (LEP).

Clockwise from center foreground: D. Nagle, D. Bryman (Chairman), E. Hoffman, G. Miller, F. Tabakin, and H. Jackson.

SEMIANNUAL PROGRAM ADVISORY COMMITTEE (PAC) MEETING

*Meeting of PAC Subcommittee on High-Energy Pion Channel (P^3).
Clockwise from center foreground: D. Bowman, R. Siegel, R. Silbar, T. W. Donnelly, G. Jones, R. Werbeck, and G. West (Chairman).*

*Meeting of PAC Subcommittee on High-Resolution Proton Spectrometer (HRS).
Clockwise from center foreground: C. Barnes, A. Bacher (Chairman), R. Serber, W. Coker, R. DeVries, D. Lind, W. Bertozzi, and H. A. Thiessen.*

CLINTON P. ANDERSON MESON PHYSICS FACILITY MILESTONES

Official Ground Breaking	February 15, 1968
Spinoff: Adoption of LAMPF Accelerating Structure for X-Ray Therapy and Radiography Machines	ca 1968
5-MeV Beam Achieved	June 10, 1970
Adoption of a LAMPF Standard Data-Acquisition System	August, 1970
100-MeV Beam Achieved	June 21, 1971
211-MeV Beam Achieved	August 27, 1971
800-MeV Beam Achieved	June 9, 1972
Spin off: First Use of Electrosurgical Forceps in Open Heart Surgery (UNM)	September 13, 1972
Discovery of ^{236}Th (Experiment Zero)	September 25, 1972
Dedication to Sen. Clinton P. Anderson	September 29, 1972
Spinoff: First Hyperthermic Treatment of Animal Tumors	October, 1972
First H^- Injector Beam	March 28, 1973
First Simultaneous H^+ and H^- Beams Beam to Area B	May 4, 1973
First Experiment (#56) Received Beam	July 15, 1973
First Meson Production, Beam to Area A	August 24, 1973
Beam to Area A East	August 26, 1973
First Medical Radioisotope Shipment	February 6, 1974
Usable 100 μA Beam to Switchyard	July 30, 1974
Pi-Mesic Atoms with 'Ticklish' Nuclei	September 5, 1974
	October 13, 1974

**SPECTRUM IDENTIFYING FIRST MESONS AT LAMPF
USING A MOMENTUM ANALYZED BEAM AND E COUNTER**

(Continued on next page)

MILESTONES

(Continued)

First Experimental Pion Radiotherapy	October 21, 1974
First Tritium Experiment (80,000 Ci)	November, 1974
Start of Great Shutdown	December 24, 1974
New Precise Measurements of Muonium Hyperfine Structure Interval and μ^+ Magnetic Moment	1975-77-80
Q Data Acquisition Software Operational	June, 1975
Spinoff: First Use of ^{82}Rb for Myocardial Imaging in Humans (Donner Lab, LBL)	June, 1975
Spinoff: First Hyperthermic Treatment of Human Cancer (UNM)	July 11, 1975
Accelerator Turn On Starts	August 1, 1975
Acceptable Simultaneous 100 μA H^+ and 3 μA H^- Beams to Switchyard	September 14, 1975
Production Beam to Area B	October 7, 1975
First Pions Through EPICS Channel	March 18, 1976
Production Beam in Area A and Area A East: End of Great Shutdown	April 5, 1976
Muon Spin Rotation Program	June, 1976
Spinoff: First Hyperthermic Treatment of "Cancer Eye" in Cattle (Jicarilla Reservation)	June 3, 1976
100 μA Production Beam in Area A	August, 1976
Experiment in Atomic Physics (H^- + laser beam): Observation of Feshbach and Shape Resonances in H^-	October, 1976
Double Charge Exchange in ^{16}O : LEP Channel	October 5, 1976
Startup of Isotope Production Facility	October 15, 1976
HRS Operation Begins	November, 1976
Maintenance by 'Monitor' System of Remote Handling	Fall, 1976
Proton Beam to WNR	March 12, 1977
Polarized Proton Beam Available	April, 1977
Spinoff: First Practical Applications Patent Licensed to Private Industry	April 12, 1977
Pion Radiotherapy with Curative Intent	May, 1977
Proton Computed Tomography Program	June, 1977
Experimental Results at Neutrino Facility	July, 1977
Cloud and Surface Muon Beams: SMC Channel	July, 1977
EPICS Operation Begins	August, 1977
300 μA Production Beam in Area A	Fall, 1977
AT-Division Established	January 1, 1978
π^0 Spectrometer Begins Operation	February, 1978
Operation of Polarized Proton Target	Spring, 1978
Successful Water-Cooled Graphite Production Target	November, 1978
Spinoff: First Thermal Modification of Human Cornea (Univ. of Oklahoma)	July 11, 1979

(Continued on next page)

MILESTONES

(Continued)

600 μ A Production Beam in Area A	November, 1979
New Limit on $\mu \rightarrow e\gamma$	December, 1979
Commercial Production of Radioisotopes	January, 1980
Spin Precessor Begins Operation	February, 1980
Data Analysis Center Operational	April, 1980
Variable Energy Operation	June, 1980
Single Isobaric Analog States in Heavy Nuclei	June, 1980
Spinoff: First Use of ^{85}Rb for Brain Tumor Imaging in Humans (Donner Lab, LBL)	September, 1980
Double Isobaric Analog States in Heavy Nuclei	October, 1980
Focal Plane Polarimeter Operational at HRS	October, 1980
New Measurement of Pion Beta Decay-- Improved Test of CVC	November, 1980

INFORMATION FOR CONTRIBUTORS

Progress at LAMPF is the progress report of MP Division of Los Alamos National Laboratory. In addition it includes brief reports on research done at LAMPF by researchers from other institutions and Los Alamos National Laboratory divisions.

Progress at LAMPF is published semiannually on April 1 and October 1. This schedule requires that manuscripts be received by December 1 and June 1, respectively.

Published material is edited to the standards of the *Style Manual* of the American Institute of Physics. Papers are not refereed, hence presentation in this report does not constitute professional publication of the material nor does it preempt publication in other journals.

Contributors can expedite the publication process by giving special care to the following specifics:

1. Drawings and figures submitted should be of quality suitable for direct reproduction after reduction to single-column width, 83 cm (3-1/4 in.).
2. Figure captions and table headings should be furnished.
3. References should be complete and accurate.
4. Abbreviations and acronyms should be avoided if possible (in figures and tables as well as text). and when used must be defined.
5. All numerical data should be given in SI units.

Research reports should be brief, one printed page or less, including figures (approximately three double-spaced typed pages). A list of recent publications relating to the experiment, for separate tabulation in this report, is much appreciated.

Contributors are encouraged to include as authors all participants in experiments so that they may receive credit for authorship and participation.

Questions and suggestions should be directed to: John C. Allred, Los Alamos National Laboratory, MS 850, Los Alamos, NM 87545.

APPENDIX A

ACTIVE AND COMPLETE EXPERIMENTS BY CHANNEL

CHANNEL: A-B

Exp. No.	Title	Spokesman	Run No. * = Complete	Beam Hours
56	STUDY OF NEUTRON SPECTRUM FROM PROTON BOMBARDMENT OF DEUTERIUM IN THE 300-600 MeV REGION	NORTHCLIFFE SIMMONS	1 *	0.0
			2 *	0.0
65	NEUTRON-PROTON POLARIZATION MEASUREMENTS USING A POLARIZED TARGET, PHASE I. THE n-p POLARIZATION OBSERVABLE $P(\theta)$	SIMMONS	1 *	996.8
66	NEUTRON-PROTON POLARIZATION MEASUREMENTS WITH A POLARIZED TARGET - PHASE II, THE n-p SPIN CORRELATION OBSERVABLE	SIMMONS	1 *	343.4
			2 *	472.0
124	MEASUREMENT OF THE NEUTRON ENERGY SPECTRUM IN $p + p \rightarrow n + \pi^+ + p$	DIETERLE MC FARLANE	1 *	39.0
125	ELASTIC NEUTRON-PROTON BACK ANGLE DIFFERENTIAL CROSS-SECTION MEASUREMENTS 300-800 MeV	DIETERLE	1 *	0.0
129	PION PRODUCTION IN NEUTRON PROTON COLLISIONS	WOLFE	1 *	319.0
189	SEARCH FOR CONDENSED NUCLEAR STATES AND STUDY OF HIGH- q^2 LOW- v NUCLEAR INTERACTIONS	VAN DYCK	1 *	0.0
193	MEASUREMENT OF SMALL ANGLE NEUTRONS ELASTIC SCATTERING FROM PROTONS	DIETERLE MC FARLANE	1 *	1091.1
			2 *	0.0
205	(n,p) CHARGE-EXCHANGE AND NEUTRON-INDUCED QUASI-FREE SCATTERING	KENEFICK RILEY	1 *	38.5
255	MEASUREMENT OF $\sigma(\theta)$ FOR n-p ELASTIC SCATTERING AT 460 MeV	NORTHCLIFFE	1 *	5.0
262	TEST OF ISOSPIN INVARIANCE IN THE REACTION $np \rightarrow d\pi^0$	BONNER	1 *	304.8
263	MEASUREMENT OF THE ENERGY AND ANGULAR VARIATION OF THE np CHARGE EXCHANGE CROSS SECTIONS	BONNER	1 *	237.1
264	MEASUREMENT OF THE ENERGY VARIATIONS OF THE nd ELASTIC DIFFERENTIAL CROSS SECTIONS NEAR 180°	BONNER	1 *	473.1
279	TEST OF CHARGE SYMMETRY IN nd AND pd SCATTERING	DIETERLE MC FARLANE	F-S*	101.0
360	THE MEASUREMENT OF THE POLARIZATION TRANSFER COEFFICIENT D_t AND A_t AT 800 MeV FOR THE REACTIONS $d(p,n)^2p$, $^6Li(p,n)^6Be$, AND $^9Be(p,n)^9B$	RILEY SIMMONS	1 *	493.5

366	NONRESONANT PION PRODUCTION IN THE REACTION $np \rightarrow \pi^+ pp$	MAYES MUTCHLER	1 *	427.7
387	ENERGY DEPENDENCE OF THE FORWARD-ANGLE np DIFFERENTIAL CROSS SECTION	BONNER	1	0.0
402	A MEASUREMENT OF THE POLARIZATION TRANSFER COEFFICIENTS $D_t(0^\circ)$ AND A_t $t(0^\circ)$ IN THE REACTION $\bar{p}p \rightarrow$ $\bar{n}X$ AT 800 MeV	GLASS SIMMONS	1 *	166.1
			2 *	83.8
403	A MEASUREMENT OF THE TRIPLE-SCATTERING PARAMETER D_t FOR THE CHARGE EXCHANGE REGION IN np SCATTERING	BONNER	1 *	0.0
			2 *	223.8
457	MEASUREMENT OF THE QUASI-FREE pn AND pp AND FREE pp ANALYZING POWERS 500-800 MeV	BHATIA SIMMONS	1	0.0
492	POLARIMETER CALIBRATIONS AND SEARCH FOR ENERGY-DEPENDENT STRUCTURE IN pp ELASTIC SCATTERING VIA CROSS SECTION, ANALYZING POWER, AND WOLFENSTEIN PARAMETER MEASURE- MENTS	MCNAUGHTON WILLARD	1	860.2
498	MEASUREMENTS OF LONGITUDINAL CROSS-SECTION DIFFERENCE FOR LONGITUDINAL POLARIZED BEAM AND TARGETS (pp , pd , np)	WAGNER BURLESON	3	0.0
504	MEASUREMENT OF THE TOTAL CROSS SECTION DIFFERENCE FOR PROTON-PROTON AND PROTON- NEUTRON SCATTERING IN PURE TRANSVERSE INITIAL SPIN STATES IN THE 400-800-MeV REGION	PHILLIPS	1 *	1568.0
505	MEASUREMENT OF THE TRANSVERSE SPIN-SPIN ASYMMETRY IN THE REACTION $pp \rightarrow d\pi^+$ IN THE 500-800-MeV REGION	PHILLIPS	1	860.2
528	EXPLORATORY MEASUREMENT OF $\Delta\sigma_L$ IN FREE NEUTRON-PROTON SCATTERING AT 800 MeV	SIMMONS NORTHCLIFFE	1	0.0
603	SEARCH FOR DELTAS IN A COMPLEX NUCLEUS BY A RADIOCHEMICAL TECHNIQUE	TURKEVICH	1	0.0

CHANNEL: A-B NUCHEM

Exp. No.	Title	Spokesman	Run No. * = Complete	Beam Hours
103	SPALLATION YIELD DISTRIBUTIONS FOR PION INTERACTIONS WITH COMPLEX NUCLEI	HUDIS	2 *	0.4
104	PROPOSAL FOR LAMPF EXPERIMENT. STUDIES OF THE PROTON- AND PION-INDUCED FISSION OF MEDIUM-MASS NUCLIDES	PATE	1 *	0.0
			2 *	5.0
105	NUCLEAR SPECTROSCOPY STUDIES OF PROTON- INDUCED SPALLATION PRODUCTS	BUNKER	1 *	10.0
			2 *	58.6

106	PROTON-INDUCED SPALLATION REACTIONS RELATED TO THE ISOTOPE PRODUCTION PROGRAM AT LAMPF	O'BRIEN	1 *	0.7
			2	37.6
118	FRAGMENT EMISSION FROM PION INTERACTIONS WITH COMPLEX NUCLEI	PORILE	1 *	0.0
			2	0.0
119	CROSS SECTIONS OF SIMPLE NUCLEAR REACTIONS INDUCED BY π^- MESONS	KAUFMAN	2 *	15.2
123	NUCLEAR STRUCTURE EFFECTS IN PION-INDUCED NUCLEAR REACTIONS	KAROL	1 *	0.0
			2 *	1.0
150	SEARCH FOR POLYNEUTRON SYSTEMS	TURKEVICH	1 *	0.0
			2 *	14.2
169	PROTON IRRADIATIONS FOR PROJECT JUMPER	ORTH SATTIZAHN	1 *	0.0
243	RECOIL STUDIES OF DEEP SPALLATION AND FRAGMENTATION PRODUCTS FROM THE INTER-ACTION OF 800-MeV PROTONS WITH HEAVY ELEMENTS	PORILE	1 *	55.8
282	MEASUREMENT OF CROSS SECTIONS FOR PROTON-INDUCED FORMATION OF SPALLATION PRODUCTS IN COPPER BY ACTIVATION ANALYSIS	DONNERT	1 *	0.6
			2 *	1.5
			3	0.1
294	HIGH-ENERGY NUCLEAR REACTIONS	KAROL	1	7.3
301	IMPAIRMENT OF SUPERCONDUCTING CHARACTERISTICS BY PROTON IRRADIATION	WILSON	1 *	185.0
326	ELECTRICAL COMPONENT RADIATION EFFECTS STUDY	HARVEY	1	179.9
407	THE EFFECT OF DISLOCATION VIBRATION ON VOID GROWTH IN METALS DURING IRRADIATION	SOMMER	1 *	516.2
			2	0.0
410	RADIATION EFFECTS IN AMORPHOUS METALS DUE TO 800-MeV PROTONS	COST	1 *	583.0
424	PRELIMINARY EXPERIMENTS FOR DOUBLE CHARGE EXCHANGE AND (μ^-, e^+) SEARCHES	TURKEVICH WARREN	1 *	8.0
465	RADIOCHEMICAL STUDY OF PION SINGLE CHARGE EXCHANGE	RUNDBERG	1	5
554	IRRADIATION OF TECHNOLOGICALLY IMPORTANT METALS WITH 800-MeV PROTONS USING THE ISOTOPE PRODUCTION FACILITY AT LAMPF	BROWN COST	1	75.2
557	EXPOSURE, IN A PARASITIC MODE, OF A 3-cm BY 3-cm BY 1-cm STACK OF SOLID TRACK DETECTORS TO A π^- BEAM	COWSIK	1	0.0
579	A RADIOCHEMICAL STUDY OF NEUTRON-DEFICIENT PRODUCTS FROM 500 MeV AND ^{238}U	FAUBEL	1	0.8
610	USE OF LAMPF BEAM STOP TO OBTAIN ^{60}Fe	HENNING KUTSCHERA	1	0.0

611	EXCITATION FUNCTIONS OF THE FOUR ^{130}Te (π^+ , p), (π^+ , n) REACTIONS	HOGAN	1	0.0
629	FEASIBILITY OF HELIUM-JET TECHNIQUES FOR STUDYING SHORT-LIVED NUCLEI PRODUCED AT LAMPF	GREENWOOD BUNKER TALBERT, J	1	0.0

CHANNEL: BIOMED

Exp. No.	Title	Spokesman	Run No. * = Complete	Beam Hours
44	RADIOBIOLOGY OF π^- MESONS, A PRELIMINARY STUDY	CARLSON	1 *	75.0
84	QUALITY OF MESON RADIATION FIELDS	PHILLIPS	1 *	0.0
143	STUDY OF THE RADIOBIOLOGICAL PROPERTIES OF NEGATIVE PIONS	KLIGERMAN KNAPP	1 * 2 * 3 *	0.0 0.0 0.0
151	AN INVESTIGATION OF PION DOSIMETRY BY PASSIVE PARTICLE DETECTORS	KNOWLES	1 *	8.0
167	HEAVY FRAGMENT FORMATION FOLLOWING THE ABSORPTION OF NEGATIVE PIONS IN ^{12}C	ZIOCK	1 *	0.0
171	STUDY OF NEGATIVE PION BEAMS BY MEANS OF PLASTIC NUCLEAR TRACK DETECTORS	BENTON	1	0.0
187	NUCLEAR GAMMA RAYS PRODUCED BY NEGATIVE PIONS STOPPING IN CARBON, NITROGEN, OXYGEN, AND TISSUE	REIDY	1	21.6
195	NUCLEAR RESONANCE EFFECT IN PIONIC ATOMS	LEON REIDY	1 * 2 *	0.0 155.2
196	A VISUALIZATION EXPERIMENT WITH CHARGED PARTICLES	DANIEL REIDY	1 *	0.0
198	EFFECTS OF PIONS ON DNA OF NONDIVIDING CELL SYSTEMS	POWERS	1 *	0.0
207	MEASUREMENT OF NEUTRON SPECTRUM AND INTENSITY RESULTING FROM π^- CAPTURE IN WATER PHANTOM AND HUMAN TISSUE	BRADBURY ALLRED	1 *	0.0
209	PION INTERACTIONS IN NUCLEAR EMULSIONS	BRADBURY ALLRED	1 *	0.0
212	COMPARATIVE EFFECTIVENESS OF NEGATIVE PIONS vs CALIFORNIUM-252 IN A TUMOR-ANIMAL SYSTEM	MEWISSEN	1 *	0.0
215	VISUALIZATION OF STOPPING PION DISTRIBUTION	PEREZ-MENDEZ BRADBURY	1	172.1
217	π^- PRODUCTION CROSS SECTIONS	PACIOTTI	1	5.9
218	PION DOSIMETRY WITH NUCLEAR EMULSIONS AND ALANINE	KATZ	1	0.0

235	RADIATION REPAIR OF NORMAL MAMMALIAN TISSUES	GILLETTE	1	68.4
236	BIOLOGICAL EFFECTS OF NEGATIVE PIONS	RAJU	1	522.0
239	STUDY OF ^{11}C AND ^{13}N PRODUCTION BY π^- IRRADIATION OF C, N, O, AND TISSUE FOR RADIOTHERAPY MONITORING	FRIEDLAND MAUSNER	1 *	55.0
			2 *	8.0
242	SURVIVAL OF SYNCHRONIZED CULTURED HUMAN KIDNEY T-1 CELLS EXPOSED TO STOPPING PIONS AND X-RAYS AT VARIOUS TIMES AFTER MITOSIS	TODD	1 *	105.5
244	SYSTEMS DEVELOPMENT FOR EFFICIENT UTILIZATION OF HIGH-PURITY GERMANIUM MOSAIC DETECTORS FOR TUMOR UTILIZATION	BRILL	1	0.0
270	THERAPY BEAM DEVELOPMENT-BIOMEDICAL CHANNEL TUNING	PACIOTTI	1	810.0
271	THERAPY BEAM DEVELOPMENT-DOSIMETRY	SMITH	1	2764.4
272	THERAPY BEAM DEVELOPMENT-MICRODOSIMETRY	DICELLO	1	551.2
273	THERAPY BEAM DEVELOPMENT-LET MEASUREMENTS	RICHMAN	1	783.7
274	PION RADIOBIOLOGY	BUSH	1	2482.0
275	PION CLINICAL TRIALS	BUSH	1	5728.0
285	MIGRATION OF ^{11}C AND ^{13}N RADIOACTIVITY PRODUCED <i>IN VIVO</i> BY NEGATIVE PIONS	MAUSNER	1 *	13.0
300	π^- COULOMB CAPTURE AND π^- TRANSFER IN TISSUE, TISSUE-EQUIVALENT LIQUID, AND SIMPLE COMPONENTS	DANIEL LEON	1 *	37.0
304	STUDY OF THE AUGER PROCESS IN PIONIC ATOMS	LEON MAUSNER	1 *	9.2
380	RBE AND OER FOR NORMAL AND TUMOR TISSUE	PHILLIPS GOLDSTEIN	1	52.1
384	PF USING MOUSE TESTES AS A BIOLOGICAL TEST SYSTEM	GERACI	1	23.7

CHANNEL: BSA-RAD

Exp. No.	Title	Spokesman	Run No. * = Complete	Beam Hours
45	RADIATION DAMAGE STUDIES - HIGH-TEMPERATURE REACTOR MATERIALS AND TYPE II SUPERCONDUCTORS	DUDZIAK GREEN GIORGI	1 *	0.0
			2 *	1833.0
111	SEARCH FOR NEW NEUTRON-RICH NUCLIDES PRODUCED BY FAST NEUTRONS	HILL	1 *	0.0
			2 *	10.8
113	RADIATION DAMAGE AND HELIUM EMBRITTLEMENT IN ELEVATED TEMPERATURE REACTOR STRUCTURAL ALLOYS	MICHEL	1	0.0

157	MICRODISTRIBUTION OF THORIUM IN GEOLOGIC SAMPLES	SEITZ	1	0.0
161	THE MICRODISTRIBUTION OF THORIUM IN METEORITES	BURNETT	1 *	11.7
174	INVESTIGATION OF THE CHEMICAL REACTIONS OF ATOMIC ¹⁹ F AS A MEANS FOR DIRECT SYNTHESIS OF ¹⁹ F-LABELED COMPOUNDS	ROWLAND MILLER	1 *	0.0
			2 *	7.0
237	RADIATION DAMAGE STUDIES ON STRUCTURAL MATERIALS FOR ADVANCED REACTORS	HOLLAND GREEN	1	0.0
326	ELECTRICAL COMPONENT RADIATION EFFECTS STUDY	HARVEY	1	294.5
406	NEUTRON FLUX CHARACTERIZATION AT A-6 RADIATION EFFECTS FACILITY	HARVEY	1 *	1306.3
415	TWO-NUCLEON-OUT PRODUCTS FROM STOPPED π^- INTERACTIONS	ORTH	1 *	0.0
467	IRRADIATION IN SUPPORT OF FERFICON STUDIES	GILMORE	1	4
542	FEASIBILITY STUDY - USING AN EXISTING NEUTRON BEAM PIPE AT LAMPF BEAM STOP FOR CRYSTAL DIFFRACTION SPECTROMETER EXPERIMENTS	LU	F-S	699.7
545	FUSION MATERIALS NEUTRON IRRADIATIONS - A PARASITE EXPERIMENT	BROWN	1	0.0
560	STUDY OF NEUTRON-IRRADIATION-INDUCED GROWTH OF METALS AT RADIATION EFFECTS FACILITY	HARVEY	1	63.4

CHANNEL: EPB

Exp. No.	Title	Spokesman	Run No. * = Complete	Beam Hours
26	NEUTRON TIME-OF-FLIGHT EXPERIMENT AT BEAM STOP	VEESER	1 *	0.0
27	p-p SPIN CORRELATION EXPERIMENTS	WILLARD	1 *	0.0
			2 *	1141.8
42	BREAKUP OF FEW-NUCLEON SYSTEMS AND NUCLEI	COLE	1 *	530.8
81	STUDY OF NEUTRON-PROTON AND PROTON-PROTON COINCIDENCE SPECTRA FROM $p + d \rightarrow n + p + p$ REACTION	PHILLIPS	1 *	0.0
			2 *	600.5
124	MEASUREMENT OF THE NEUTRON ENERGY SPECTRUM IN $p + p \rightarrow n + \pi^+ + p$	DIETERLE MC FARLANE	2 *	301.0
			3	0.0
128	WNR STORAGE RING STRIPPER EXPERIMENT	HAYWARD	1 *	0.0
137	SEARCH FOR PARITY-VIOLATING CONTRIBUTION TO SCATTERING OF HADRONS	NAGLE MISCHKE FRAUENFELD	1 *	316.6
			2 *	363.4
			3 *	346.5

153	INVESTIGATION OF NUCLEAR GAMMA-RAYS RESULTING FROM IN-FLIGHT PION AND PROTON REACTIONS	EISENSTEIN	1 *	0.0
159	CHARGED PARTICLE EMISSION IN PROTON-INDUCED REACTIONS AS A FEASIBILITY STUDY IN THE USE OF INTRINSIC Ge DETECTORS WITH THE PRIMARY LAMPF BEAM	EISENSTEIN	1 *	0.0
176	P-NUCLEUS TOTAL AND TOTAL REACTION CROSS-SECTION MEASUREMENTS	ANDERSON	1 *	0.0
			2 *	296.6
192	MEASUREMENT OF THE EMITTANCE GROWTH IN H ⁻ STRIPPING	HAYWARD	1 *	70.0
194	p-p D, R, AND A MEASUREMENTS	MCNAUGHTON	1 *	185.2
			2	252.0
197	INVESTIGATION REACTION $p + d \rightarrow {}^3\text{He} + \pi^0$ AT LAMPF ENERGIES	HUNGERFORD	1 *	363.0
200	STUDY OF THE PHOTODETACHMENT SPECTRUM OF H ⁻ IN THE VICINITY OF 11 eV	BRYANT	1 *	128.8
219	DOUBLE PION PRODUCTION IN PROTON-PROTON SCATTERING	BEVINGTON	1 *	422.0
223	STUDIES OF THE (p,np) CHARGE-EXCHANGE REACTION	HOFFMANN	F-S*	66.3
241	DIRECT LEPTON PRODUCTION AT LAMPF ENERGIES	HOFFMAN MISCHKE	1 *	531.2
278	STUDY OF REACTION MECHANISMS USING INTERNAL CONVERSION TECHNIQUES	HOFFMANN MOORE	1 *	53.0
279	TEST OF CHARGE SYMMETRY IN nd AND pd SCATTERING	DIERLE MC FARLANE	F-S*	67.0
			1 *	0.0
289	MEASUREMENT OF THE PHASE OF THE FORWARD NUCLEON-NUCLEON SPIN-INDEPENDENT ELASTIC-SCATTERING AMPLITUDE AT 800 MeV	WHITTEN	1 *	354.6
323	STARK EFFECT QUENCHING OF RESONANCES IN THE PHOTODISINTEGRATION OF THE H ⁻ ION	BRYANT GRAM	1 *	350.6
336	STUDY OF THE SPIN DEPENDENCE OF PROTON-PROTON PION PRODUCTION REACTIONS	MUTCHLER PINSKY	1 *	419.4
			2	0.0
			3	0.0
			4	0.0
339	SURVEY OF PHOTODETACHMENT CROSS SECTION OF H ⁻ FROM THRESHOLD TO 15 eV AND ITS DEPENDENCE UPON ELECTRIC FIELD	BRYANT GRAM	1 *	1363.1
341	STUDY OF $pd \rightarrow dn'n$ REACTION MECHANISMS	PHILLIPS	1 *	229.0
449	A SURVEY OF SINGLE AND DOUBLE PHOTO-DETACHMENT CROSS SECTION OF THE H ⁻ ION FROM 14 TO 21.8 eV	BRYANT DONAHUE	1 *	570.7
			2	0.0

468	MECHANISMS OF LUMINESCENCE INDUCED BY PROTONS INCIDENT OF ULTRAVIOLET-GRADE OPTICAL MATERIALS	BECHER	1 *	70.8
492	POLARIMETER CALIBRATIONS AND SEARCH FOR ENERGY-DEPENDENT STRUCTURE IN pp ELASTIC SCATTERING VIA CROSS SECTION, ANALYZING POWER, AND WOLFENSTEIN PARAMETER MEASUREMENTS	MCNAUGHTON WILLARD	1	0.0
498	MEASUREMENTS OF LONGITUDINAL CROSS-SECTION DIFFERENCE FOR LONGITUDINAL POLARIZED BEAM AND TARGETS (pp, pd, np)	WAGNER BURLESON	1 *	1664.5
			2	0.0
512	PROTON-PROTON ELASTIC-SCATTERING MEASUREMENTS OF THE $A_{ss}(\theta)$, $A_{ll}(\theta)$, AND $A_{st}(\theta)$ SPIN-CORRELATION PARAMETERS AT 500, 650, AND 800 MeV	MCNAUGHTON WILLARD	1	0.0
			2	0.0
			3	0.0
			4	0.0
517	POLARIZED BEAM AND TARGET EXPERIMENTS IN THE p-p SYSTEM. PHASE 1. A_v AND A_{vv} FOR THE $d\pi^+$ CHANNEL AND A_{vv} FOR THE ELASTIC CHANNEL FROM 500 TO 800 MeV	SIMMONS JARMER NORTHCLIFFE	1	0.0
518	POLARIZED BEAM AND TARGET EXPERIMENTS IN THE p-p SYSTEM. PHASE 2 MEASUREMENTS OF A_{zz} AND A_{xz} FOR THE $d\pi^+$ CHANNEL AND FOR THE ELASTIC CHANNEL FROM 500 TO 800 MeV	SIMMONS JARMER NORTHCLIFFE	1	0.0
526	MEASUREMENT OF ANALYZING POWERS IN pd $\rightarrow$ pd, pd $\rightarrow$ d π , AND pp $\rightarrow$ pp REACTIONS AT 520, 600, 650, AND 730 MeV	CVERNA ANDERSON KING	1	0.0
			2	0.0
530	H ⁻ MAGNETIC STRIPPING RATES	JASON	1 *	237.2
586	A STUDY OF THE EFFECTS OF VERY STRONG ELECTRIC FIELDS ON THE STRUCTURE OF THE H ⁻ ION	BRYANT GRAM	1	0.0
587	FUNDAMENTAL EXPERIMENTS WITH RELATIVISTIC HYDROGEN ATOMS - EXPLORATORY WORK	SMITH DONAHUE	1	0.0
588	A SEARCH FOR LONG-LIVED STATES OF THE H ⁻ ION	CLARK BRYANT	1	0.0
589	FREE FORWARD np ELASTIC-SCATTERING ANALYZING POWER MEASUREMENTS AT 800 MeV	GLASS NORTHCLIFFE	1	0.0
590	MEASUREMENT OF D θ IN p-n AND n-p SCATTERING AT 800, 650 MeV AND OTHER ENERGIES WITH ASSOCIATED p-p MEASUREMENTS	SIMMONS NORTHCLIFFE	1	0.0
			2	0.0
591	AN INVESTIGATION OF INCLUSIVE ONE-PION PRODUCTION IN PROTON-NUCLEUS COLLISIONS	DEVRIES DIGIACOMO	1	0.0

592	AN INVESTIGATION OF TWO-PION PRODUCTION AND CORRELATIONS IN PROTON-NUCLEUS COLLISIONS AT 800 MeV	DEVRIES DIGIACOMO	1	0.0
633	MEASUREMENT OF p-p ELASTIC SCATTERING IN THE COULOMB INTERFERENCE REGION BETWEEN 300 AND 800 MeV	PAULETTA FROM	1	0.0
634	MEASUREMENT OF PARITY VIOLATION IN THE P-NUCLEUS TOTAL CROSS SECTIONS AT 800 MeV	CARLINI TALAGA YUAN	1	0.0
635	SPIN MEASUREMENTS IN pd ELASTIC SCATTERING	BONNER IGO BLESZYNSKI	1	0.0
636	A MEASUREMENT OF THE WOLFENSTEIN POLARIZATION PARAMETERS D_{LL} , D_{SL} , K_{LL} , AND K_{SL} FOR p-p ELASTIC SCATTERING	HOLLAS	1	0.0
637	A MEASUREMENT OF THE VECTOR POLARIZATION OF THE DEUTERON IN THE REACTION $pp \rightarrow d\pi^+$	BONNER	1	0.0

CHANNEL: EPICS

Exp. No.	Title	Spokesman	Run No. * = Complete	Beam Hours
9	ELASTIC AND INELASTIC PION SCATTERING FROM CALCIUM ISOTOPES	MCCARTHY MORRIS	1 *	646.7
13	STUDY OF π^+ -INDUCED DOUBLE CHARGE EXCHANGE REACTIONS	SETH	1 *	334.5
14	π^+ AND π^- ELASTIC AND INELASTIC SCATTERING FROM OXYGEN-16	THIESSEN	1 * 2 *	798.8 218.0
18	SURVEY OF PI SCATTERING BY COMPLEX NUCLEI	ZEIDMAN	1 * 2 * 3 *	282.8 198.4 64.3
23	A SURVEY OF PION-NUCLEUS ELASTIC AND INELASTIC SCATTERING AT 180 MeV	WHARTON	1 *	300.5
39	SEARCH FOR (π, p) REACTIONS WITH EPICS	MACEK THIESSEN	1 *	295.5
74	STUDY OF PION-INDUCED DOUBLE-CHARGE-EXCHANGE REACTIONS ON LOW-Z ELEMENTS	PEREZ-MENDEZ STETZ	1 *	346.0
87	π^+ AND π^- SCATTERING FROM ^3He AND ^4He	MCCARTHY	1 *	358.1
130	EPICS TUNEUP PROPOSAL. PION CARBON SCATTERING	THIESSEN	1 * 2 *	221.0 674.4
133	PRELIMINARY PION CHANNELING EXPERIMENTS	GEMMELL	1 *	200.9
156	SURVEY OF QUASI-ELASTIC PION SCATTERING	SWENSON	1 *	190.0
229	π^+ VS π^- INELASTIC EXCITATION OF LOW-LYING COLLECTIVE STATES IN N=28 NUCLEI	BRAITHWAITE MOORE	1 *	281.8

245	STUDY OF THE (π^+,n) AND (n,π,p) REACTIONS IN ${}^{34}\text{He}$ AND HEAVIER NUCLEI BY DETECTING RECOILING TRITONS OR DEUTERONS	KALLNE THIESSEN	1 *	943.9
246	STUDIES OF π^+ SCATTERING AT 50 MeV FROM LIGHT NUCLEI	EISENSTEIN	1 *	564.0
265	STUDY OF PROMPT NUCLEAR DE-EXCITATION GAMMA RAYS FROM PION INTERACTIONS WITH π^+ AND ${}^{12}\text{C}$	MORRIS BRAITHWAITE	1 *	319.0
310	(π^+, π^-) DOUBLE-CHARGE-EXCHANGE REACTIONS USING CORE 2N TARGETS	BRAITHWAITE MORRIS	1 *	265.2
317	INELASTIC PION SCATTERING TO THE 1^+ STATES OF ${}^{12}\text{C}$	PETERSON	1 *	246.5
325	PION AND MUON MULTIPLE COULOMB-SCATTERING EXPERIMENT ON THE EPICS BEAM LINE	HANSON	1 *	69.7
342	STUDY OF THE (π^+,p) REACTION IN ${}^{12}\text{C}$	MCCARTHY KALLNE	1 *	151.2
368	ELASTIC PION SCATTERING TO THE 19.2 ± 0.3 MeV STATE IN ${}^{12}\text{C}$	MOORE	1 *	246.5
369	INELASTIC PION SCATTERING BY ${}^{17}\text{O}$, ${}^{16}\text{O}$, AND ${}^{19}\text{F}$	DEHNHARD	1	44.1
389	INELASTIC PION SCATTERING FROM LIGHT NUCLEI ${}^{10}\text{B}$, ${}^{11}\text{B}$, ${}^{10}\text{N}$, ${}^{15}\text{N}$	MORRISON ZEIDMAN	1 *	685.0
			2 *	0.0
			3 *	0.0
391	INELASTIC π^+ SCATTERING ON ${}^7\text{Li}$	PETERSON	1 *	201.7
413	MASS MEASUREMENT OF ${}^{20}\text{Ne}$ AND ${}^{40}\text{Ar}$ BY THE (π^+, π^-) REACTION	SETH NANN	1 *	0.0
419	π^+ vs π^- -INELASTIC EXCITATION OF SINGLE PARTICLE AND CORE-COUPLED STATES IN ${}^{207}\text{Pb}$ AND ${}^{208}\text{Bi}$	BRAITHWAITE MORRIS MOORE	1 *	25.3
442	STUDY OF THE INCLUSIVE PION DOUBLE-CHARGE-EXCHANGE REACTION	KALLNE	1 *	124.7
446	STUDY OF E0 GIANT RESONANCES	HALPERN EISENSTEIN THIESSEN	1	0.0
449	STUDY OF π^+ DOUBLE-CHARGE-EXCHANGE SCATTERING AT SMALL ANGLES ON VARIOUS NUCLEI	BURLESON	1 *	399.7
452	ELASTIC AND INELASTIC SCATTERING OF π^+ BY ${}^{12}\text{C}$	DEHNHARD	1 *	219.5
456	THE (n,d) REACTION ON ${}^{12}\text{C}$ AT 60 MeV	HOISTAD	1	0.0
480	AN INVESTIGATION OF THE STABILITY OF ${}^3\text{H}$, ${}^3\text{H}$, AND ${}^3\text{He}$ BY (π^+, π^-) REACTIONS	SETH	1 *	444.7
483	COMPARATIVE STUDY OF THE (π^+, π^-) AND (π^-, π^+) REACTIONS ON ${}^{12}\text{C}$	NANN SETH	1 *	444.7

478	π^+ ELASTIC SCATTERING FROM DEUTERIUM	MASTERSON	1 *	148.3
481	EXCITATION OF HIGH-SPIN STATES IN TZ = 0 S-D SHELL NUCLEI BY PION ELASTIC SCATTERING	GEESAMAN	1 *	134.7
484	INELASTIC PION SCATTERING FROM ^{148}Sm AND ^{152}Sm	MORRIS	1	0.0
495	ISOSPIN MIXING IN ^{12}C	MORRIS BRAITHWAITE	1 *	424.1
506	INELASTIC PION SCATTERING TO THE UN- NATURAL PARITY LEVELS IN ^{12}C AND ^6Li	COTTINGAME BRAITHWAITE	1 *	0.0
510	ENERGY DEPENDENCE OF ELASTIC AND INELASTIC SCATTERING OF π^+ BY ^{12}C AND 116 AND 280 MeV	DEHNHARD	1 *	61.1
			2	0.0
516	THE (π^+, p) REACTION OF $^{18,18}\text{O}$	ANDERSON HOISTAD	1 *	36.0
522	EXCITATION OF GIANT RESONANCE STATES IN ^{90}Zr AND ^{208}Pb WITH 150-MeV PIONS	KING ANDERSON PETERSON	1 *	198.6
539	SEARCH FOR PURE NEUTRON/PROTON TRANSITIONS IN ^{14}C	BAER HOLTKAMP	1 *	345.7
546	INVESTIGATION OF THE SPIN FORM FACTOR OF TRITIUM AND ^3He	BRISCOE NEFKENS	F-S*	60.9
			1	0.0
549	A STUDY OF THE DCX REACTION MECHANISM. THE $^{42}\text{Ca}(\pi^+, \pi^-)^{42}\text{Ti}$ REACTION	SETH	1 *	349.3
550	EXCITED STATE SPECTRA OF THE EXOTIC NUCLEI ^{18}C AND ^{18}Ne BY (π^-, π^+) DCX REACTIONS	SETH	1	0.0
558	MEASUREMENT OF (π^+, π^-) REACTIONS ON $^{13,14}\text{C}$ AND ^{26}Mg	BAER BURLESON	1	0.0
565	EXCITATION OF HIGH-SPIN PARTICLE-HOLE STATES IN ^{56}Fe AND ^{58}Ni	ZEIDMAN GEESAMAN	1	0.0
570	INVESTIGATION OF THE STRUCTURE OF ^{16}O WITH PION INELASTIC SCATTERING	HOLTKAMP FORTUNE	1	0.0
572	A-DEPENDENCE OF THE (π^+, π^-) REACTION AND THE WIDTH OF A DOUBLE ISOBARIC ANALOG STATE IN HEAVY NUCLEI	GREENE MOORE	1	0.0
573	PION SCATTERING FROM ^{24}Mg AND ^{26}Mg	BLANPIED	1	0.0
577	MEASUREMENT OF ANGULAR DISTRIBUTIONS FOR $^{16}\text{O}(\pi^+, \pi^-)^{16}\text{Ne}$	GREENE FORTUNE	1	0.0
581	π^+ ELASTIC SCATTERING FROM DEUTERIUM AT 237 MeV	MASTERSON BOUDRIE	1	0.0
597	THE STUDY OF BROAD-RANGE PION INELASTIC SCATTERING SPECTRA (WITH EMPHASIS ON THE EXCITATION OF THE GIANT MONOPOLE RESONANCE)	HALPERN EISENSTEIN	1	0.0

598	INELASTIC PION SCATTERING TO THE UN- NATURAL PARITY LEVELS IN ^6Li	COTTINGAME	1	0.0
601	DETERMINATION OF ISOSCALAR AND ISOVECTOR TRANSITION RATES FOR LOW-LYING COLLECTIVE STATES IN ^{90}Zr AND ^{208}Pb BY π^+ AND π^- INELASTIC SCATTERING	HINTZ	1	0.0
602	NEUTRON-PROTON COMPONENTS OF INELASTIC TRANSITIONS IN PION SCATTERING ON ^{23}Na AND ^{25}Mg	HARVEY DEHNHARD	1	0.0
605	A DIBARYON SEARCH AT EPICS	SETH	1	0.0
606	TESTS OF THE (N - Z) DEPENDENCE OF PION DOUBLE CHARGE EXCHANGE	SETH	1	0.0
612	MASS OF ^{14}Be	SETH	1	0.0
617	A STUDY OF THE (3/2, 3/2) RESONANCE IN LIGHT NUCLEI	ZIOCK	1	0.0
618	INELASTIC π^2 SCATTERING FROM THE N = 28 ISOTONES	MORRIS MOORE	1	0.0
619	INELASTIC PION SCATTERING TO 0^+ AND 2^+ STATES IN ^{40}Ca AND ^{42}Ca	MOORE FORTUNE MORRIS	1	0.0
620	THE NUCLEAR REACTION $\pi^+ \text{ vs } \pi^-$ INELASTIC SCATTERING ON ^{40}Ca	MOORE	1	0.0
621	GOOD-RESOLUTION STUDY OF $^{16}\text{O}(\pi, \pi')$	DEHNHARD FORTUNE	1	0.0
622	INVESTIGATION OF THE STRONG CANCELLATIONS OF NEUTRON-PROTON TRANSITION AMPLITUDE IN ^{14}C	HOLTKAMP BAER	1	0.0
625	INELASTIC SCATTERING OF PIONS TO GIANT RESONANCES	KING ANDERSON PETERSON	1	0.0

CHANNEL: HRS

Exp. No.	Title	Spokesman	Run No. * = Complete	Beam Hours
4	LARGE-ANGLE ELASTIC SCATTERING OF PROTONS FROM HELIUM AND QUASI-ELASTIC KNOCKOUT OF ALPHA PARTICLES BY 800-MeV PROTONS	IGO	1 *	458.0
5	INELASTIC SCATTERING OF 800-MeV PROTONS FROM NUCLEI TO STUDY QUASI-FREE MODES	CHRIEN PALEVSKY	1 *	532.7
10	SEARCH FOR (p, π) REACTIONS WITH HRS	SPENCER	1	112.9
15	ELASTIC SCATTERING AND TOTAL CROSS-SECTION MEASUREMENTS OF PROTON ON HYDROGEN, DEUTERIUM, AND HELIUM	IGO TANAKA	1 *	0.0
			2 *	75.0
			3 *	249.0

49	ELASTIC AND INELASTIC PROTON SCATTERING FROM THE NICKEL ISOTOPES AND FROM ⁹⁰ Y	PETERSON	1 *	68.3
117	HIGH-RESOLUTION STUDY OF THE NEUTRON PICK-UP REACTION	IGO	1 *	273.2
138	INELASTIC PROTON SCATTERING AND EXCITATION OF STATES OF INTERMEDIATE COLLECTIVITY IN OPEN-SHELL NUCLEI	MCDANIELS SWENSON	1 *	184.2
139	PRELIMINARY PROTON-SCATTERING SURVEY WITH HRS	SPENCER TANAKA	1 *	695.1
178	PROTON-SCATTERING SURVEY ON S-D SHELL NUCLEI	SPENCER HINTZ	1 *	209.3
183	PROTON-SCATTERING SURVEY ON HEAVY DEFORMED NUCLEI	HINTZ SPENCER	1 *	382.1
202	(p,t) REACTION ON SPHERICAL NUCLEI	IGO	1 *	0.0
204	EXCITATION AND ASYMMETRY MEASUREMENT OF T ≈ 1, HIGH-SPIN, NONNORMAL PARITY PARTICLE-HOLE STATE BY (p,p') SCATTERING IN THE INTERMEDIATE-ENERGY RANGE	IGO	1 *	127.0
223	STUDIES OF THE (p,np) CHARGE-EXCHANGE REACTION	HOFFMANN	F-S*	0.0
233	SEARCH FOR DELTA-CONFIGURATIONS NUCLEI	SETH SPENCER	1	112.9
249	THE (p,π') REACTION ON ⁴ He WITH 800-MeV PROTONS	WHITTEN	1	199.7
256	P-NUCLEUS ELASTIC SCATTERING AT Q ₂ = ⁹ Be, C, AND THE STUDY OF P-NUCLEUS INTERACTIONS IN CO AND AU UP TO m* = q ² /2v ≈ 20	FRANKEL	1 *	107.6
258	STUDY OF MECHANISMS FOR THE EJECTION OF HIGH-MOMENTUM PARTICLES FROM NUCLEI BY STUDY OF THE COINCIDENCE SPECTRUM IN p + a → (p,d,t) + (p,d,t) + X	FRANKEL FRATI	1 *	178.7
			2	0.0
261	INTERMEDIATE-ENERGY (p,d) REACTION MECHANISM STUDIES	RICKEY SHEPARD PETERSON	1 *	0.0
311	ELASTIC-SCATTERING SURVEY USING POLARIZED PROTONS	HOFFMANN	1 *	715.3
			2 *	245.6
345	STUDY OF THE STRUCTURE FUNCTION AND THE CONNECTION BETWEEN ELASTIC AND INELASTIC CROSS SECTION AT LARGE t IN THE p- ⁴ He INTERACTION	FRANKEL FRATI VAN DYCK	1	0.0
346	STUDY OF HIGH-MOMENTUM COMPONENTS IN NUCLEI USING A POLARIZED PROTON BEAM	FRANKEL	1 *	209.8
347	SEARCH FOR ORBIT-FLIP STATES BY INELASTIC PROTON SCATTERING	HINTZ	1 *	209.3

352	DETERMINATION OF NEUTRON MASS DISTRIBUTION FROM ELASTIC PROTON MEASUREMENTS [P(t) AND da/dt] ON ISOTOPES IN THE CALCIUM REGION	WHITTEN	1 *	204.8
354	SCATTERING OF 800-MEV PROTONS FROM ^{12}C AND ^{13}C AT MOMENTUM TRANSFER $>4 \text{ fm}^{-1}$	BLANPIED	1 *	324.1
355	FURTHER ELASTIC SCATTERING CROSS SECTION AND ANALYZING POWER MEASUREMENTS ON ^{208}Pb AND $^{116,124}\text{Sn}$	HOFFMANN	1 *	130.0
			2 *	55.0
356	ANALYZING POWER AND CROSS SECTION MEASUREMENTS FOR INELASTIC PROTON EXCITATION OF SIMPLE STATES	GLASHAUSER BAKER SCOTT	1 *	199.9
			2	0.0
385	MEASUREMENT OF THE POLARIZED PROTONS + NEUTRONS ANALYZING POWER, $A_N(\theta)$ FROM $\theta_{\text{c.m.}} 10-70^\circ$	HOFFMANN	1 *	140.6
			2 *	108.8
386	TOTAL REACTION CROSS SECTIONS FOR p^+ NUCLEI AT 800 MeV	HOFFMANN	1 *	256.1
			2	0.0
392	A MEASUREMENT OF THE TRIPLE-SCATTERING PARAMETERS D, R, A, R', AND A' FOR PROTON-PROTON AND PROTON NEUTRON SCATTERING AT 800 MeV	HOFFMANN	1	0.0
			2	0.0
395	THE (p,π^+) -REACTION ON ^{16}O AND ^{40}Ca	BAUER HOISTAD NANN	1 *	195.8
399	EXCITATION OF GIANT MULTIPOLE RESONANCES BY 200-400 MeV PROTONS	BERTRAND	1	0.0
405	THE (p,π^-) REACTION ON $^{12,13}\text{C}$	HOISTAD BAUER SETH	1	162.7
411	MEASUREMENT OF SPIN-FLIP PROBABILITIES IN PROTON INELASTIC SCATTERING AT 800 MeV AND SEARCH FOR COLLECTIVE SPIN-FLIP MODES, PRELIMINARY SURVEY	HINTZ MOSS	1	151.4
425	PROTON ELASTIC SCATTERING AT ~800 MeV BY $^{40,48}\text{Ca}$, ^{90}Zr , ^{208}Pb	SETH HOFFMANN	1 *	283.2
431	CROSS SECTION AND ANALYZING POWER FOR INELASTIC PROTON EXCITATION OF UNNATURAL PARITY STATES IN ^6Li , ^{12}C , ^{14}N , AND ^{16}O	GLASHAUSER MOSS	1 *	181.0
432	CROSS SECTION FOR EXCITATION OF UNNATURAL PARITY STATES IN ^{12}C AT $E_p < 800 \text{ MeV}$	GLASHAUSER MOSS	1	148.9
433	ELASTIC SCATTERING DIFFERENTIAL CROSS SECTIONS AND ANALYZING POWERS FOR POLARIZED $p + ^{40,48}\text{Ca}$, ^{90}Zr AND ^{208}Pb AT ~400 MeV	HOFFMANN SETH	1 *	0.0

438	THE (p,d) REACTIONS ON $^{12,13}\text{C}$ ^7Li , ^{16}O ^{25}Mg , ^{28}Si , AND ^{60}Cu BETWEEN 650 AND 800 MeV	IGO	1	162.5
450	PRELIMINARY CROSS SECTION MEASUREMENTS FOR THE (p,t) REACTION AT 400 MeV	HINTZ	1 "	0.0
451	INELASTIC PROTON SCATTERING IN THE RANGE 300 TO 500 MeV	HINTZ	1 2	221.3 0.0
462	ANALYZING POWER AND DIFFERENTIAL CROSS SECTIONS FOR THE REACTIONS $p + p \rightarrow d + \pi^+$ AND $p + d \rightarrow t + \pi^+$ AT ~ 600 AND 400 MeV	SETH NANN	1	0.0
470	REACTIVE CONTENT OF THE OPTICAL POTENTIAL	BARLETT HOFFMANN	1 *	247.5
472	STUDY OF THE (p,d) REACTION ON ^{90}Zr , ^{140}Ce , AND ^{208}Pb AT 800 MeV	WHITTEN	1 *	79.5
473	STUDY OF GIANT MULTIPOLE RESONANCES WITH 800-MeV PROTONS	MOSS ADAMS CAREY	1 * 2	110.8 100.7
474	A MEASUREMENT OF SPIN-DEPENDENT EFFECTS IN $p + d$ ELASTIC AND INELASTIC SCATTERING	CORNELIUS	1	0.0
475	SCATTERING OF 0.8-GeV PROTONS FROM ^{20}Ne AND ^{22}Ne	BLANPIED	1	154.9
476	THE ANALYZING POWER FOR POLARIZED PROTONS + $^{24,26}\text{Mg}$ AT 500 AND 800 MeV	BLANPIED	1	82.9
479	MEASUREMENT OF R, A, R', AND A' IN ELASTIC AND INELASTIC SCATTERING OF 800-MeV PROTONS FROM LIGHT NUCLEI - REVISED VERSION OF Q PROPOSAL	IGO	1	106.3
485	THE ENERGY DEPENDENCE IN THE (p, π^+) REACTION	HOISTAD	1	0.0
486	INELASTIC SCATTERING OF PROTONS POPULATING THE 4^- (3.44-MeV) LEVEL OF ^{208}Pb . A SEARCH FOR CRITICAL OPALESCENCE	IGO GLASHAUSER MOSS	1 *	65.6
439	SEARCH FOR M1 GIANT RESONANCES IN THE (p,p') REACTION AT $E_p = 800$ MeV	MOSS	1 *	63.9
490	MEASUREMENT OF POLARIZED PROTON-PROTON AND POLARIZED PROTON-DEUTRON ELASTIC SCATTERING IN THE COLUMB INTERFERENCE REGION BETWEEN 600 AND 800 MeV	PAULETTA	1	0.0
508	DIBARYON RESONANCES IN PION PRODUCTION	SETH	1 * 2	178.0 0.0
519	STUDY OF THE REACTION $p(\text{pol}) + d \rightarrow (p,\pi) + X$ TO MEASURE THE ANALYZING POWER AND STRUCTURE FUNCTION FOR BACKWARD PARTICLES	FRANKEL	1 *	130.3

520	STUDY OF THE REACTION $p(\text{POLARIZED}) + {}^3\text{He} \rightarrow (p,d,\pi,\dots) + X$ TO MEASURE THE ANALYZING POWER STRUCTURE FUNCTIONS FOR BACKWARDS PARTICLES	FRANKEL	1	0.0
531	EXCITATION OF UNNATURAL-PARITY STATES IN ${}^{12}\text{C}$ AT 500 MeV	GLASHAUSSER MOSS	1	101.3
532	MEASUREMENTS OF CROSS SECTIONS AND ANALYZING POWER IN THE $(p,2p)$ REACTION ON DEUTERIUM	FRANKEL	1	0.0
533	THE ASYMMETRY IN THE (p,n) REACTION ON ${}^6\text{Li}$ AT 800 MeV	HOISTAD SETH	1	0.0
535	A STUDY OF THE RELATION BETWEEN THE (p,d) AND (π,p) REACTION IN A PION EXCHANGE MODEL	ANDERSON HOISTAD	1	0.0
538	ANALYZING POWER AND CROSS-SECTION MEASURE- MENTS OF THE ${}^4\text{He}(p,d){}^3\text{He}$ REACTION	SHEPARD KING	1 2	0.0 0.0
540	ELASTIC SCATTERING FROM LIGHT NUCLEI	IGO BLESZYNSKI	1	0.0
556	A PROPOSAL TO STUDY THE (p,p') PROCESS LEADING TO π -ATOMIC STATES	BERTOZZI	1	52.6
563	$p + p$ ELASTIC SCATTERING AT 800 AND 500 MeV	HOFFMANN	1	0.0
580	CROSS SECTIONS AND ANALYZING POWERS FOR ELASTIC AND INELASTIC SCATTERING OF 515-MeV PROTONS FROM ${}^{12}\text{C}$	SEESTROM-MORRIS DEHNHARD	1	43.6
583	MEASUREMENT OF C_{LL} IN THE COULOMB INTERFERENCE REGION	PAULETTA GAZZALY	1	0.0
585	MEASUREMENT OF p - p AND p - d ELASTIC SCATTERING IN THE COULOMB INTERFERENCE REGION BETWEEN 500 AND 800 MeV	PAULETTA	1	0.0
613	STUDY OF DEEPLY BOUND HOLE STATES IN THE TIN ISOTOPES VIA THE $(p-d)$ REACTION	SAHA SETH	1	0.0
616	NUCLEAR INFORMATION FROM THE SPIN ROTATION AND DEPOLARIZATION PARAMETERS IN THE ${}^{12}\text{C}(p,p')$ REACTION TO THE $1^+ 12.72$ -MeV $T = 0$ AND TO THE $1^+ 15.11$ -MeV $T = 1$ LEVELS	BLESZYNSKI MCCLELLAND HINTZ MOSS	1	0.0
623	MEASUREMENT OF CROSS SECTION, ANALYZING POWER AND DEPOLARIZATION PARAMETERS IN THE ${}^{28}\text{Si}(p,p'){}^{28}\text{Si}$ ($6^- T = 0$ AND $T = 1$) REACTION AT 400 MeV	GLASHAUSSER	1	0.0
624	AN ATTEMPT TO OBSERVE DIRECTLY COUPLING OF PARTICLE-HOLE STATES TO Δ -HOLE STATES	GOODMAN	1	0.0
626	MEASUREMENT OF THE DEPOLARIZATION PARAMETERS $D_{NN'}$, D_{LS} AND $D_{SS'}$ IN PROTON-NUCLEUS SCATTERING AT VERY HIGH EXCITATION ENERGIES	GLASHAUSSER MCGILL	1	0.0

627	MEASUREMENT OF THE RELATIVE SIGN OF NEUTRON PROTON TRANSITION MATRIX ELEMENTS IN (p,p') REACTIONS	HYNES BERNSTEIN	1	0.0
630	A STUDY OF PROTON INELASTIC SCATTERING AT 0° AND A SEARCH FOR GIANT MONOPOLE AND GIANT MAGNETIC DIPOLE EXCITATIONS	CAREY HINTZ MCCLELLAND MOSS	1	0.0
631	STUDY OF THE SPIN-FLIP PROBABILITY FOR ELASTIC AND INELASTIC SCATTERING FROM ODD- MASS NUCLEI	SEESTROM-MORRIS CAREY MOSS DEHNHARD	1	0.0
632	CAN PROTON DENSITY DIFFERENCES BE EXTRACTED FROM MEDIUM-ENERGY P-NUCLEUS ELASTIC- SCATTERING DATA	BARLETT HOFFMANN	1	0.0
641	MEASUREMENT OF CROSS SECTION AND ANALYZING POWERS FOR ELASTIC AND INELASTIC SCATTERING OF 400 TO 500 PROTONS FROM ¹² C	HARVEY SEESTROM-MORRIS	1	0.0
642	REACTIVE CONTENT OF THE OPTICAL POTENTIAL. PHASE 2	MCGILL HOFFMANN	1	0.0
643	STRUCTURE OF STATES IN THE OXYGEN ISOTOPES VIA MEASUREMENTS OF THE SPIN DEPOLARIZA- TION AND SPIN ROTATION OBSERVABLES	AAS HYNES	1	0.0
644	TESTS OF THE POLARIZATION-ANALYZING POWER EQUALITY IN ELASTIC SCATTERING OF INTERMEDIATE- ENERGY PROTONS FROM NUCLEI	IGO	1	0.0

CHANNEL: ISORAD

Exp. No.	Title	Spokesman	Run No. * = Complete	Beam Hours
184	PRODUCTION OF ⁸² Sr	OBRIEN	1 *	0.0
210	ISOTOPE PRODUCTION FACILITY IRRADIATION VANADIUM, MOLYBDENUM AND LANTHANUM TARGETS	OBRIEN	1 *	0.0
211	NEUTRON IRRADIATION OF COPPER SINGLE CRYSTALS	GREEN	1 *	0.0
267	PREPARATION OF RADIOISOTOPES FOR MEDICINE AND THE PHYSICAL SERVICES USING THE LAMPF ISOTOPE PRODUCTION FACILITY	OBRIEN	1	12578.9
554	IRRADIATION OF TECHNOLOGICALLY IMPORTANT METALS WITH 800-MeV PROTONS USING THE ISOTOPE PRODUCTION FACILITY AT LAMPF	BROWN COST	1	0.0

CHANNEL: LEP

Exp. No.	Title	Spokesman	Run No. * = Complete	Beam Hours
2	TOTAL PION CROSS SECTIONS	JAKOBSON	1 * 2 *	0.0 663.4

25	PION DOUBLE-CHARGE-EXCHANGE REACTION	BURMAN	1 *	0.0
			2 *	881.2
			3 *	268.2
28	STUDIES OF THE π^+, π^0 REACTION	YAVIN	1 *	195.0
29	ELASTIC SCATTERING OF π^+ AND π^- AT 10-30 MeV	PREEDOM	1 *	0.0
			2 *	0.0
35	CLUSTER EFFECTS IN NUCLEAR PION CAPTURE	ZIOCK	1 *	297.5
50	RADIATIVE PION CAPTURE IN LIGHT NUCLEI	CROWE ROWE	1 *	0.0
			2 *	460.3
54	ELASTIC SCATTERING OF MESONS IN THE ENERGY RANGE 20-60 MeV	PREEDOM	1 *	264.6
			2 *	707.4
67	DEVELOPMENT OF PION BEAM MONITORING TECHNIQUES	DROPESKY	1 *	0.0
			2 *	87.5
79	CALIBRATION OF THE PION BEAM TRANSPORT SYSTEMS AND A PION BEAM MONITOR	PHILLIPS	1 *	0.0
96	SCATTERING OF 20-50-MeV π^+ BY HYDROGEN AND DEUTERIUM	NAGLE	1 *	0.0
			2 *	728.0
102	EXCITATION FUNCTIONS AND ANGULAR DISTRIBUTION RECOIL STUDIES OF SIMPLE PION-INDUCED NUCLEAR REACTIONS	MARKOWITZ	1 *	0.0
121	PION-INDUCED NUCLEAR REACTIONS	SEGEL	1 *	0.0
			2 *	150.0
122	PIONIC ATOM X RAYS AND NUCLEAR DISTRIBUTIONS	KUNSELMAN	1 *	0.0
131	A STUDY OF THE $\pi^+ + d \rightarrow p + p$ REACTION AT PION ENERGIES 10-60 MeV	PREEDOM	1 *	0.0
			2 *	260.0
140	STUDY OF THE (π^+, d) REACTION WITH AN INTRINSIC Ge DETECTOR	BARNES	1 *	0.0
			2 *	385.0
			3 *	0.0
144	SEARCH FOR THE C-VIOLATION DECAY $\pi^0 \rightarrow 3\gamma$	HIGHLAND MACEK	1 *	333.0
162	STUDIES OF THE (π^+, π^0) REACTION ON LIGHT ELEMENTS	YAVIN ALSTER	1 *	0.0
164	PION TOTAL CROSS SECTION MEASUREMENTS WITH AN ORIENTED ^{169}Ho TARGET	FISHER MARSHAK	1 *	88.0
170	STUDY OF REACTION $^{13}\text{C}(\pi^+, \pi^0)^{13}\text{N}$ (GROUND STATE)	ALSTER	1 *	0.0
180	ELASTIC AND INELASTIC π^+ -NUCLEUS SCATTERING AT 25, 50, AND 75 MeV	EISENSTEIN	1 *	0.0
			2 *	191.3

181	MEASUREMENTS OF THE $\pi^- p \rightarrow \pi^0 n$ ANGULAR DISTRIBUTION AT LOW ENERGIES AND CALIBRATION OF THE π^0 SPECTROMETER	ALSTER BOWMAN	1 *	346.0
			2 *	859.2
190	A PRECISION MEASUREMENT OF THE $\pi^- - \pi\pi^0$ MASS DIFFERENCE	ZIOCK	1	0.0
191	π^+ -NUCLEUS INELASTIC SCATTERING TO GIANT RESONANCES	HALPEHN	1 *	0.0
			2 *	292.7
			3 *	484.4
			4 *	284.4
209	PION INTERACTIONS IN NUCLEAR EMULSIONS	BRADBURY ALLRED	1 *	0.0
234	A STUDY OF THE INELASTIC PION SCATTERING REACTION AT PION ENERGIES 10-100 MeV	GOTOW	1 *	436.3
247	DISTRIBUTION OF PRODUCTS FROM INTERACTIONS OF STOPPED π^- WITH SEVERAL MEDIUM- AND HEAVY-MASS NUCLEI	ORTH	1 *	35.6
			2 *	59.5
284	MEASUREMENT OF THE ${}^3\text{He}(\pi^-, \pi^0){}^3\text{He}$ ANGULAR DISTRIBUTION	COOPER HEFFNER	1	209.0
293	STUDY OF THE DOMINANT REACTION MODES FOR PIONS INTERFACING WITH COMPLEX NUCLEI	SEGEL	1 *	151.0
295	STUDY OF THE PION-DEUTERON SINGLE-CHARGE- EXCHANGE REACTION $d(\pi^-, \pi^0)2n$	BOWMAN MOINESTER	1	0.0
299	AN INVESTIGATION OF THE REACTION $(\pi^+, \pi^+ + p)$	ZIOCK	1 *	0.0
			2 *	960.1
			3 *	0.0
303	A SURVEY OF PION SINGLE-CHARGE-EXCHANGE SCATTERING USING BACK ANGLE GAMMA SPECTROSCOPY	JACKSON	1 *	152.3
			2 *	290.9
			3	0.0
315	HIGH-RESOLUTION STUDY OF THE $(\pi^+, 2p)$ REACTION	WHARTON	1 *	0.0
			2 *	338.1
			3	233.4
316	π^- -NUCLEUS ELASTIC SCATTERING BETWEEN 20 AND 50 MeV	SETH BURLESON	1 *	699.6
			2 *	0.0
320	A COMPARISON OF (π^+, xn) AND (π^-, xn) REACTIONS	CHURCH	3 *	33.0
322	SYSTEMATIC STUDY OF PION-INELASTIC SCATTERING AT ENERGIES BELOW 100 MeV	BERTRAND GOTOW	1 *	877.1
324	PRECISION MEASUREMENT OF RATIOS OF CERTAIN LIGHT ELEMENT PION EXCITATION FUNCTIONS	HALPERN	1 *	118.6
333	$\pi^\pm$ -NUCLEAR ELASTIC SCATTERING AT ENERGIES BETWEEN 50 AND 100 MeV	GOTOW	1 *	512.2

348	STUDY OF GIANT RESONANCES WITH RADIATIVE PION CAPTURE ON MEDIUM-Z NUCLEI AT LEP	CROWE	1 *	761.7
349	NUCLEAR REACTIONS OF ^{127}I WITH PIONS	PORILE	2	25.0
350	STUDY OF PION ABSORPTION MECHANISMS IN NUCLEI	SEGEL SCHIFFER	1 *	225.8
388	LOW-ENERGY PION ELASTIC SCATTERING FROM THE PROTON AND DEUTERON AT 180°	HOLT	1 *	392.2
393	ANGULAR DISTRIBUTION MEASUREMENTS OF THE PION SINGLE-CHARGE-EXCHANGE REACTION ON ^{13}C	ALSTER MOINESTER	1	279.8
401	STUDY OF THE ISOBARIC ANALOG CHARGE EXCHANGE REACTION $^{15}\text{N}(\pi^+, \pi^0)^{15}\text{O}$	BOWMAN COOPER	1	101.6
412	SEARCH FOR ANALOG STATE TRANSITIONS IN (π^+, π^0) REACTIONS ON ^7Li , ^{27}Al , ^{93}Zr , ^{120}Sn , AND ^{208}Pb AND FOR COLLECTIVE ISOVECTOR STATES IN THE (π^-, π^0) REACTION ON ^{93}Zr	BAER BOWMAN CVERNA	1	270.6
415	TWO-NUCLEON-OUT PRODUCTS FROM STOPPED π^- INTERACTIONS	ORTH	1 *	121.6
416	STUDY OF FAST PION-INDUCED FISSION OF URANIUM	DROPESKY	3	15.0
465	RADIOCHEMICAL STUDY OF PION SINGLE CHARGE EXCHANGE	RUNDBERG	1	13.0
483	MEASUREMENT OF THE ANGULAR DEPENDENCE OF TENSOR POLARIZATION IN THE $^3\text{H}(\pi^+, \pi^+)^3\text{H}$ REACTION	HOLT	1 *	478.3
487	MEASUREMENT OF THE NUCLEAR RESONANCE EFFECT IN SOME PIONIC ATOMS	REIDY LEON	1 *	202.8
523	STUDY OF $^{14}\text{C}(\pi^+, \pi^0)^{14}\text{N}$ REACTION	GOODMAN BAER	1	24.6
524	STUDY OF THE ISOVECTOR TERMS IN π -NUCLEUS INTERACTIONS WITH (π^+, π^0) REACTIONS ON $^{40,42,44,48}\text{Ca}$ AND $^{112,118,124}\text{Sn}$	BAER BOWMAN CVERNA	1	138.6
525	EXCITATION OF ISOVECTOR TRANSITIONS WITH PION SINGLE CHARGE EXCHANGE ON ^{12}C	KING MOINESTER	1	9.2
527	STUDY OF THE $^{10}\text{B}(\pi^-, \pi^0)^{10}\text{B}$ REACTION	BAER BOWMAN	1	0.0
536	EFFICIENCY MEASUREMENTS FOR π^+ IDENTIFICATION IN THE PLASTIC BALL DETECTOR	GUTBROD	1 *	106.7
541	A SEARCH FOR NUCLEAR CRITICAL OPALESCENCE USING THE REACTION $^{40}\text{Ca}(\pi^+, 2\gamma)$	COOPER	1	0.0
543	A PRODUCT RECOIL STUDY OF THE $(\pi^+, \pi^+ n)$ REACTION	CARETTO	1	7.8
544	SEARCH FOR A FAST FISSION PROCESS	WILHELMY	1	48.0

553	STUDY OF TARGET THICKNESS EFFECTS IN THE CROSS-SECTION MEASUREMENT OF THE PION SINGLE-CHARGE-EXCHANGE REACTION $^{13}\text{C}(\pi^+, \pi^0)^{13}\text{N}(\text{g.s.})$ FROM 50 TO 350 MeV	RUNDBERG	2	69.0
561	π^- -NUCLEAR ELASTIC SCATTERING AT ENERGIES BETWEEN 30 AND 80 MeV	BLECHER OBENSHAIN HYNES	1	0.0
567	A STUDY OF THE $\pi^+ + d \rightarrow p + p$ REACTION AT PION ENERGIES 5-200 MeV	GOTOW MINEHART RITCHIE	1	0.0
576	STUDY OF THE $(\pi^+, 2p)$ AND $(\pi^-, 2p)$ REACTIONS ON THE ISOTOPIC PAIRS ^{16}O , ^{18}O , AND $^{40-48}\text{Ca}$	ROOS FREEDOM CHANT	1	0.0
596	AN EXPERIMENTAL TEST OF GENERALIZED WHEELER-FEYNMAN ABSORBER THEORY BY DIRECT OBSERVATION OF MUON-NEUTRINO RECOIL	CRAMER MORRIS BRAITHWAITE MOORE	1	0.0
607	STUDY OF ISOVECTOR GIANT RESONANCES WITH PION CHARGE EXCHANGE	ALSTER BAER BOWMAN	1	0.0

CHANNEL: LINE B

Exp. No.	Title	Spokesman	Run No. * = Complete	Beam Hours
179	DIFFERENTIAL PRODUCTION CROSS SECTIONS OF MULTIPLY-CHARGED FRAGMENTS IN PROTON AND PION-INDUCED SPALLATION OF LIGHT NUCLEI	BOWMAN	1 *	1341.4

CHANNEL: LINE X-BS

Exp. No.	Title	Spokesman	Run No. * = Complete	Beam Hours
184	PRODUCTION OF ^{82}Sr	OBRIEN	1 *	0.0

CHANNEL: NEUTRINO-A

Exp. No.	Title	Spokesman	Run No. * = Complete	Beam Hours
31	A NEUTRINO EXPERIMENT TO TEST MUON CONSERVATION	NEMETHY	1 * 2 *	6713.2 1097.4
148	NEUTRINO ELECTRON ELASTIC SCATTERING AT LAMPF (A FEASIBILITY STUDY)	REINES CHEN	1 * 2 *	0.0 1132.0
225	A STUDY OF NEUTRINO ELECTRON ELASTIC SCATTERING	CHEN REINES	1	0.0

254	FEASIBILITY STUDY FOR THE MEASUREMENT OF THE INELASTIC NEUTRINO SCATTERING CROSS SECTIONS IN ^{39}K	FIREMAN	1 *	1026.0
559	SEARCH FOR NEUTRINO OSCILLATIONS	DUONG-VAN PHILLIPS	1	0.0
609	ANTI-NEUTRINO OSCILLATION EXPERIMENTS AT LAMPF	KRUSE	1	0.0
638	A SEARCH FOR OSCILLATIONS USING MUON-NEUTRINOS	DOMBECK	1	0.0
645	A SEARCH FOR NEUTRINO OSCILLATIONS AT LAMPF	LING ROMANOWSKI	1	0.0

CHANNEL: NULL

Exp. No.	Title	Spokesman	Run No. * = Complete	Beam Hours
298	MEASUREMENT OF LIGHT OUTPUT vs ENERGY FOR VARIOUS SCINTILLATORS	SELOVE	1 *	0.0

CHANNEL: PJP

Exp. No.	Title	Spokesman	Run No. * = Complete	Beam Hours
302	800-MeV PROTON IRRADIATION OF AN ALUMINUM SAMPLE	GREEN	1 *	326.6
327	PIP, PROTON IRRADIATION PORT	WILSON	1 *	16.9

CHANNEL: P³

Exp. No.	Title	Spokesman	Run No. * = Complete	Beam Hours
32	PRECISION MEASUREMENT OF THE PROCESSES $\pi^+ \rightarrow \pi^0 + e^+ + \nu$	MC FARLANE MACEK	1 *	0.0
			2 *	1092.2
34	ELASTIC SCATTERING OF π^+ ON DEUTERONS	MINEHART	1 *	0.0
58	MEASUREMENT OF $\pi^- + p \rightarrow \gamma + n$	NEFKENS FITZGERALD	1 *	0.0
67	DEVELOPMENT OF PION BEAM MONITORING TECHNIQUES	DROPESKY	1 *	0.0
			2 *	220.2
79	CALIBRATION OF THE PION BEAM TRANSPORT SYSTEMS AND A PION BEAM MONITOR	PHILLIPS	1 *	0.0

80	FORWARD ELASTIC SCATTERING OF π^+ AND π^- FROM ^{12}C , ^{13}C , ^{16}O , ^{40}Ca , ^{208}Pb	PHILLIPS	1 *	0.0
			2 *	528.8
82	INVESTIGATION OF PION-INDUCED REACTIONS ON LIGHT ELEMENTS WITH THREE PARTICLES IN THE FINAL STATE	PHILLIPS	1 *	425.3
90	A TEST OF THE REVERSAL INVARIANCE IN SINGLE PION PHOTOPRODUCTION THROUGH A STUDY OF RECIPROCITY IN THE REACTIONS $\pi^- {}^3\text{He} \rightarrow \gamma t$ (AND ITS INVERSE) AND $\pi^- t \rightarrow {}^3\text{He} \gamma$ (AND ITS INVERSE)	SHERMAN SHIVELY GLODIS SPENCER WADLINGER NEFKENS	1 *	0.0
			2 *	806.9
99	MEASUREMENT OF THE CROSS SECTION FOR $\pi^- + p \rightarrow \pi^- + \pi^+ + n$ WITH A MAGNETIC SPECTROMETER	REBKA GRAM	1 *	0.0
			2 *	646.0
102	EXCITATION FUNCTIONS AND ANGULAR DISTRIBUTION RECOIL STUDIES OF SIMPLE PION-INDUCED NUCLEAR REACTIONS	MARKOWITZ	1 *	0.0
103	SPALLATION YIELD DISTRIBUTIONS FOR PION INTERACTIONS WITH COMPLEX NUCLEI	HUDIS	1 *	0.0
			2 *	295.7
104	PROPOSAL FOR LAMPF EXPERIMENT. STUDIES OF THE PROTON- AND PION-INDUCED FISSION OF MEDIUM-MASS NUCLIDES	PATE	1 *	0.0
			2 *	118.7
118	FRAGMENT EMISSION FROM PION INTERACTIONS WITH COMPLEX NUCLEI	PORILE	1 *	0.0
			2 *	97.0
119	CROSS SECTIONS OF SIMPLE NUCLEAR REACTIONS INDUCED BY π -MESONS	KAUFMAN	1 *	27.8
			2 *	186.8
120	MEASUREMENT OF THE POLARIZATION ASYMMETRY AND THE DIFFERENTIAL CROSS SECTION OF PION-NUCLEON CHARGE EXCHANGE FROM 160 TO 500 MeV	NEFKENS FITZGERALD	1 *	870.2
			2	90.3
121	PION-INDUCED NUCLEAR REACTIONS	SEGEL	1 *	0.0
			2 *	0.0
123	NUCLEAR STRUCTURE EFFECTS IN PION- INDUCED NUCLEAR REACTIONS	KAROL	1 *	0.0
			2 *	75.0
			3 *	135.1
			4 *	0.0
144	SEARCH FOR THE C-VIOLATION DECAY $\pi^0 \rightarrow 3\gamma$	HIGHLAND MACEK	2 *	602.1
153	INVESTIGATION OF NUCLEAR GAMMA-RAYS RESULTING FROM IN-FLIGHT PION AND PROTON REACTIONS	EISENSTEIN	1 *	0.0

154	ELASTIC SCATTERING OF π^+ AND π^- FROM THE HELIUM ISOTOPE	MINEHART MCCARTHY	1 *	7.2
			2	0.0
181	MEASUREMENTS OF THE $\pi p \rightarrow \pi^0 n$ ANGULAR DISTRIBUTION AT LOW ENERGIES AND CALIBRATION OF THE π^0 SPECTROMETER	ALSTER BOWMAN	2 *	204.3
195	NUCLEAR RESONANCE EFFECT IN PIONIC ATOMS	LEON REIDY	2 *	0.0
			3 *	163.1
201	$\pi^- d \rightarrow 2d$ REACTION AT 100-500 MeV	MINEHART	1 *	338.0
214	PIONIC X-RAY ABSOLUTE YIELDS AS A FUNCTION OF Z	HARGROVE LEON	1 *	199.1
221	PRECISION MEASUREMENT OF THE DECAY RATE FOR THE DALITZ DECAY MODE OF THE π^0 MESON	HOFFMAN	1 *	351.5
222	MEASUREMENT OF THE DECAY RATE FOR $\pi^0 \rightarrow e^+e^-$	MISCHKE	1 *	945.8
247	DISTRIBUTION OF PRODUCTS FROM INTERACTIONS OF STOPPED π^- WITH SEVERAL MEDIUM- AND HEAVY-MASS NUCLEI	ORTH	2 *	28.0
248	STUDY OF THE $(\pi, \pi\pi)$, (π, Δ) , (π, B_Δ) , AND (π, n) REACTIONS IN ^3He AND ^6Li BY MEASURING RECOIL SPECTRA	KALLNE MCCARTHY GUGELOT	1 *	674.4
283	CHARGED-PARTICLE EMISSION FOLLOWING μ -CAPTURE	KRANE SHARMA	1 *	31.0
286	PROTON AXIAL TOMOGRAPHY	HANSON	1 *	345.5
304	STUDY OF THE AUGER PROCESS IN PIONIC ATOMS	LEON MAUSNER	1 *	78.6
309	INCLUSIVE π^+ AND π^- DOUBLE CHARGE EXCHANGE ON ^{16}O AND ^{40}Ca	REBKA	1	0.0
319	DETERMINING THE MECHANISM FOR MULTI-NUCLEON AND CLUSTER REMOVAL IN 200-MEV π -NUCLEAR INTERACTIONS	LIND	1 *	283.0
320	A COMPARISON OF (π^+, xn) AND (π^-, xn) REACTIONS	CHURCH	1 *	57.8
			2 *	170.1
337	MEASUREMENT OF THE CROSS SECTION FOR $\pi^- p \rightarrow \pi^-, \pi^+ n$ AT 200 AND 229 MeV	REBKA GRAM	1 *	999.8
349	NUCLEAR REACTIONS OF ^{127}I WITH PIONS	PORILE	1 *	74.5
			2	55.2
358	ELASTIC SCATTERING OF PION FROM DEUTERIUM	MINEHART	1 *	514.0
383	MEASUREMENT OF $\pi^+ + p$ ELASTIC SCATTERING	SADLER NEFKENS	1 *	700.5
			2 *	844.5
373	A COMPARISON OF RESIDUAL NUCLEI YIELDS FROM π^- ABSORPTION IN ^{112}Cd (GROUND STATE) AND ^{112}D (FIRST EXCITED STATE)	REIDY LEON	1 *	94.1

390	A STUDY OF INCLUSIVE INELASTIC PION SCATTERING NEAR THE $\Delta(3/2,3/2)$ RESONANCE	JACKSON	1 *	453.0
394	APPLICATION OF PROTON COMPUTED TOMOGRAPHY	HANSON	1 *	195.3
396	COMPARISON OF MEASURED PIONIC ATOM CASCADE INTENSITIES WITH THEORETICAL INTENSITIES OBTAINED USING PARAMETERS FROM MUONIC ATOM STUDIES	REIDY	1 *	110.9
400	SEARCH FOR THE RARE DECAY $\mu^+ \rightarrow e^+e^+e^-$	DUONG-VAN HOFFMAN	1 *	156.8
404	A KINEMATICALLY COMPLETE STUDY OF THE $(\pi, \pi'p)$ REACTION ON ^{16}O ABOVE THE RESONANCE BY DETECTING PIONS AND PROTONS IN COINCIDENCE	HAMM SWENSON	1 *	401.5
416	STUDY OF FAST PION-INDUCED FISSION OF URANIUM	DROPESKY	1 * 2 * 3	141.0 17.0 11.0
420	DEVELOPMENT OF A HIGH-RESOLUTION LIQUID-ARGON CHARGED-PARTICLE DETECTOR OF MEDIUM-ENERGY PARTICLES	GRUHN FLYNN	1	0.0
439	PARTICLE GAMMA-RAY COINCIDENCE STUDIES FROM π -NUCLEAR REACTIONS	LIND	1 * 2	239.0 0.0
455	HIGH-PRECISION STUDY OF THE μ^+ DECAY SPECTRUM	ANDERSON	1	0.0
458	THE EXCITATION FUNCTION FOR THE SINGLE-CHARGE-EXCHANGE REACTION $^{65}\text{Cu}(\pi^-, \pi^0)^{65}\text{Ni}$	KAUFMAN	1	80.4
459	CROSS-SECTION MEASUREMENTS OF THE $^{14}\text{N}(\pi^-, \pi^0)^{14}\text{O}$ (GROUND STATE) REACTION	VIEIRA	1 *	96.0
465	RADIOCHEMICAL STUDY OF PION SINGLE CHARGE EXCHANGE	RUNDBERG	1	99.1
466	NUCLEAR CONFIGURATION OF INDIVIDUAL CORE-COUPLED STATES IN ^{209}Bi FROM INELASTIC π^- SCATTERING	FUNSTEN PLENDL	1 *	219.6
469	STUDY OF THE $^{91}\text{Zr}(\pi^-, \pi^0)^{90}\text{Zr}$ CHARGE-EXCHANGE REACTION	MCGILL HOFFMANN	1	0.0
480	DISCRETE STATES FROM PION DOUBLE CHARGE EXCHANGE ON HEAVY NUCLEI	ZEIDMAN	1	0.0
500	FISSION FRAGMENT DISTRIBUTIONS IN FAST PION-INDUCED FISSION OF ^{238}U	RUNDBERG	1	72.2
513	π^- QUASI-FREE SCATTERING FROM THE HELIUM ISOTOPES	MCCARTHY MINEHART	1 * 2	0.0 0.0
543	A PRODUCT RECOIL STUDY OF THE (π^-, π^+n) REACTION	CARETTO	1	25.0
544	SEARCH FOR A FAST FISSION PROCESS	WILHELMY	1	48.0

553	STUDY OF TARGET-THICKNESS EFFECTS IN THE CROSS-SECTION MEASUREMENT OF THE PION SINGLE-CHARGE-EXCHANGE REACTION $^{13}\text{C}(\pi^+, \pi^0)^{13}\text{N}$ (g.s.) FROM 50 TO 350 MeV	RUNDBERG	1	61.3
555	TOTAL CROSS-SECTION MEASUREMENTS OF THE SINGLE-CHARGE-EXCHANGE REACTION $^{13}\text{C}(\pi^+, \pi^0)^{13}\text{N}$ (g.s.)	IMANISHI VIEIRA	1 *	139.0
562	STUDY OF THE PION ABSORPTION MECHANISM THROUGH THE $A(\pi, p)X$ REACTION AT $T_\pi = 500$ MeV	JACKSON SCHIFFER	1	0.0
564	STUDY OF SMALL ANGLE $^4\text{He}(\pi^-, \pi^+)$ REACTION	MCKEOWN	1	0.0
595	AN ON-LINE GAM-RAY STUDY OF PION-INDUCED SINGLE NUCLEON REMOVAL REACTIONS ON ^{13}C AND ^{40}Ca	ORTIZ VIEIRA	1	0.0
614	STUDIES OF SCALAR AND VECTOR PARTS OF THE $\pi-\pi$ INTERACTION BY MEASURING NUCLEAR DEEXCITATION GAMMA-RAY CORRELATION FOLLOWING INELASTIC PION SCATTERING	FUNSTEN	1	0.0
617	A STUDY OF THE (3/2, 3/2) RESONANCE IN LIGHT NUCLEI	ZIOCK	1	0.0
628	STUDY OF THE $(\pi, \pi p)$ REACTION AND QUASI-FREE SCATTERING IN ^4He	ASHERY	1	0.0

CHANNEL: RADAMAGE-1

Exp. No.	Title	Spokesman	Run No. * = Complete	Beam Hours
302	800-MeV PROTON IRRADIATION OF AN ALUMINUM SAMPLE	GREEN	1 *	0.0

CHANNEL: SMC

Exp. No.	Title	Spokesman	Run No. * = Complete	Beam Hours
7	NUCLEAR STRUCTURE PHYSICS USING STOPPED MUONS	SHERA	1 *	0.0
			2 *	617.3
12	MUONIC X-RAYS AND NUCLEAR CHARGE DISTRIBUTIONS	POWERS KUNSELMAN	1 *	173.0
			2 *	141.9
37	ULTRAHIGH PRECISION MEASUREMENTS OF MUONIUM GROUND-STATE ENERGY LEVELS, HYPERFINE STRUCTURE INTERVAL AND MUON MAGNETIC MOMENT	HUGHES CRANE	1 *	0.0
			2 *	940.4
51	TECHNIQUES FOR MATERIALS IDENTIFICATION AND ANALYSIS	MALANIFY	1 *	119.3

60	CHEMICAL EFFECTS IN THE CAPTURE OF NEGATIVE MESONS IN MATTER	KNIGHT SCHILLACI	1 *	0.0
			2 *	451.5
76	SEARCH FOR MUONIUM-ANTIMUONIUM TRANSITION	CHANG KANE	1 *	0.0
85	GAMMA-NEUTRINO CORRELATION AFTER NEGATIVE MUON CAPTURE	WELSH	1 *	193.6
100	TISSUE CHEMICAL ANALYSIS WITH MU-MESIC X RAYS	HUTSON	1 *	0.0
			2 *	167.0
101	FEASIBILITY STUDIES. MEASUREMENT OF MUONIC X RAYS AND NUCLEAR GAMMA-RAYS WITH CRYSTAL DIFFRACTION SPECTROMETERS AT LAMPF	BOEHM LU	F-S*	103.0
122	PIONIC ATOM X RAYS AND NUCLEAR DISTRIBUTIONS	KUNSELMAN	2 *	64.8
142	NEGATIVE MUON-INDUCED FISSION IN THE ACTINIDE ELEMENTS	HUIZENGA	1 *	0.0
			2 *	520.3
163	INVESTIGATION OF CHANGES IN CHARGE DISTRIBUTIONS FOR NUCLEI NEAR Z=28 BY ELECTRON SCATTERING AND MUONIC X RAYS	PERKINS SHERA	1 *	0.0
165	MUONIUM FORMATION IN HELIUM AND OTHER RARE GASES	HUGHES	1 *	0.0
166	MUONIC X RAYS AND NUCLEAR CHARGE DISTRIBUTIONS ELECTRIC QUADRUPOLE MOMENTS OF $_{67}\text{Ho}^{165}$ AND $_{73}\text{Ta}^{181}$	POWERS	1 *	0.0
173	PHYSICS OF THE PION AND THE PIONIC ATOM	BOEHM VOGEL	1 *	600.9
			2 *	309.6
175	SEARCH FOR THE FORMATION OF MUONIC HELIUM ($\alpha\mu^-e$)	HUGHES	1 *	0.0
206	SEARCH FOR THE 2S METASTABLE STATE OF MUONIC HYDROGEN	HUGHES EGAN	1 *	497.0
213	MUON TRANSFER STUDY	SHERA STEFFEN	1 *	50.9
240	ISOTOPE AND ISOTONE SHIFTS IN THE $1f_{7/2}$ SHELL	SHERA WOHLFAHRT	1 *	294.1
266	TRAPPING OF POSITIVE MUONS AT DEFECTS IN METALS	GAUSTER HEFFNER	1 *	223.0
			2 *	106.1
			3 *	9.0
268	MEASUREMENT OF THE GROUND-STATE HYPERFINE STRUCTURE INTERVAL OF THE MUONIC HELIUM ATOM ($\alpha\mu^-e^-$)	SOUDER HUGHES	1 *	518.6
276	PERTURBED CIRCULAR POLARIZATION OF MUONIC X RAYS	YAMAZAKI	1 *	0.0
			2 *	183.8
			3 *	235.1

277	MUONIC X-RAY ANALYSIS OF CORE SAMPLES FROM OIL-BEARING FORMATIONS	ALLRED	1 *	33.0
283	CHARGED-PARTICLE EMISSION FOLLOWING μ^- CAPTURE	KRANE SHARMA	1 *	138.3
			2 *	88.6
288	STUDIES OF μ^- CAPTURE PROBABILITIES FOR SOLID-STATE SOLUTIONS	NAUMANN	1 *	180.1
292	NEUTRON EMISSION FROM MUON-INDUCED REACTIONS ON ACTINIDE ELEMENTS	HUIZENGA	1 *	196.2
			2 *	138.3
297	A BICENTENNIAL PROPOSAL TO STUDY THE BEHAVIOR OF POSITIVE MUONS IN SOLIDS	BROWN	1 *	144.1
			2 *	137.1
			3 *	47.1
328	MEASUREMENT OF THE DECAY RATE AND PARITY-VIOLATING ASYMMETRY FOR $\mu^+ \rightarrow e^+ \gamma$	BOWMAN COOPER	1 *	1666.3
330	FUNDAMENTAL MUONIC X-RAY MEASUREMENTS OF INTEREST TO MATERIALS ANALYSIS	HUTSON YATES-WILLIAMS	1 *	90.4
			2 *	67.8
331	FAST MUON REACTIONS WITH ^{12}C , ^{46}Ti , AND ^{58}Ni	ORTH	1 *	97.2
			2 *	78.0
334	NUCLEAR CHARGE PARAMETERS OF ^{41}Ca AND STABLE Cd AND Te ISOTOPES	SHERA WOHLFAHRT	1 *	162.4
			2	125.3
335	MONOPOLE AND QUADRUPOLE CHARGE DISTRIBUTIONS IN THE SAMARIUM AND GADOLINIUM ISOTOPES	SHERA YAMAZAKI	1 *	298.7
344	HIGHER PRECISION MEASUREMENT OF MUON MAGNETIC MOMENT AND OF MUONIUM hfs INTERVAL	HUGHES	1 *	425.6
357	MUONIC X-RAY SPECTRA OF GASES. 1. DENSITY AND ADMIXTURE EFFECTS	KNIGHT	1 *	145.1
364	SEARCH FOR THE EXCITED 2S STATE OF MUONIUM	EGAN DENISON HUGHES	1 *	535.8
			2 *	167.7
371	MUONIC X-RAY SPECTRA OF GASES. 2. CAPTURE PROBABILITIES IN MIXTURES	HUTSON	1 *	122.7
374	μ^- CAPTURE PROBABILITIES FOR SELECTED SOLID BINARY COMPOUNDS	SCHILLACI	1 *	161.7
375	μSR STUDY OF DIFFUSION IN METALS IN THE PRESENCE OF PARAMAGNETIC IONS	SCHILLACI	1 *	194.6
			2 *	287.0
			3 *	45.0
377	INVESTIGATION ON THE EFFECT OF GRAIN SIZE IN MUON CAPTURE IN INHOMOGENEOUS SYSTEMS	REIDY	1 *	28.0

382	μ SR INVESTIGATION OF THE EFFECTS OF IMPURITIES ON THE TRAPPING AND DIFFUSION OF μ^+ PARTICLES IN BCC METALS	KOSSLER BROWN	1	96.4
400	SEARCH FOR THE RARE DECAY $\mu^+ \rightarrow e^+g^+e^-$	DUONG-VAN HOFFMAN	1 *	54.4
408	MACROSCOPIC DIFFUSION STUDIES IN METALS	HEFFNER LEON	1 *	81.0
414	BONE CALCIUM ASSAY WITH MUONIC X RAYS - SIGNAL/NOISE AND REPRODUCIBILITY STUDIES	HUTSON REIDY	1 *	118.6
417	STUDY OF THE NUCLEAR AUGER PROCESS IN HEAVY MUONIC ATOMS	HUIZENGA	1 *	120.0
421	SENSITIVE SEARCH FOR $\mu^+ \rightarrow e$ CONVERSION	SOUDER FRANKEL HUGHES	1	6.0
427	MAGNET RESONANCE STUDIES OF μ^+ -ELECTRON DEFECT COMPLEXES IN NONMETALS	ESTLE	1 *	253.3
			2	140.4
			3	24.0
436	NEGATIVE MUON SPIN ROTATION AND RELAXATION IN MAGNETIC MATERIALS	YAMAZAKI HAYANO	1 *	196.2
444	SEARCH FOR THE DECAY $\mu \rightarrow e\gamma$	BOWMAN HOFSTADTER	1	0.0
445	SEARCH FOR THE LEPTON FLAVOR-VIOLATING DECAY $\mu^+ \rightarrow e^+\nu\bar{\nu}$	MATIS BOWMAN	1 "	54.4
454	MEASUREMENT OF THE ETA PARAMETER IN MUON DECAY	CROWE	1 *	73.5
			2 *	0.0
464	RADIATIVE MUON CAPTURE IN GASEOUS ^3He	WU DUGAN HUGHES LU EGAN	1	0.0
491	EXPERIMENTAL DETERMINATION OF THE STRONG INTERACTION SHIFT IN THE $2p-1s$ TRANSITION OF PIONIC DEUTERIUM AND HYDROGEN ATOMS	BOVET	1	646.6
494	NUCLEAR CHARGE PARAMETERS OF THE STABLE Ru AND Pd ISOTOPES	HOEHN	1	51.0
499	MUON LONGITUDINAL AND TRANSVERSE RELAXATION STUDIES IN SPIN-GLASS SYSTEMS	DODDS MACLAUGHLIN HEFFNER	1 *	329.6
			2	0.0
514	A μ SR STUDY OF MUONIUM-SUBSTITUTED FREE RADICALS	VERGAMINI COOKE ESTLE	1	36.0

529	PART 1. MEASUREMENT OF THE RESIDUAL MUON POLARIZATION IN HELIUM-3 MUONIC ATOM (A FEASIBILITY TEST FOR PART 2) AND PART 2. ANGULAR CORRELATIONS IN THE CAPTURE OF POLARIZED MUONS IN GASEOUS HELIUM-3	WU DUGAN HUGHES LU EGAN	1 *	136.0
			2	0.0
547	SEARCH FOR FAST MUONIUM IN VACUUM	EGAN HUGHES KANE	1 *	231.4
			2	0.0
552	ULTRAHIGH PRECISION MEASUREMENTS ON MUONIUM	HUGHES EGAN	1	0.0
571	MUON SPIN ROTATION STUDIES OF DILUTE MAGNETIC ALLOYS	DODDS HEFFNER SCHILLACI	1	209.4
594	PRECISION DETERMINATIONS OF SOME RELATIVE MUONIC COULOMB CAPTURE RATIOS IN OXIDES OF DIFFERENT VALENCES	REIDY	1	0.0
639	MUON SPIN ROTATION STUDY OF MUON BONDING AND MOTION IN SELECT MAGNETIC OXIDES	BOEKEMA DENISON	1	0.0
640	TRANSVERSE AND LONGITUDINAL FIELD μ SR MEASUREMENTS IN SELECTED TERNARY METALLIC COMPOUNDS	DODDS HEFFNER MACLAUGHLIN	1	0.0
646	HYPERFINE STRUCTURE OF MUONIC HELIUM-3 AND MUONIC HELIUM-4 ATOMS	HUGHES EGAN	1	0.0

CHANNEL: SWY-LABS

Exp. No.	Title	Spokesman	Run No. * = Complete	Beam Hours
105	NUCLEAR SPECTROSCOPY STUDIES OF PROTON-INDUCED SPALLATION PRODUCTS	BUNKER	1 *	0.0
118	FRAGMENT EMISSION FROM PION INTERACTIONS WITH COMPLEX NUCLEI	PORILE	1 *	0.0
269	800-MeV PROTON IRRADIATION OF METAL SAMPLES	GREEN	1 *	4.5
381	ALUMINA CERAMIC RADIATION EFFECTS STUDY	HARVEY	1 *	0.0

CHANNEL: TTA

Exp. No.	Title	Spokesman	Run No. * = Complete	Beam Hours
86	COUNTER EXPERIMENTS IN THE THIN TARGET AREA	POSKANZER	1 *	0.0
			2 *	743.0
			3 *	1128.0
308	AN ATTEMPT TO MAKE DIRECT ATOMIC MASS MEASUREMENTS IN THE THIN TARGET AREA	BUTLER POSKANZER	1	4316.5

APPENDIX B

ACTIVE SPOKESMEN, INSTITUTIONS, AND EXPERIMENTS

SPOKESMEN	INSTITUTIONS	EXPERIMENTS
ADAMS, G. S.	MIT	473
ALSTER, J.	TEL AVIV U	393, 607
ANDERSON, H. L.	LOS ALAMOS	455
ANDERSON, R. E.	LOS ALAMOS	526, 535
BAER, H. W.	LOS ALAMOS	412, 523, 524, 527, 558, 607
BAKER, F. T.	U GEORGIA	356
BAUER, T. S.	SACLAY	405
BENTON, E. V.	U SAN FRANCISCO	171
BERTOZZI, W.	MIT	556
BERTRAND, F. E.	ORNL	399
BHATIA, T. S.	TEXAS A&M U	457
BLANPIED, G. S.	U SO CAROLINA	475, 476, 573
BLECHER, M.	VPI STATE U	561
BLESZYNSKI, M.	UCLA	540
BONNER, B. E.	LOS ALAMOS	387
BOUDRIE, R. L.	LOS ALAMOS	581
BOVET, E.	CALTECH	491
BOWMAN, J. D.	LOS ALAMOS	295, 401, 412, 444, 445, 524, 527, 607
BRADBURY, J. N.	LOS ALAMOS	215
BRAITHWAITE, W. J.	U TEXAS AUSTIN	596
BRILL, A. B.	VANDERBILT U	244
BRISCOE, W. J.	UCLA	546
BROWN, J. A.	LOS ALAMOS	382
BROWN, R. D.	LOS ALAMOS	545, 554
BRYANT, H. C.	U NEW MEXICO	449, 586, 588
BURLESON, G. R.	NEW MEXICO STATE U	498, 558
BUSH, S.	U NEW MEXICO	274, 275
BUTLER, G. W.	LOS ALAMOS	308
CARETTO, A. A.	CARNEGIE-MELLON U	543
CAREY, T. A.	LOS ALAMOS	473
CHANT, N. S.	U MARYLAND	576
CHEN, H. H.	UC IRVINE	225
CLARK, D. A.	U NEW MEXICO	588
COOKE, D. W.	MEMPHIS STATE U	514
COOPER, M. D.	LOS ALAMOS	284, 401, 541
CORNELIUS, W. D.	LOS ALAMOS	474
COST, J. R.	LOS ALAMOS	554
COTTINGAME, W. B.	NEW MEXICO STATE U	598
COWSIK, R.	WASHINGTON U	557
CRAMER, J. G.	U WASHINGTON	596
CVERNA, F. H.	LOS ALAMOS	412, 524, 526
DEHNHARD, D.	U MINNESOTA	369, 510, 580, 602
DEVRIES, R. M.	LOS ALAMOS	591, 592
DICELLO, J. F.	LOS ALAMOS	272
DIETERLE, B. D.	U NEW MEXICO	124
DIGIACOMO, N. J.	LOS ALAMOS	591, 592
DODDS, S. A.	RICE U	499, 571
DONAHUE, J. B.	LOS ALAMOS	449, 587
DUGAN, G.	COLUMBIA U	464, 529
DUONG-VAN, M.	LOS ALAMOS	559
EGAN, P. D.	YALE U	464, 529, 547, 552
EISENSTEIN, R. A.	CARNEGIE-MELLON U	446, 597
ESTLE, T. L.	RICE U	427, 514
FAUBEL, W.	LOS ALAMOS	579
FITZGERALD, D. H.	UCLA	58, 120

SPOKESMEN	INSTITUTIONS	EXPERIMENTS
FLYNN, E. R.	LOS ALAMOS	420
FORTUNE, H. T.	U PENNSYLVANIA	570, 577
FRANKEL, S.	U PENNSYLVANIA	345, 421, 520, 532
FRATI, W.	U PENNSYLVANIA	345
FUNSTEN, H. O.	COLL WM&MARY	466
GAZZALY, M. M.	U MINNESOTA	583
GEESAMAN, D. F.	ANL	565
GERACI, J. P.	U WASHINGTON	384
GILLETTE, E. L.	COLORADO STATE U	235
GILMORE, J. S.	LOS ALAMOS	467
GLASHAUSSER, C.	RUTGERS U	356, 432, 531
GLASS, G. C.	TEXAS A&M U	589
GOLDSTEIN, L. S.	UC SAN FRANCISCO	380
GOODMAN, C. D.	ORNL	523
GOTOW, K.	VPI STATE U	567
GRAM, P. A. M.	LOS ALAMOS	586
GREEN, W. V.	LOS ALAMOS	237
GREENE, S. J.	NEW MEXICO STATE U	572, 577
GRUHN, C. R.	LOS ALAMOS	420
HALPERN, I.	U WASHINGTON	446, 597
HARVEY, A.	LOS ALAMOS	326, 560
HARVEY, C. J.	U TEXAS AUSTIN	602
HEFFNER, R. H.	LOS ALAMOS	284, 499, 571
HINTZ, N. M.	U MINNESOTA	411, 450, 451, 601
HOEHN, M. V.	LOS ALAMOS	494
HOFFMANN, G. W.	LOS ALAMOS	386, 392, 469, 563
HOFSTADTER, R.	STANFORD U	444
HOISTAD, B.	U TEXAS AUSTIN	405, 456, 485, 533, 535
HOLLAND, J. R.	WESTINGHOUSE	237
HOLTKAMP, D. B.	U MINNESOTA	570
HUGHES, V. W.	YALE U	421, 464, 529, 547, 552
HYNES, M. V.	LOS ALAMOS	561
IGO, G. J.	UCLA	202, 438, 479, 540
JACKSON, H. E.	ANL	303, 562
JARMER, J. J.	LOS ALAMOS	517, 518
KANE, J. R.	COLL WM&MARY	547
KAROL, P. J.	CARNEGIE-MELLON U	294
KATZ, R.	U NEBRASKA	218
KAUFMAN, S. B.	ANL	458
KING, N. S. P.	LOS ALAMOS	525, 526, 538
KOSSLER, W. J.	COLL WM&MARY	382
KRUSE, H. W.	LOS ALAMOS	609
LIND, V. G.	UTAH STATE U	439
LU, D. C.	YALE U	464, 529, 542
MACLAUGHLIN, D. E.	UC RIVERSIDE	499
MASTERSON, T. G.	U COLORADO	581
MATIS, H. S.	LOS ALAMOS	445
MCFARLANE, W. K.	TEMPLE U	124
MCCARTHY, J. S.	U VIRGINIA	154, 513
MCGILL, J.	U TEXAS AUSTIN	469
MCKEOWN, R. D.	ANL	564
MCNAUGHTON, M. W.	LOS ALAMOS	194, 492, 512
MICHEL, D. J.	NRL	113
MINEHART, R. C.	U VIRGINIA	154, 513, 567
MOINESTER, M. A.	LOS ALAMOS/TEL AVIV U	295, 393, 525
MOORE, C. F.	U TEXAS AUSTIN	572, 596
MORRIS, C. L.	LOS ALAMOS	484, 596
MOSS, J. M.	LOS ALAMOS	411, 432, 473, 531
MUTCHLER, G. S.	RICE U	336
NANN, H.	INDIANA U	462
NEFKENS, B. M. K.	UCLA	58, 120, 546

SPOKESMEN	INSTITUTIONS	EXPERIMENTS
NORTHCLIFFE, L. C.	TEXAS A&M U	517, 518, 528, 589, 590
OBENSHAIN, F. E.	ORNL	561
OBRIEN, H. A.	LOS ALAMOS	106, 267
ORTH, C. J.	LOS ALAMOS	595
PACIOTTI, M. A.	LOS ALAMOS	217, 270
PAULETTA, G.	UCLA	490, 583, 585
PEREZ-MENDEZ, V.	LBL	215
PHILLIPS, G. C.	RICE U	505, 559
PHILLIPS, T. L.	UC SAN FRANCISCO	380
PINSKY, L. S.	U HOUSTON	336
PLENDL, H. S.	FLORIDA STATE U	466
PORILE, N. T.	PURDUE	349
POSKANZER, A. M.	LBL	308
PREEDOM, B. M.	U SO CAROLINA	576
RAJU, M. R.	LOS ALAMOS	236
REBKA, G. A.	U WYOMING	309
REIDY, J. J.	U MISSISSIPPI	187, 594
REINES, F.	UC IRVINE	225
RICHMAN, C.	LOS ALAMOS	273
RITCHIE, B. G.	U SO CAROLINA	567
ROOS, P. G.	U MARYLAND	576
RUNDBERG, R. S.	LOS ALAMOS	465, 500, 553
SCHIFFER, J. P.	ANL	562
SCHILLACI, M. E.	LOS ALAMOS	571
SCOTT, A.	U GEORGIA	356
SEESTROM-MORRIS, S. J.	LOS ALAMOS	580
SEITZ, M. G.	ANL	157
SETH, K. K.	NORTHWESTERN U	233, 405, 462, 533, 550, 605, 606
SHEPARD, J. R.	U COLORADO	538
SHERA, E. B.	LOS ALAMOS	334
SIMMONS, J. E.	LOS ALAMOS	457, 517, 518, 528, 590
SMITH, A. R.	U NEW MEXICO	271
SMITH, W. W.	U CONNECTICUT	587
SOMMER, W. F.	LOS ALAMOS	407
SOUDER, P. A.	YALE U	421
SPENCER, J. E.	SLAC	10, 233
THIESSEN, H. A.	LOS ALAMOS	446
TURKEVICH, A. L.	U CHICAGO	603
VANDYCK, O. B.	LOS ALAMOS	345
VERGAMINI, P. J.	LOS ALAMOS	514
VIEIRA, D. J.	LOS ALAMOS	595
WAGNER, R.	ANL	498
WHARTON, W. R.	CARNEGIE-MELLON U	315
WHITTEN, C. A.	UCLA	249
WILHELMY, J. B.	LOS ALAMOS	544
WILLARD, H. B.	NSF	492, 512
WOHLFAHRT, H. D.	LOS ALAMOS	334
WU, C. S.	COLUMBIA U	464, 529
ZEIDMAN, B.	ANL	480, 565
ZIOCK, K. O. H.	U VIRGINIA	190

APPENDIX C

VISITORS TO LAMPF DURING THE PERIOD JULY 1 — DECEMBER 31, 1980

Bjarne Aas UC, Los Angeles
 Gary S. Adams Massachusetts Inst. of Tech.
 Yasuyuki Akine UNM Cancer Center
 Douglas M. Alde Columbia Univ.
 Chester Alexander Univ. of Alabama
 Richard C. Allen UC, Irvine
 John C. Allred Consultant
 Howard I. Amols UNM Cancer Center
 Konrad A. Aniol Univ. of Washington
 David A. Appel Univ. of New Mexico
 Mary Jean Arntzen UNM Cancer Center
 Leonard B. Auerbach Temple Univ.
 Richard E. Auerbach Temple Univ.
 Robert D. Auerbach Temple Univ.
 Andrew D. Bacher Indiana Univ.
 Stephen D. Baker Rice Univ.
 Toni A. Balch UNM Cancer Center
 Gregory A. Balchin Univ. of South Carolina
 Martin L. Barlett Univ. of Texas
 David B. Barlow Northwestern Univ.
 Charles A. Barnes California Inst. of Tech.
 Peter D. Barnes Carnegie-Mellon Univ.
 Bernd Bassalleck Carnegie-Mellon Univ.
 David A. Bell Rice Univ.
 William Bertozzi Massachusetts Inst. of Tech.
 Hans A. Bethe Cornell Univ.
 Tarlochan S. Bhatia Texas A&M Univ.
 Hans Bichsel Univ. of Washington
 James A. Biggs Argonne National Lab.
 Richard P. Bird Columbia Univ.
 Georgia D. Blaine Colorado State Univ.
 Gary S. Blanpied Univ. of South Carolina
 Keith W. Blazey Rice Univ.
 Elizabeth H. Bleszynski UC, Los Angeles
 Marek Bleszynski UC, Los Angeles
 Thomas H. Blewitt Argonne National Lab.
 Carolyn A. Blies UNM Cancer Center
 Paul R. Bolton Yale Univ.
 Fred O. Borcharding UC, Los Angeles
 Mark A. Bosko Northwestern Univ.
 Jonathan S. Boswell Univ. of Virginia
 Eric Bovet California Inst. of Tech.
 Dale E. Boyce Univ. of Chicago
 Kenneth Boyer Univ. of Texas

Wilfred Braithwaite Univ. of Texas
 Reinhard Brandt Philipps Univ., Lnberge
 William J. Briscoe UC, Los Angeles
 Douglas M. Brock Colorado State Univ.
 George A. Brooks UC, Irvine
 Howard C. Bryant Univ. of New Mexico
 Douglas Bryman Univ. of British Columbia, TRIUMF
 James A. Buchanan Rice Univ.
 Anthony Buffa California Polytechnic State Univ.
 Carolyn J. Burbach Temple Univ.
 William J. Burger Massachusetts Inst. of Tech.
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