LBL-5363

PHYSICS, COMPUTER SCIENCE and MATHEMATICS DIVISION

ANNUAL REPORT

1 January - 31 December 1975

Lawrence Berkeley Laboratory
University of California
Berkeley, California

Work done under
U.S. Energy Research and Development Administration
Contract No. W-7405-eng-48

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161
Price: Printed Copy $5.00 Microfiche $2.25

LBL-5363
UC-34 Physics
TID-4500-R64

PHYSICS, COMPUTER SCIENCE and MATHEMATICS DIVISION

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Joseph V. Lepore
Editor

Lawrence Berkeley Laboratory
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Contents

INTRODUCTION

This annual report of the Physics, Computer Science and Mathematics Division describes the scientific research and other work carried out within the Division during the calendar year 1975. The Division has changed its name from the "Physics Division" to that indicated above, to properly reflect its true responsibilities. At the same time, work in Heavy-Ion Nuclear Science will be funded in the future through the new Nuclear Science Division, and so a summary of that work appears in the Annual Report of the Nuclear Science Division. Similarly, the work on Atomic Physics is now contained within the new Materials and Molecular Research Division. The Mathematics and Computing Group has now separated into two parts: the Computer Center, which manages the large computing facilities at the Lab on a recharge basis, and the Computer Science and Mathematics Group, which does research in various fields as described in this report and also provides programming expertise on a recharge basis as needed by other Divisions of the Laboratory. A third part of the original group is the Real-Time Systems Group, which has since been transferred to the Electrical Engineering Department at LBL and will function as a support group in conjunction with a small computer maintenance group formerly in our Physics Systems Group. The entire RTS Group now deals with hardware and software design and maintenance for small computers.

The major physics research activity of the Division is in high-energy physics. A vigorous program in this frontier field is maintained both in experimental and theoretical work. Experimental work is carried out at the Stanford Linear Accelerator Center (SLAC), at Fermi National Accelerator Laboratory (FNAL), and at Brookhaven National Laboratory (BNL). The work done at SLAC with SPEAR, the Stanford Positron Electron Accelerator Ring, has been the most exciting in recent years because of the discovery of the ψ particles by an LBL-SLAC team of collaborators. A related family of particles known as χ's has also been found and is described in this report.

This year we report substantial activity in a new area which reflects the very special relation between LBL and SLAC. A new Positron Electron Colliding Beam Project (PEP) has begun as a joint effort by LBL and SLAC. The construction of the accelerator itself is a joint effort involving the Accelerator Division at LBL with help from our accelerator theorists, but in addition the Physics Research Division is responsible for design of the experimental areas and facilities. We are also involved with selection and staff work for the various PEP committees: the PPC(PEP Policy Committee) and the EPC(Experimental Program Committee).

A second PEP Summer Study was held in 1975 at LBL sponsored by LBL, SLAC, and SLUO

(The SLAC-LBL Users Organization) with participants from all over the country and from abroad. The proceedings issued as LBL-4800 and SLAC-190 have become the basic text for all those who are designing future experiments both for PEP and for PETRA in Europe. As this report is being written in 1976, it has become known that PEP is in the President's budget and construction will begin, to be completed in 1980.

The Division continues its Medium-Energy Physics program at the Bevatron and at LAMPF. The 184-inch Synchrocyclotron is now run by the Accelerator Division and only for the medical program.

The scientific staff of the Division is composed of Staff and Faculty (UCB) Senior Scientists, Divisional Fellows, Term Appointees, and postdoctoral and graduate students working to fulfill the requirements for their doctorate. The graduate students contribute substantially to the laboratory's research program while fulfilling the requirements for their advanced degrees.

Substantial progress and exciting discoveries have been made during this year in all areas of research done in the Division. There is no way to do justice to the work in a short summary.

I. EXPERIMENTAL PHYSICS

The experimental physics program consists of research in high-energy particle physics, medium-energy physics, astrophysics, astronomy, and cosmic rays.

High-energy physics experimental observations, our major activity, are at the present time mainly carried out at SLAC, FNAL, and BNL. While there is extensive collaboration among high-energy particle physics groups because of the complexity and expense of modern experiments, the LBL contribution toward planning, construction of equipment, and data analysis of them is mainly carried out here.

Planning is in process for experiments that will be conducted at the PEP facility to be constructed at SLAC. Since PEP, planned to become operational in 1980, will be the next major event in the U.S. hierarchy of high-energy accelerators, a great deal of excitement has been generated. The results from SPEAR suggest that a whole new field of particle "spectroscopy" may be opened up with PEP. Because of the importance of PEP and because of the novelty and complexity of the experimental apparatus required by it, the development of such equipment is reported immediately below rather than in the section on experimental techniques and instrumentation development.

Research in medium-energy physics is carried out at the Bevatron and at LAMPF.

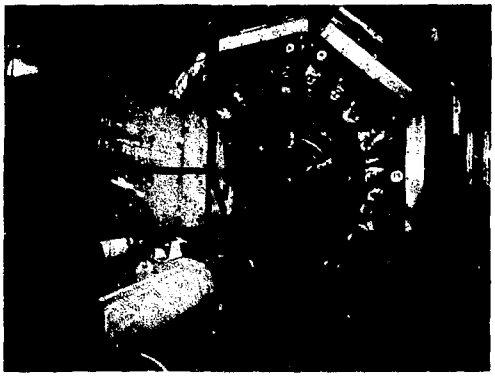
Work in astrophysics, astronomy, and cosmic rays is done at several appropriate cooperating observatories and by balloon or U-2 flights.

A. High-Energy Physics

1. SPEAR

Discovery of Other ψ Particles

The spectacular discovery of the ψ particles, which occurred at SPEAR last year, has been followed by a series of exciting new discoveries. The LBL-SLAC magnetic detector has operated almost continuously for the past year, and new resonance-like structures in the cross section for electron-positron annihilation, which have been found near 4 GeV, may be interpreted as additional members of the ψ particle family. Thus, three additional levels have been observed between the $\psi(3.1)$ and $\psi(3.7)$: a level called P_c, first observed at DESY, was confirmed in our work and has the feature that it results from photon decay of the $\psi(3.7)$; then decays by a second photon to $\psi(3.1)$. The most likely value of its mass is 3.5 GeV. In addition, we have found two other levels that occur by photon decay from the $\psi(3.7)$ and then decay into multipion systems: they are the $\chi(3.53)$, which decays into $2\pi^+2\pi^-$ and $3\pi^+3\pi^-$; and the $\chi(3.41)$, which decays into $\pi^+\pi^-$, K^+K^-, $2\pi^+2\pi^-$, and $3\pi^+3\pi^-$. Furthermore, there are at least two additional resonances above the $\psi(3.7)$ that are relatively broad: the $\psi(4.15)$ with a width of about 200 MeV, which was seen earlier, and the $\psi(4.4)$, which we have recently observed with a width of about



The huge, 250-ton Mark I magnetic detector at SPEAR used by LBL and SLAC physicists in identifying the new psi particles. In the center of the detector is the interaction region, just behind Carl Friedberg, where electrons and positrons collide head-on during operation. This massive array of spark chambers and counters can distinguish electrons, muons, and pions from each other and can measure their momenta, directions, and velocities. (XBB 7311-7292)

George Trilling (left) and Gerson Goldhaber, co-leaders of the LBL group of physicists collaborating with SLAC, and co-discoverers with SLAC of the psi particles, discuss plans for experiments that will reveal additional members of the psi particle family. (CBB-753-2077)

30 MeV. A search for other very narrow resonances has been completed. This search goes in 2.5-MeV steps from the $\psi(3.7)$ up to 7.5 GeV, the highest energy obtained so far. We did not observe any additional sharp spikes at the level of between 10% and 20% of the intensity of the signal at the $\psi(3.1)$. In a small region around 6 GeV (5.7 to 6.09 GeV), a more detailed search places a limit of less than 2% of the ψ intensity on any possible narrow spike in this region.

Polarized Electron and Positron Beams

The SPEAR, colliding e^+e^- beam machine, has the remarkable property of transversely polarizing the electron and positron beams. At a total energy of 7.4 GeV, anisotropy in in the distribution of hadron prongs as a function of the azimuthal angle ψ has been observed. The distributions are indicative of the polarization expected for spin 1/2 initial states, in agreement with expectations from the parton model. Furthermore, we observed

that at this energy the hadron distributions are no longer consistent with phase space but rather showed marked "jet" characteristics. This means that for given events we find a jet axis with respect to which the hadrons distribute themselves with low transverse momentum. This feature is again in accord with the parton model.

All of the work reported above is done as a collaborative experiment among members of the Trilling-Goldhaber and Chamberlain groups and Group A of LBL and the Richter and Perl groups of SLAC. LBL scientists were responsible for the shower counters, endcap chambers, and proportional wire counters for the SLAC-LBL magnetic detector, while the software for track reconstruction was a SLAC-LBL collaboration. All other equipment was constructed by the SLAC groups.

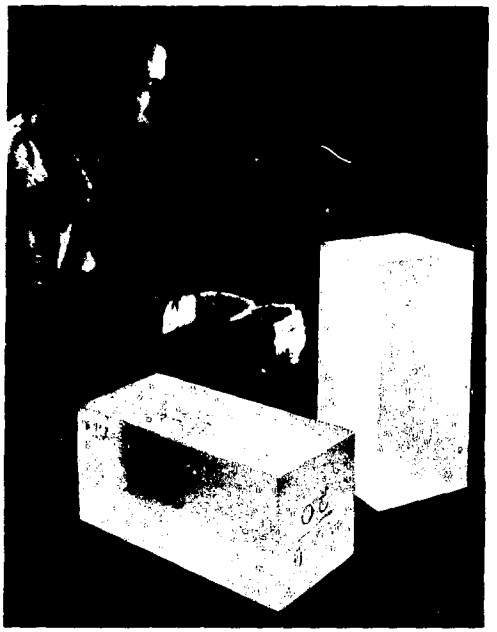
Lead Glass Wall Particle Detector

The lead-glass wall project is for the construction of a particle detector at SPEAR that is sensitive to photons and electrons. The apparatus consists of an assembly of lead-glass shower detectors combined with track chambers, which will be attached to the outside of the SPEAR magnetic detector. After the events have been tagged as having an electron or photon shower, the information from the magnetic detector will be used to study the production of these particles in conjunction with the charged particles detected.

The device will be used to study anomalous electron production and production of photons and π^0's in e^+e^- annihilation at SPEAR. The primary aim is to search for and tag events which might arise from the production and the leptonic or semi-leptonic decays of new particles (charmed particles, heavy leptons, or any new objects). The apparatus proposed will also be able to measure inclusive production of γ rays above 100 MeV and π^0's above 500 MeV/c.

This work is a collaboration among SLAC, the University of Hawaii, and LBL. The responsibility for building the apparatus has been divided between LBL and SLAC. The staff at LBL is responsible for building the lead-glass counters with the associated electronics and monitoring system and their supporting framework. The electronics for the energy trigger in the lead-glass array is also being designed and built at LBL. A series of tests was carried out at the MARK III accelerator at Stanford to determine the optimum glass type and photomultipliers for lead-glass Cerenkov counters. In addition, the energy resolutions of a variety of different counter geometries were measured.

So far, 57 of the 318 lead-glass counters needed for the array have been built. This fraction of the final lead-glass wall is now being studied in an electron and pion beam at SLAC to test all the components, as well as to study the e/π separation capabilities of the system. It is designed to achieve a π/e rejection of 2×10^{-3} at 1-GeV π/e energy. The components we have tested so far are (1) Lead-glass counters, (2) Light-emitting diode (LED) system for monitoring the phototube gains to a few percent, (3) Adders (electronic devices to add the energy deposited in a row of counters), which are part of the trigger system. System automatic digital converters for data acquisition, which were designed and built at LBL, will soon be tested.



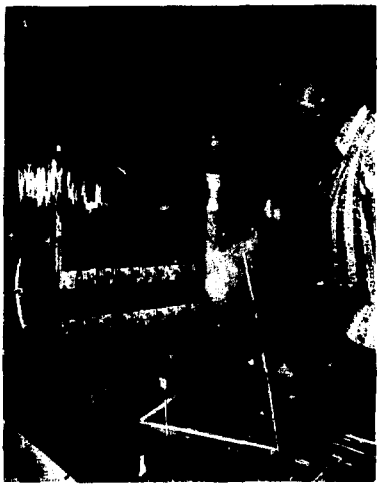
Blocks of lead glass are polished in the glass shop at LBL under the direction of Jack Brode, and will be used to form the "lead glass wall" electron shower detectors to be used in conjunction with the SPEAR magnetic detector.
(CBB 765-3994)

Data Analysis Systems

Until December 1975 we maintained a completely independent system for data analysis starting with raw tapes filtered for cosmic-ray events and using the LBL computer system. This analysis system, independently operated from a similar one at SLAC, has proved extremely valuable in all instances of cross checking the validity of observed effects in the data. Starting in January 1976 it will be possible to work confidently with the data at the track-reconstructed level, when this operation is carried out at SLAC. A detailed analysis of the physics results is continuing. In particular, we have developed a tie-in to bubble-chamber kinematic fitting programs, which may be used to improve the raw measurements by kinematic fitting.

Mark II Magnetic Detector

We have continued design studies for the Mark II magnetic detector, scheduled for installation at SPEAR in 1977. A small model of this system was tested at SLAC, and the results obtained for energy resolution are consistent with expectations based on shower development theory. The planned detection system of lead-liquid argon shower counters will yield both energy measurements and position information on electron and gamma-ray



A preliminary test model of the liquid argon shower counter is being examined by Donna Jones and Don Briggs of the Trilling/Goldhaber Group. This model will provide basic data for the initial design of the full-scale model to be used at SPEAR.
(CBB 7510-8087)

showers, as well as pi-electron separation. Design studies are in progress for the full-size shower counters that will completely surround the three-meter diameter Mark II solenoidal magnet.

2. PEP Studies

Increasing effort is being directed toward PEP, both in the development of advanced technology, and in the consideration of e^+e^- physics and the design of new experiments and detectors. Major projects now under development are the time projection chamber, the PEP streamer chamber, and the construction of superconducting solenoids to be used with detection chambers.

Closed-circuit television meetings between LBL and SLAC facilitate progress on PEP. LBL Director Andrew Sessler (left), Walt Hartsough, (right front), Tom Elioff and others participate in the first PEP Experimental Program Committee meetings. (XBB 754-2594)

Time Projection Chamber

The time projection chamber project is for development and construction of a charged particle detector for PEP and will allow viewing of the entire 4π of solid angle around an interaction region. In this program we are exploring the feasibility of new ideas in drift chamber technology, such as suppression of electron diffusion by magnetic fields and detection techniques that provide intrinsically three-dimensional data. Such a particle detector will offer dramatically improved pattern recognition in high-multiplicity events. The basic advantages of this detector concept result from the configuration of *parallel* magnetic and electric fields. Track images (i.e., the

ionization electrons left behind by a high-energy particle) are drifted through an argon-methane mixture to a plane of wires, which gives a measurement of dE/dx through pulse-height information as well as localization of the trajectories through induced pulses on a segmented cathode plane. The resolution of dE/dx will be ± 2% in giving particle mass identification, even in the relativistic region. The sensitive solid angle of the device should be approximately 90% of 4π. Momentum resolution will be 1%.

Important time-projection chamber studies completed this year follow:

- Extensive high-accuracy measurements of transverse diffusion of electrons in various mixtures of argon-methane have been completed. The measurements were done with and without magnetic field, and the results show that substantial suppression of electron diffusion does occur, allowing track translation over large distances without serious degradation. For example, the results show that transverse diffusion of only 170 microns is observed (with magnetic field) after a drift length of 15 cm; without magnetic field, the diffusion is ten times greater.

- The effects of nonparallelism of the magnetic and electric fields have been studied experimentally. The results are in good agreement with a relatively simple model, which ignores the longitudinal drift. From this work it appears that the field quality needed is on the order of ± 1/3%. Although demanding, this quality of field appears practical.

- An evaluation of alternative readout schemes has led to the conclusion that the optimum geometry is a plane of proportional wires with a segmented cathode plane. This approach preserves the intrinsically three-dimensional quality of the data and makes maximal use of all electrons in the track.

- Studies of dE/dx are in progress at the Bevatron. These studies will provide data for optimization of a large-scale prototype time-projection chamber as well as new information about energy loss in extremely thin absorbers. A 48-wire system is operational and over two million triggers have been collected.

Streamer Chamber

Recent PEP Summer Studies have described a proposed general purpose streamer chamber facility that uses an array of 200 charged couple device (CCD) sensors to record the streamer chamber tracks. A program is in progress to test this concept and uses a single CCD camera to image the LBL streamer chamber. Successful tests would be encouraging for a PEP detector collaboration.

The 1975 PEP Summer Study brings together an international group of physicists for a month's intensive study of the design and concept of detectors and experimental areas. (XBB 758-6182)

A prototype CCD camera, including a driver/amplifier and CAMAC module for scan readout controls, is being built. It incorporates a Fairchild CCD 221 to study its feasibility as the basic module for a PEP Streamer Chamber readout system. The large dynamic range of the CCD makes it suitable for particle identification based on the relativistic rise in ionization in the streamer chamber gas.

Superconducting Solenoids for Use with Particle Detectors

There is a class of detectors that will be used around storage ring accelerators that will require superconducting solenoids with high current density. Inside the coil the momenta of the charged particles will be measured by using magnetic fields of 1.0 to 2.0 tesla. Information about charged or neutral particles outside the coil that have traversed the coil will be collected by other detectors (Cerenkov, shower counters, etc.) Coil diameters of 1 to 2 m typically are considered. Two types of magnets are considered: (a) the continuous solenoid with a minimum thickness because of absorption and electromagnetic showering, and (b) the lumped coil magnet with coils subtending the minimum possible solid angle around the beam intersection.

Studies of different magnet configurations have been performed before and during the 1975 PEP Summer Study. A continuous solenoid has been designed, which is 1 m in diameter, 1/3 of a radiation length in thickness and consists

A new concept in magnet design was established when this one-meter-diameter superconducting solenoid successfully performed at its design current of 700 amperes. This success was achieved by using a new technique of inducing gentle quenches under controlled conditions and gradually increasing the energy up to full design current. Leading the team are Philippe Eberhard (right), physicist in charge; Michael A. Green (left), chief design engineer; and John D. Taylor, coordinator of the test setup.
(XBB 7512-8779)

of four identical modules. Two such modules have been built, and one has been tested to the full design current, 700 A. For this test, an original testing method has been used and the properties of quenches have been studied to help improve future designs.

3. SLAC Experiments

In collaboration with groups from the California Institute of Technology and Stanford Linear Accelerator Center, we are studying the diffractive production and decay of nucleon isobars produced by 14-GeV/c pions. Counters and wire spark chambers are used to trigger the SLAC 40-inch hydrogen bubble chamber on pictures that have a fast outgoing track of more than 8 GeV/c. The external measurements of the fast forward track allow both an efficient trigger and increased resolution. Some 400,000 pictures with incident π^- and 600,000 pictures with incident π^+ have been taken.

Work was completed on several studies that used the 700,000 pictures that were taken in 1969 of 7.1 GeV/c π^+ interactions in the SLAC 82-inch hydrogen bubble chamber. We have completed a detailed spin-parity analysis of the B meson and established the existence of a high mass Δ^{++}. A study was made of backward elastic π^+p scattering at 3.7 and 7.1 GeV/c, and an analysis of η and η' production at 7.1 GeV/c was completed.

The measurement, reconstruction, and particle identification for 120,000 π^-p events and 160,000 π^+p events have been prepared. This work was done at SLAC as a Cal Tech, LBL, and SLAC collaboration.

Several facets of the analysis are in progress. In order to study proton diffraction it is necessary to identify all of the exchange mechanisms that contribute to the sample: a study of the transverse momentum distribution has provided insight into the relative amounts of the various exchange processes. The N* production is compared with that found at much higher energies at the ISR in order to assess the energy dependence of diffraction. A new statistical test of factorization has been developed, and its application to the data is in progress.

4. FNAL

π^-p Charge Exchange Scattering and Regge Trajectories

This project concerns the π^-p reactions (1) $\pi^-p \to \pi^0 n$, (2) $\pi^-p \to \eta n$, (3) $\pi^-p \to \pi^0 +$ anything, and (4) $\pi^-p \to \pi^0 +$ neutrals, in the energy range of 20 to 200 GeV/c. Analysis of the data has been completed. The differential cross sections for both reactions have steep forward peaks with small dips at $t = 0$. The presence of this forward dip suggests that a strong spin-flip contribution to the scattering amplitudes persists at high energies. In reaction (1) there is a break in the differential cross-section slope near the value $-t = 0.6$ (GeV/c)^2. This structure is observed up to the highest energy measured. Both differential cross sections were integrated in t to obtain total cross sections.

Reactions (1) and (2) are classic from the point of view of the Regge pole model. Each reaction is dominated by the exchange of a single Regge trajectory, i.e., the ρ in reaction (1) and the A_2 in reaction (2). Effective Regge trajectories have been computed to show that these trajectories are not linear but tend to flatten out at higher values of -t. In addition, the ρ and the A_2 trajectories are not exchange-degenerate. Although the data otherwise fit a model of the Regge form, the usual two assumptions of exchange degeneracy and linear trajectories are not supported by the data.

In addition, the t = 0 cross section from reaction (1) can be used to determine the difference between the π^+p and π^-p total cross sections. We have made this computation and it shows that our results agree very well with the total cross section measurements from FNAL.

The data-taking phase of an experiment has been completed in which the inclusive production of π^0 and η at large transverse momenta ($P_\perp$) in $\pi^\pm p$, pp, and K^+p interactions are being studied. The experiment provides the first detailed comparison of this unusual production phenomenon between these various reactions at high energies and hence should yield significant information about the possible quark or parton structure of these particles.

At beam momenta of 100 and 200 GeV/c, data were collected for center-of-mass production angles (θ_{cm}) from about 10 to 110 degrees. Thus far, only the π^+p and pp data near θ_{cm} = 90 deg have been analyzed. In the transverse momentum ($P_\perp$) region studied, 1 to 4 GeV/c, the measured invariant cross sections for inclusive π^0 production vary by about a factor of a million. The ratio of inclusive π^0 production sectors, $R(p/\pi) = \sigma(pp \to \pi^0 + X)/\sigma(\pi p \to \pi^0 X)$, decreases with increasing $P_\perp$ and is independent of beam energy when expressed as a function of $X_\perp = P_\perp/P_{max}$. A comparison of the data with predictions of various theoretical models indicates significant disagreement in every case. In particular, models that assume quark-anti-quark "fusion" interactions as dominant production mechanisms can be ruled out. This is a collaboration with BNL and the California Institute of Technology.

Test of the Triple Regge Formalism

Preparations have been completed for a new experiment which will investigate the reaction $\pi^-p \to \pi^0 +$ anything in the forward direction. The triple-Regge formalism has been successful in fitting the pp inclusive cross sections in the kinematic region $0.8 \leq x \leq 1.0$, but since the formalism has so many free parameters in pp interaction, this is not a very conclusive test. The triple-Regge prediction for the reaction $\pi^-p \to \pi^0 +$ anything is very simple by comparison, and the measurement of this inclusive cross section should provide a definitive test of the triple-Regge theory and extend the knowledge of the ρ trajectory to much larger values of the momentum transfer than are now accessible.

The reactions involved are $\pi^-p \to (\pi^0, \eta, \omega, \ldots) + X$ and $\pi^-p \to (\pi^0, \eta, \omega, \ldots) + X_0$. These include (3) and (4) as major contributions. In reaction (3), X includes both charged and neutral particles in the final state, and in reaction (4), X_0 includes only neutral particles. The π^0 (or η, ω, etc.) appears in the largely unexplored kinematic region in which the reaction is nearly elastic, i.e. where $x = P_\perp/P_{max}$ lies between 0.8 and 1. The momentum transfer that will give P in this range lies between 0 and 3 $(GeV/c)^2$. The new triple-Regge theory allows a determination of the ρ trajectory from these data. The much larger cross section for inelastic reactions permits a clear measurement of the ρ or A_2 trajectory out to values of -t that are substantially larger than can be reached when we observe only elastic charge-exchange reactions. A secondary objective is to test the new triple-Regge theory in π^-p reactions in the regions where elastic and inclusive data overlap. One-pole exchanges are simple to handle and the theory makes predictions that are unambiguous. Comparison of trajectories from elastic data via conventional Reggeism and from inclusive data via triple-Regge theory should provide a definitive test for the new theory. A third feature of the triple-Regge study is the illumination of the relations between high $P_\perp$ and low $P_\perp$ phenomena by observing these reactions in the intervening kinematic range between

triple-Regge and high $P_\perp$ regions.

The interchange model of high $P_\perp$ processes predicts that the ρ trajectory will asymptotically approach -1 at large momentum transfers. This prediction can be tested by invoking the triple-Regge formalism: From preliminary data on $\pi^- p \to \pi^0 n$ (elastic) it appears that the prediction is consistent with the data, within statistics. The triple-Regge experiment will serve to improve statistics several-fold, and will correspondingly sharpen the test of the Interchange Model prediction.

The work on the above four reactions is carried out by Group A and the Kenney/Helmholz Groups in collaboration with the California Institute of Technology.

Hadron Interactions at High Energy

In collaboration with U.C. Davis, we have undertaken an exploratory program in the 15-ft bubble chamber at NAL to study hadron interactions at high energies. The first phase of this program is to develop scanning and measuring techniques and to develop reconstruction programs. The physics objectives of this experiment include a search for charm, a direct measurement of neutral-charged particle correlations, inclusive cross sections for the production of vector mesons and Δ(1238), and a study of hypercharge transfer contributions.

In late December 1975 we completed taking some 29,000 pictures at the Fermilab 15-ft bubble chamber. The chamber was filled with liquid hydrogen and exposed to a beam of 400-GeV/c protons. For analyzing this film we have modified one scan table and are modifying a second to provide two magnifications of the projected image, with a factor of approximately 3.5 between the two sizes. These tables are also equipped with image-plane digitizers, which will be used to guide the machines that measure events. The reconstruction programs have been tested and successfully used to reconstruct events from this film. Preliminary scanning and measuring are now underway while further refinements are made to the analysis chain.

Neutrino Interactions

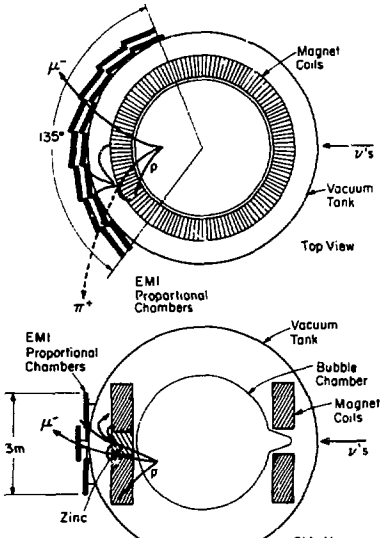
The large capability for scanning and measuring streamer and bubble chamber film has been devoted primarily to several neutrino experiments run at the Fermilab 15-ft bubble chamber, in which the group is collaborating with other users with less scanning and measuring capabilities.

Neutrino interactions in the Fermilab 15-ft bubble chamber have been studied with the chamber filled with either hydrogen or with a mixture of 75% neon and hydrogen.

The important physics topics that have been studied thus far in neutrino-proton interactions in hydrogen are deep inelastic interactions, diffractive elastic production, single-particle hadron inclusive distributions, Δ^{++} production, inclusive neutral current production, strange particle production, and search for exotic states.

Evidence for the existence of a particle with entirely new physical properties was found in scanning a portion of the 80,000 pictures taken with the neon-hydrogen mixture. Events of the type $e^+ \mu^- K^0$ were observed that had the property or "quantum number" that may correspond to the one called "charm" predicted by theorists several years ago. This is an Hawaii-LBL-Wisconsin collaboration.

The $\pi^+ p$ and pp interactions have been studied at 100 and 200 GeV/c. The FNAL 30-inch hydrogen bubble chamber has been exposed to unseparated positive beams of 100 and 200 GeV/c; the identity of the incident particle was tagged by using a Cerenkov counter and multiwire proportional chambers placed in the beam. This system was designed and built by an FNAL-MIT collaboration. A total of 100,000 and 70,000



A simulated neutrino interaction, $\nu + p \rightarrow \mu^- + p + \pi^+$, in the 15-foot bubble chamber at Fermilab. The μ^- produced passes easily through the superconducting magnet coils and hits the external muon identifier (EMI) plane along the trajectory observed in the chamber. The π^+ hadron interacts in the zinc between the magnet coils, and does not appear in the region expected by extrapolating its track to the EMI. The proportional chambers are mounted directly on the vacuum tank to maximize the solid-angle coverage.

pictures were taken at 100 and 200 GeV/c incident momentum respectively. This is a collaboration with U.C. Davis.

Search for High-Mass Mesons (ψ Particles)

Stimulated by the discovery of the ψ/J and ψ' particles, a search was made for narrow high-mass mesons via their photon decay modes. The reactions studied were $\pi^- + p \rightarrow m\gamma + n$ (or N^*) at 100 GeV/c, where m is the number of photons hitting the detector. For example, peaks in the 2γ mass spectrum would represent particles with C = even and spin J = even. We are in the process of data analysis. Thus far, no evidence of the production of new particles with masses in the range 0.4 to 5 GeV/c has been found.

As a by-product, highly accurate data on a variety of two- and three-body final states such as $\pi^- p \rightarrow n\omega$, $n\eta'$, nf^0, $n\pi^0\pi^0$ have been collected.

Deep Inelastic Muon Scattering

The scale invariance of electromagnetic interactions has been tested in deep-inelastic muon scattering. All data from the experiment have been reconstructed, momentum-fit, and compared to Monte Carlo simulations. Recent analysis has shown clear evidence for deviations from Bjorken scaling. We have a new experiment under way in the Fermilab muon beam, which has the following physics objectives:

- to search for heavy neutral mesons predicted by gauge theories;
- to study deep-inelastic virtual Compton scattering;
- to measure the deep-inelastic muon scattering structure function at very high momentum transfers;
- to investigate the q^2-dependence of virtual photoproduction of dimuon states (ψ's and states of higher mass).

Our preparations for an experiment to explore rare muon-induced reactions are well under way. The magnet design was completed at LBL early in the year; Fermilab has approved the design and has solicited bids for the magnet materials and fabrication. Prototypes of the proportional chambers and of the associated electronics have been constructed and are under test. The calorimeter counters have been

fabricated and are being tested. Time stability of the photomultipliers is being studied extensively for improving the calorimeter performance. Monte Carlo studies have been carried out to improve the trigger efficiency; fabrication of the trigger counters will be completed this year. Effort has begun on development of both the on-line data acquisition programs and the off-line analysis programs. This is a collaboration with FNAL and Princeton.

Polarization Studies

Preparations for the measurement of the polarization parameter in high-energy $\pi^{\pm}p$, $K^{\pm}p$, and pp scattering are being made at FNAL. The apparatus is complete in the sense that all components have been shipped to Fermilab that are essential to the polarization measurements. Seven of the eight multiwire proportional counters (MWPC) are connected to the system and will be reading in data in early 1976. Beam tune-up and some equipment tests have already been accomplished. Further tests are in progress and significant data-taking should be in progress by April 1976. Additional equipment is needed – another very large MWPC is being constructed so that the Wolfenstein parameter D can be measured simultaneously with the polarization P. This experiment is a collaborative effort involving physicists from Harvard, Yale, Argonne National Laboratory, Fermi National Accelerator Laboratory, and LBL.

5. BNL

K^-p Charge-Exchange Scattering

A bubble chamber experiment has been completed on the reactions $K^-p \to \Lambda\pi^0$, $\Sigma^0\pi^0$ and $K^-p \to K^-p$, $\bar{K}^0n$ covering the K^- momentum region 220 to 470 MeV/c. A coupled-channel partial-wave analysis of these reactions, covering all momenta up to 470 MeV/c, has also been carried out.

Experiments are in progress at Brookhaven to measure the total K^-p charge-exchange cross section as well as the charge-exchange angular distribution in the momentum range from 400 to 1100 MeV/c. The same apparatus will be used for studying the total cross sections of $K^-p \to \bar{K}^0n$ and $\bar{p}p \to \bar{n}n$.

These experiments have also led to measurements of the total cross section and a series of differential cross sections for $K^-p \to \bar{K}^0n$ in the region from 500 to 1100 MeV/c – a search for baryon resonances in the $\bar{K}$-nucleon system. The $\bar{K}$-nucleon system requires a much more complicated partial-wave analysis than does the pion-nucleon system primarily because of the existence of several channels ($\bar{K}n$, $\Lambda\pi$, $\Sigma\pi$) that must be analyzed simultaneously. Currently a unique phase-shift solution cannot be obtained due to the lack of precise data. Current analyses are ambiguous, especially in the region from 600 to 800 MeV/c.

Some uncertainty exists with data around 900 MeV/c. Some analyses need one resonance to fit the data, while another requires two. The charge-exchange reaction is of particular interest because it represents the difference between two isospin amplitudes ($I = 1$ and $I = 0$), and thus is sensitive to small changes in either one. A recent BNL experiment that measured K^-p and K^-d total cross sections found bumps in the K_n $I = 1$ total cross section at 540 MeV/c and 600 MeV/c, which they interpreted as possible new resonances.

The experimental work on the charge-exchange total cross-section measurement was completed in March 1975, and the data analysis is now nearing completion. No evidence is found for the bumps observed by the BNL experiment, but a new structure has appeared: a flat shoulder in the region from 850 to 925 MeV/c. These data should provide significant new constraints on the partial-wave analysis since

it represents an improvement in statistical accuracy by a factor of 50.

A significant effort this year has been directed toward the differential cross-section measurements. We assembled, tested, and operated an almost completely new set of experimental apparatus at BNL, and yet in spite of this, the experimental work should be completed by May 1976. Some preliminary data analysis has already been done, but the major work will not be done until after the experimental running is completed. Here also a significant improvement in the data has been achieved, increasing the accuracy by a factor of 25.

$\bar{p}p$ Reactions

In addition to the above experiments, a third experiment has been completed, which involved modifying the apparatus used in measuring the K^-p charge-exchange total cross section in order to measure the $\bar{p}p \to \bar{n}n$ total cross section from 300 to 1000 MeV/c. This reaction is currently of great interest. One theoretical model suggests the existence of several resonances in the $\bar{n}n$ system in this energy region. Also, a recent experiment found evidence for a narrow resonance with mass 1432 ± 9 MeV (475 MeV/c) in the $\bar{p}p$ total cross section. Experimental work and analysis is now complete, and although the momentum resolution is rather large, ± 20 MeV/c, no evidence for this resonance is found. The data are consistent with the BNL data only if the resonance has the unlikely spin value of $J \geq 14$.

6. Bevatron

Kaon Form Factor

A $K^0\mu 3$ polarization measurement of the real and imaginary parts of the kaon form factor was made by determining the variation of the muon polarization direction in $K^0\mu 3$ decays as a function of the kinematic configuration of the decay. We have completed the analysis. If we assume $\Lambda = 0$ (no q^2 dependence) and $\mathrm{Im}\,\xi = 0$, we obtain $\xi(0) = 0.178 \pm 0.105$. In contrast to the results of previous polarization experiments, this result is in statistical agreement with other recent results obtained from studies of the Dalitz plot distribution from $K^0\mu 3$ decays. If it is assumed that $\mathrm{Im}\,\xi$ is independent of q^2, one finds $\mathrm{Im}\,\xi = 0.35 \pm 0.30 + 0.21\ \mathrm{Re}\,\xi(0)$.

Baryon Exchange Reactions

A current experiment on baryon exchange reactions is designed to study exchange mechanisms in backward π^-p inelastic scattering around 4 GeV/c. A large-aperture Cerenkov counter and hodoscope were used to trigger the LBL streamer chamber on interactions producing a fast-forward proton or K^+. We have completed picture taking, and analysis is well under way.

Approximately 70,000 events representing ~ 2/3 of the available data have been measured on the COBWEB system. Programs have been developed to incorporate beam and downstream spark chamber measurements into the streamer chamber measurements, significantly improving the resolution over the bare streamer chamber measurements. π^-p inelastic scattering events are being studied at small u values. These data are being used in several ways:

- A search for backward A1 and A2 production by both N and Δ exchange.
- A study of backward vector meson production and decay; $\pi^-p \to pp^-$, $\pi^-p \to N^{*0}\rho^0$, $\pi^-p \to N^{*0}\omega^0$. Final statistics will allow a study of each of these reactions at a level of 500 to 1000 events. Comparisons can be made with reactions in which a ρ and ω

are exchanged. The ρ^0- ^{0} interference in this backward production is seen.

- A study of backward nucleon isobar production and cascading N* decays. Approximately 5% of the proton triggers in this study came from the decay of Λ^0's. This allows the study of the reaction $\pi^- p \to \Lambda^0 K^{*0}$ in detail. Based on approximately 1/4 of the final data, the polarization of the Λ^0 at small u shows a dip near u = -0.15.

- A search for exotic mesons.

7. Other

Charge Multiplicities of Particles with High Transverse Momentum

Charge multiplicities associated with charged particles of high transverse momentum have been studied. At the CERN ISR in the s-range 550 to 4000 $(GeV/c)^2$, large transverse momentum secondaries (0.6 to 4 GeV/c) have been identified by using the wide-angle spectrometer at angles of 45, 62.5, and 90 degrees. Correlated charged secondaries have been detected in a 150-element scintillator hodoscope surrounding the interaction region. Data for each particle type: $\pi^{\pm}$, $K^{\pm}$, and $p^{\pm}$ show that the associated multiplicity increases with transverse momentum and with s, the total center-of-mass energy. There are significant differences between particle types, however; the largest multiplicities are correlated with protons that have large transverse momentum. This work was done in collaboration with Daresbury and Rutherford Laboratories and the Universities of Illinois and Liverpool.

$\bar{p}p$ Interactions

The CERN 81-cm bubble chamber was exposed to antiprotons with momenta between 1.0 and 1.6 GeV/c, yielding 182,000 events. First and second measurements of these events have been completed on the spiral reader, and the data was analyzed at LBL and in Italy. This is an LBL, Padua, Pisa, and Turbin collaboration.

πp Data Analysis with Barrelet Zeros

Partial-wave analyses of $\pi^- p$ elastic scattering have been carried out in the method of Barrelet zeros. Recent precision polarization measurements of this reaction make it possible to use this powerful method and allow a comparison with classical methods.

By using all available differential cross-section and polarization data on $\pi^+ p$ elastic scattering below 2.2 GeV/c, the Barrelet zero trajectories have been unambiguously determined, with sufficient accuracy to delineate two zeros at the lower energies and six zeros near 1.9 GeV. These zeros, together with the forward direction phase given by dispersion relation, allow construction of the partial-wave amplitudes between 1.2 and 2.2 GeV; these amplitudes are found to satisfy partial-wave uncertainty. Examination of the Barrelet zero trajectories corresponding to the results of the classical partial-wave analyses shows important violations of general principles, raising questions about the complete reliability of such partial-wave analyses.

Monopoles

An alternate explanation of the event reported this year as evidence for a monopole has been worked out. In addition a review of the entire experimental situation has been given.

B. Particle Data Group

The Particle Data Center is involved in five active projects detailed below, which

The Particle Data Group compiles large masses of data into published form and develops the necessary computer techniques for managing the information. (XBB 757-5550)

reflect four major activities:

- Compilation of particle properties, and the issuance of "Review of Particle Properties" with its associated data booklet
- Compilation of cross sections, angular distributions, density matrix elements, etc., for particle interactions, with periodic issuance of reports and tapes covering these data
- Compilation of bibliographic information and experiment description (beam, target, momentum, reactions, etc.) for all approved accelerator proposals, preprints, reports, and published articles in experimental particle physics; publication of an index of documents of beam, momentum, and reaction
- Development of a computerized data-base management system to store, maintain, update, retrieve, and display the compiled information referred to above.

1. Data-Base Management System (BKY-DBMS)

The general purpose data-base management system (BKY-DBMS) initiated by our group has continued to be developed, primarily under the aegis of the Math and Computing group (which has adopted it for general lab use) but with continued input from the PDG.

2. Particle Physics Document File

The application of BKY-DBMS to the management of our "Particle Physics Document File" has progressed substantially. All of the "special processors" have been completed that are needed to check the validity of file information input and to convert this information to internal storage form. Trial runs of this system have been carried out by using that portion of the document file containing currently active accelerator proposals from all major particle physics laboratories in the world. This proposal file now contains some 200 entries encoded in the standard Document File language. This work is being done in collaboration with the SLAC Library and a printed index of the file is soon to be issued. In addition to its own usefulness (in helping to prevent duplicate experiments, for example), this index will serve as a prototype for our subsequent index of all experimental particle physics documents. The initial data base for the complete Document File is still being assembled; catching up on the backlog has turned out to be more time-consuming than expected. We are, however, now adding new document entries to the file on a steady-state basis.

3. Particle Physics Reaction-Data File

Work is also proceeding on the "Particle Physics Reaction-Data File," which will eventually contain the actual data on reactions, extracted from our particle physics documents. Most of this work is currently being done by various collaborators at the California Institute of Technology, Durham University, Rutherford High Energy Laboratory, and McGill University.

4. πN Data

The πN data compilation, data amalgamation, and partial-wave analysis project has continued. We have completed incorporating the ηn threshold into the parametrization of the interpolating surface and have extended the energy range down to 800 MeV. Hyperbolic dispersion relation constraints have been introduced into the partial-wave analysis, and resonance-pole parameters have been extracted.

5. IRATE/OPTIK

The IRATE/OPTIK text entry and editing system has continued to develop. The system is now capable of producing complex, scientific text and tables such as are found in a journal article. This includes equations and formulas involving fractions, sub- and superscripts, mathematic and Greek symbols, etc. Using this system we have produced one of the main tables in the "Review of Particle Properties," as well as several other parts of that report.

C. Medium-Energy Physics

The experimental program of this group in medium-energy physics is carried out at the Los Alamos Meson Factory (LAMPF) and at the Bevatron. When available, the 184-Inch Synchrocyclotron is used for testing instrumentation and apparatus. The emphasis is on stopped

pions and muons, on the scattering of light nuclei, and on x-ray spectra from K^- and π^- capture.

One objective is to use low-energy pions and muons to study their intrinsic properties and to use them as probes for nuclei and condensed materials.

1. Radiative Pion Capture in Nuclei

The study of the radiative pion capture, i.e. the measurement of the high-energy gamma-ray spectrum produced when pions are captured in nuclei, has been pursued in several directions:

First, we have accurately fixed the interpretation of the basic quantitative structure of the photo pion transition operator by comparing theory with measurements on a series of light nuclei.

Second, just recently we have been able to make consistent comparisons of the results obtained on the same nuclei, with electron scattering, photo pion production near threshold, and muon capture processes, and so establish an accurate set of constants.

Third, a new set of reactions is chosen to use radiative pion capture as a probe to study the excited states of nuclei. Examples of giant dipole states, search for quadrupole excitations, and other new states have been explored.

Fourth, since radiative pion capture has been shown to introduce the same Gamow-Teller transitions as the axial-vector part of ordinary muon capture, one expects the matrix elements for the transitions to bound states (e.g., $\pi^- {}^6\mathrm{Li} \to {}^6\mathrm{He}\gamma$, $\pi^- {}^3\mathrm{He} \to \mathrm{T}\gamma$, $\pi^- {}^{12}\mathrm{C} \to {}^{12}\mathrm{B}\gamma$) can be combined with information from other weak and electromagnetic processes dealing with the same state to test predictions from conserved vector current and from partially conserved axial current hypotheses, as for example the Goldberger-Treiman relation for the nuclear case.

The systematic study of gamma-ray spectra from the capture of negative pions in nuclei has been an ongoing program. The current studies are of the three light nuclei: $^{14}\mathrm{N}$, $^{10}\mathrm{B}$, and $^{3}\mathrm{H}$.

The photon spectra in the capture of stopped pions on $^{14}\mathrm{N}$ and $^{10}\mathrm{B}$ were measured in the 50 to 150 MeV region with a high-resolution pair spectrometer. The total radiative-capture branching ratios are $2.13 \pm 0.21\%$ and $2.27 \pm 0.22\%$, respectively for $^{14}\mathrm{N}$ and $^{10}\mathrm{B}$. The spectrum corresponding to the first 13-MeV excitation in each of the residual nuclei $^{14}\mathrm{C}$ and $^{10}\mathrm{Be}$ is dominated by the transition to the analog of a giant M1 state of the target nucleus. The ground-state transitions in both nuclei are resolved experimentally. The measured branching ratio for the extremely weak $^{14}\mathrm{C}$ (ground state) transition is $(3 \pm 2) \times 10^{-5}$. There is evidence for selective excitation of the analogs of the giant dipole spin-isospin states of $^{14}\mathrm{N}$, of which the 3^- component appears to be the strongest. In $^{10}\mathrm{B}$ the transition strength to the giant resonance region is more fragmented. The analysis employed an impulse-approximation Hamiltonian with amplitudes taken directly from the fundamental process on the nucleon, $\pi^0 + p \to n + \gamma$, and shell-model wave functions obtained by using realistic interactions in the 1s, 1p, and 2s-1d shells. Also, a calculation for the $^{14}\mathrm{C}$ (ground state) transition from 1s capture was done by using the "elementary-particle soft pion" hypothesis.

The photon spectrum from the pion capture reaction $\pi^- + {}^3\mathrm{H} \to 3n\gamma$ was measured, as in $^{14}\mathrm{N}$ and $^{10}\mathrm{B}$ above. All previous investigations on the A = 3 reactions are plagued by the fact that although a (3p) or (3n) system is produced, there is at least one additional strongly interacting particle in the final state. The reaction that we studied, $\pi^- {}^3\mathrm{H} \to 3n\gamma$, has only

an extra photon in the final state. A previous experiment, $\pi^- {}^3\mathrm{He} \rightarrow dn\gamma$ or $pnn\gamma$, demonstrated that radiative capture of the stopped pions produces final states in which three nucleons are preferentially found with low relative momenta – a favorable situation for the search of resonant states. None were found, but since T = 1/2 channel contributes most of the rate (82%), possible structures of the weaker T = 3/2 channel could have been obscured. The measured branching ratio $(\pi^- + {}^3\mathrm{H} \rightarrow nnn\gamma)/(\pi^- + {}^3\mathrm{H} \rightarrow nnn\gamma$ or $nn)$ is $4.5 \pm 0.8\%$. The shape of the photon spectrum was in satisfactory agreement with theoretical calculations, which included final state interactions among the three neutrons.

2. Elastic Scattering of Alpha Particles from Helium

An experiment on elastic scattering of alpha particles from helium at equivalent proton bombarding energies of 400 MeV and 1 GeV has been completed at the Bevatron. This experiment was designed for two purposes: (1) to study the four-momentum transfer region between 0.1 and 0.7 $(\mathrm{GeV/c})^2$ at 1-GeV bombarding energy, since in this region there is a large discrepancy in data taken at BNL and Saclay, and (2) to provide data at 400 MeV to help us understand the rather remarkable energy dependence of $p^4\mathrm{He}$ elastic in the intermediate energy range below 1.1 GeV. The data set is complete, and the analysis of the data is quite far along.

3. Elastic Scattering of Protons from Helium

Elastic scattering of 4.9- and 2.8-GeV protons from helium has also been investigated. In the energy region of 1.1 to 23 GeV (CERN) there are no published data on this reaction. There is a very remarkable difference between the relatively shallow minima observed at energies below 1.1 GeV and the deep minimum observed at 23 GeV. The measurements discussed in this section span some of the intermediate range and thus provide data on the energy dependence. Also the measurements at 4.9 GeV extend to large four-momentum transfers at small angles because of the high momentum of the projectile (5.75 GeV/c). The angular range is small enough at this energy so that multiple scattering theories which depend on the validity of the eikonal approximation can be used. This removes one obstacle towards making a significant comparison of the data with nuclear models for helium. The data set is complete and the analysis is being pursued.

The magnetic spectrometer built for this experiment and for research in heavy-ion physics has undergone a number of modifications: The event rate of the system was increased by replacing the 4-μsec delay lines with the 1.2-μsec delay lines in the large, exit, wire chambers. Low noise amplifiers and timing discriminators with slewing times less than ± 300 psec were designed and built for these applications.

4. Properties of Nuclei

We are continuing research on the properties of nuclei by using particle interactions in the 100 MeV to 1 GeV range. Some of this work was started at the 184-Inch Synchrocyclotron and is being continued at the Bevalac and at LAMPF.

The Bevalac is being used also in a study of the properties of the light nuclei $^2\mathrm{H}$, $^3\mathrm{He}$, and $^4\mathrm{He}$. The elastic cross sections at medium- to large-momentum transfers are being measured so that we may understand the wave function structure, particle correlations, and the validity of the Glauber model.

The experimental program at the Bevalac is a collaboration with UCLA.

Data analysis for the $\pi^+ \rightarrow e\nu\nu$ experiment performed at the 184-Inch Synchrocyclotron has been completed. The calibration measurements on the lead glass Cerenkov counters and the spark chamber system have also been finished.

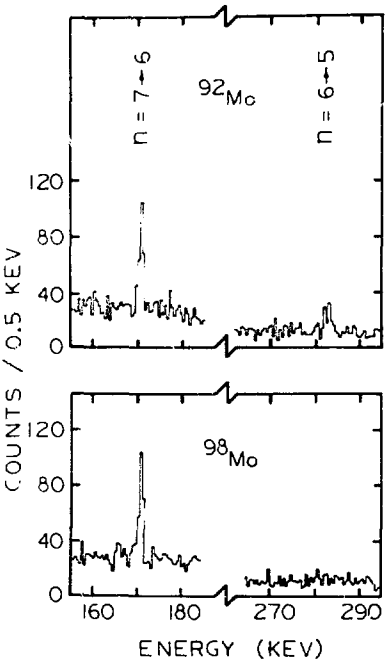
5. Chemical Effects in μ^- Capture

We have concluded a study of chemical effects in the capture of negative muons, an LBL-Princeton collaboration. Materials with chemical structures that are simply related have been analyzed for their muonic x-ray intensities. By using a deexcitation-cascade computer code, we were able to relate the observed intensity variations within the K- and L-series to the muon angular momentum at the time of atomic capture. Our analysis indicates that this initial angular momentum is determined by the size and shape of the electron cloud about each ion. A detailed final report is in preparation.

In a search for back-decay gamma rays from the shape isomer of ^{238}U following μ^- capture, no candidates were found with yields greater than 2% of the muon stoppings. The intensities of the gamma-rays were insufficient to permit definitive lifetime measurements of individual peaks; however, for 500-KeV energy ranges of gamma-ray pulses, lifetimes have been determined that are consistent with recent measurements that use decay electrons, and 36 measurements that are larger than fission-lifetime. This discrepancy is consistent with significant isomer excitation by the atomic cascade of the muon. Such excitation may permit the use of muons to study Coulomb effects on the shape-isomer-barrier structure.

6. K^- Nuclear Interactions

The reaction of negative kaons with molecules, atoms, and nuclei are being investigated over a wide range of chemical compounds and elements at the Bevatron. We are using measurements of the energies and intensities of the emitted x rays to determine properties of the kaon-nucleus interaction. A sort of "mesic chemistry" is evolving that may have application to solid-state and atomic physics.



This graph shows portions of the kaonic x-ray spectra of ^{92}Mo and ^{98}Mo and attenuation of the n = 6 → 5 line in ^{98}Mo. X-ray spectra of negative kaons emitted subsequent to capture by molecules and atoms are being investigated.
(XBL-7512-9940)

For the first time, the dynamic E2 mixing has been observed for kaonic atoms. Two molybdenum isotopes were studied (^{98}Mo and ^{96}Mo). The kaonic transition n = 6 → 5 was present in ^{97}Mo, but was absent in ^{98}Mo due to quadrupole mixing with the first excited nuclear state, which caused the kaons to be absorbed from the n = 6 level.

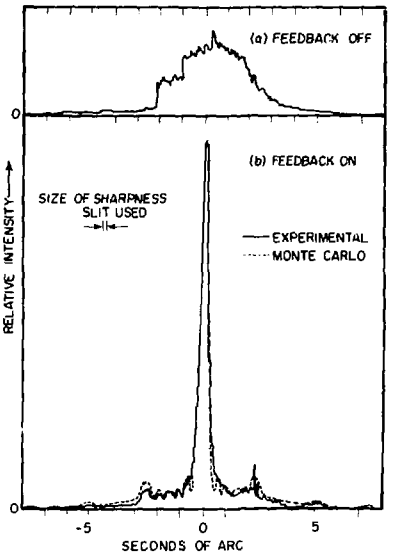
A measurement of the intrinsic quadrupole moment of a nucleus (^{175}Lu) was made by splitting its kaonic x-ray line.

Several elements and their hybrids were studied to verify the reduction in x-ray intensities due to the presence of hydrogen.

D. Astrophysics, Astronomy, and Cosmic Rays

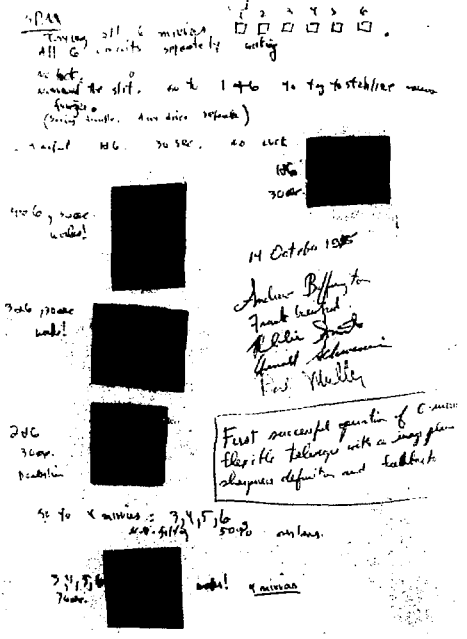
1. "Rubber Mirror"

The resolving power of optical telescopes with apertures greater than 10 cm has been limited by atmospheric distortion rather than by diffraction ever since the first astronomical telescopes were built hundreds of years ago. Some progress has been made with interferometers, but so far, complete image reconstruction has been impossible. The present project is intended to eliminate atmospheric distortion in a ground-based telescope through the use of a feed-back scheme and an optical element ("rubber mirror"), which can compensate for the distortions introduced by the atmosphere. We have worked out and completed the theory of this feedback scheme, which indicates that the system should work for celestial objects brighter than abou. 12th magnitude. The scheme attempts to maximize the "image sharpness" which can be defined as $\int I^2$, where I is the intensity of the image as a function of the coordinates in the image plane. The system, when fully constructed, can be conveniently employed on existing telescopes, and is presently designed for implementation on a 30-inch telescope maintained near Berkeley by the University of California Astronomy Department.



Images of laser light viewed through 250 meters of turbulent atmosphere. The corrected diffraction peak is improved tenfold over the uncorrected image. The curves are normalized to the same area.
(XBL 762-2228)

A simple feedback system has been built and tested and was used to stabilize the fringes in a Michelson interferometer against fluctuations introduced by a 1000-foot-path length through turbulent air. Then a more advanced version was built, which consisted of a 12-inch telescope and a linear array of six mirror



A page from the scientists' notebook on the first successful operation of the "rubber mirror" that eliminates atmospheric distortion of a star's image--the bugaboo of optical astronomy. (XBB 7510-7570)

elements driven by piezoelectric transducers. This new system has been attached to the 20-inch telescope at the University of California's Leuschner Observatory. In spite of a prevalence of bad weather, the system has been used to make an image of Sirius whose full width at half maximum is one third of a second of arc. This is the best resolution that has been achieved in astronomy.

2. Observation of Optical Pulsars by Using Fast Photometry

Work on fast photometry and the study of the optical behavior of compact astronomical objects (white dwarfs, neutron stars, black holes) has continued. In particular, a substantial effort has been made to understand the optical pulsations from the x-ray source Hercules X-1.

Fast photometry deals with the measurement of the visible behavior of astronomical objects on a short time scale – seconds or less. This technique is well suited to the study of rapid variations in luminosity that are seen in compact objects.

Data collection systems and sophisticated computer programs to search for weak periodic signals are undergoing refinements and modifications to suit the objects under study.

In 1975 we completed a major phase of the study of the optical behavior of the x-ray pulsar HZ Her-Her X-1. By carefully analyzing the apparent frequency of optical pulsations and comparing these with the x-ray frequency, we found the masses of both stars in this binary system. In particular, the first accurate measurement of the mass of a neutron star ($M_{Her\ X\text{-}1} = 1.3M_{\odot}$) has been made.

The wavelength spectrum of these pulses promises significant additional insight into this fascinating binary system. Data were collected with the 120-inch telescope and are being analyzed to determine this spectrum.

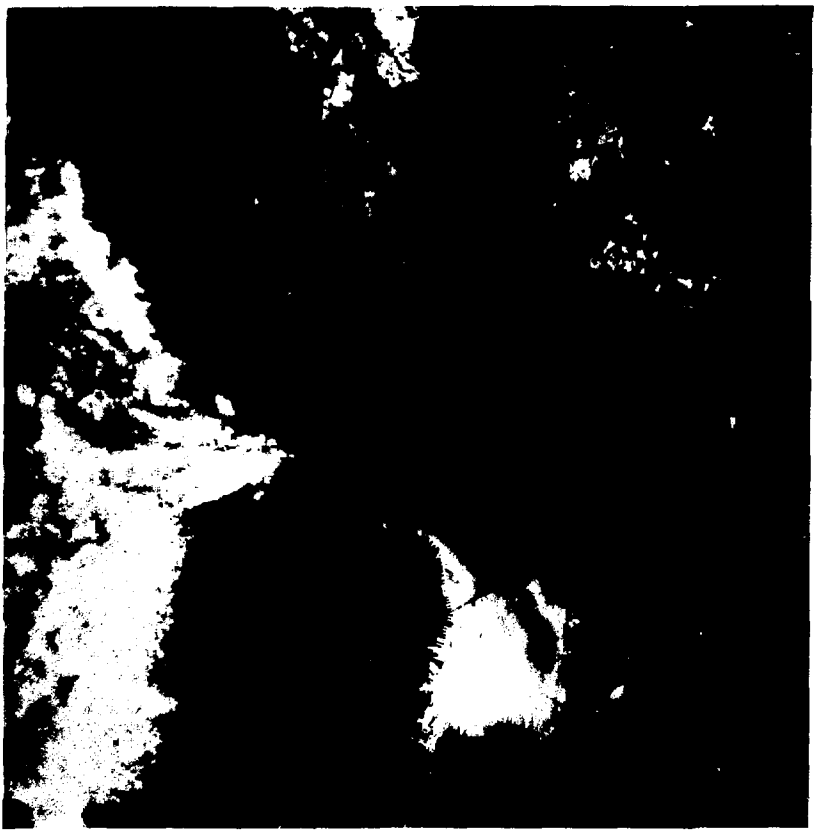
In the hope of discovering other optical pulsars, searches were made for optical pulses in a number of objects. Among these were the binary radio pulsar PSR 1913+16 and another x-ray pulsar Centaurus X-3. Unfortunately, no other optical pulses have been detected so far.

The mathematical theory needed to calculate the eclipse duration of binary systems with a point-like star (a neutron star) and a Roche-lobe-filling star has been developed. This theory is important for a proper interpretation of the observed eclipses of some x-ray sources.

3. Large-Scale Anisotropy of Primordial Black-Body Radiation

The project to detect and map large-scale anisotropy in the 3°K primordial black-body radiation is continuing. If the earth moves relative to a frame fixed with respect to the ancient and distant matter of the universe in which the average energy is kT, then in an earth frame this energy will be $kT' = kT[1 + (v/c)\cos\theta]$, with v the earth's speed. With an angular resolution of 15° and a sensitivity of 2×10^{-4}°K, existing measurements will be improved by a factor between 10 and 20. The earth's motion being studied is from the rotation of the Milky Way galaxy, as well as the orbit of the earth around the sun. We will detect possible rotation of the universe (with respect to local inertial frames) with sufficient sensitivity to see less than 10^{-3} radians per age of the universe (about 10^{10} years). In addition, we expect to detect anisotropies from irregularities in the primordial plasma, which must have been present if current theories of galaxy formation are correct. Radiometers will be flown in U-2 aircraft at 65,000 feet.

We have finished fabricating the experimental equipment, and Lockheed has finished modifying the U-2 upper hatch to fit our experiment. The two radiometers and their antennas have been installed in the U-2 mock-up and tested for its noise figure, radio frequency interference shielding, and ground loop pickup. After this initial checkout, the instrument was installed in the modified U-2 upper hatch for further testing. Before the end of this transition period, the equipment will be checked out in a series of daytime "piggy-back" flights, performed simultaneously with other U-2 missions to study earth resonances.



The Bay Area as viewed from a U-2 observation plane. The plane is to be used to carry instruments for studies of possible large-scale anisotropy of the primordial black-body radiation. An immediate objective is to look for movement of the earth relative to a possible fixed frame of the universe.
(CBB 753-1764)

E. Instrumentation Development

The work in instrumentation development is concerned with multiwire proportional counters, microchannel plate photomultipliers, drift chambers, and electronics for physics systems. Other large-scale instrumentation projects such as the lead glass wall, the time projection chamber, and the liquid argon detector are covered in the relevant programmatic write-ups.

A three-plane multiwire proportional counter. This apparatus is being used for the detection of particles having high transverse momentum that result from the head-on collisions of heavy ions.
(CBB 7310-6020)

1. Particle Detectors

The design of a high-resolution magnetic detector capable of extensive particle identification is underway as described in Section IA2, Time Projection Chamber. The design will be optimized for the study of weak neutral currents and of particles with new quantum numbers. A proposal based on this design will be submitted to the PEP program committee by the end of 1976.

2. Superconducting Magnet for Detector

The large solenoidal magnet used in this design requires considerable engineering effort. A study of high-current density, intrinsically stabilized, superconducting magnets has been undertaken by the LBL Mechanical Engineering Department and the Rutherford Laboratory. In November 1975 one module of a solenoid that is one-third radiation length thick and of one-meter diameter was successfully tested. Our immediate program includes testing two such modules simultaneously in order to study quench propagation in coupled systems.

3. External Muon Identifier (EMI)

The external muon identifier (EMI) has been developed and is now in operation at Fermilab. It consists of a set of 24 multiwire proportional chambers placed behind the 15-foot bubble chamber. The EMI was developed by LBL and the University of Hawaii, and constructed at LBL with FNAL support. This system has been operational for all neutrino and antineutrino runs with the 15-foot chamber.

In October 1975, a three-day "EMI School" was held at FNAL, which was attended by 50 experimenters who wanted to learn about the EMI and how to operate it.

FNAL has approved plans for LBL and the University of Hawaii to improve the EMI. These include the construction of more chambers to provide double chamber coverage for at least part of the area, addition of one more channel of read-out on the chambers, construction of new digitizers that will allow operation at higher data rates, and construction of a "picket

fence" array of counters in the bubble chamber vacuum to provide a prompt time signal for an event, so as to effectively reduce the background.

An active program has been underway at LBL to develop and improve programs for analyzing the data from the 15-foot chamber – EMI hybrid system.

4. Drift Chambers, Multiwire Proportional Counters, and Delay Lines

A set of two, high-accuracy, cylindrical drift chambers of approximately 90 cm diameter and 150 cm length has been designed and built. In the meantime, tests have been performed with small chambers, which show, in particular, that these chambers can be operated in regions where the electron drift velocity is saturated.

The characteristics of a combined drift chamber with lead glass plates and delay-line readout for gamma shower detection are under investigation.

Much instrumentation research has concentrated on developing various combinations of drift and multiwire proportional chambers with delay line readouts and other techniques. Considerable effort has been devoted to improving the properties of electromagnetic delay lines of various kinds and their associated electronics (low-noise amplifiers, low-time-slewing discriminators).

We are continuing to develop new forms of delay lines, such as metal plated on plastic. For the wire-wound lines, parameters have been varied to improve the delay-to-rise-time ratio (D/R > 50 at present). Our goal is to obtain the narrowest possible two-pulse resolution. The metal-plated delay lines are for use in lead-glass drift chambers and in other applications requiring a multiplicity of delay lines per chamber.

5. Signal Discriminators

An economically attractive, zero-crossing discriminator has been developed for use with signals characteristic of the readout by delay lines from multiwire proportional chambers. A time walk of only ± 200 psec for signals of 100 nsec rise and fall time over a 50:1 amplitude range has been achieved with production units.

An "intelligent" discriminator, which all-in-one provides timing signals and gates for the shower width, shower centroid, and total charge of up to four consecutive signals on a delay line, has been developed for a Fermilab experiment in a cooperative effort with the High Energy Physics Laboratory at Stanford.

6. Modular System for Data Digitization

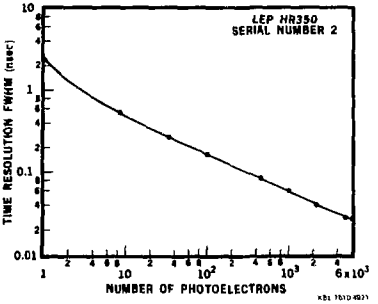
We have designed and fabricated an economical modular system for the digitization of analog data from hundreds of event channels. The system digitizes various combinations of time, charge (pulse height), and/or dc analog voltages: Resolution for time digitization is 12 bits; in the time mode, multiplexing provides added economy and/or accommodates channels with multiple hits. Readout via the CAMAC standard data bussing system allows for discretionary readout of either (1) only those channels that

experienced "hits" during an event, or (2) all channels.

An eight-channel charge-converter and digitizer "card" for the large-scale digitizing system. The large-scale digitizer systems are designed for general use and will be used for digitizing the charge and time-of-arrival of signals from particle detectors. This system will have a maximum of 8192 channels. (CBB-769-8540)

7. Microchannel Plate Detectors

An investigation of microchannel plate detectors with and without photocathodes is being made. Provided that their anticipated insensitivity to magnetic fields can be confirmed, the will be ideal for use in the presence of hi h magnetic fields – such as would be encountered in proposed PEP detectors. They are also important for ultra-fast time-of-flight measurements. A program to measure their resolving time and behavior in magnetic fields is under way.



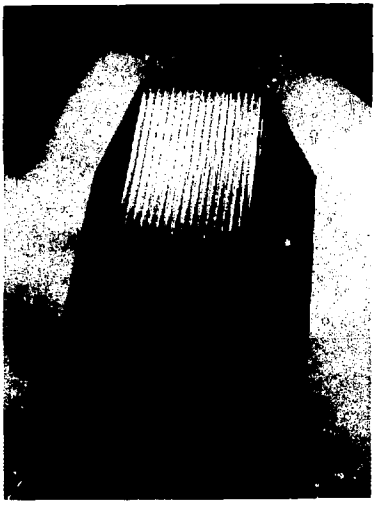
The performance of the micro-channel plate photomultiplier HR 350 is measured in the phototube test facility, which is an especially high-resolution photomultiplier evaluation system. The time resolution of the photomultiplier as a function of the number of photo-electrons per pulse is one of the characteristics tested. (XBL 7610-4921)

8. Methane-Filled Chambers

Measurements have been carried out on the timing resolution and position accuracy of low pressure, parallel plate, methane-filled chambers with avalanche multiplication. This type of counter is expected to have a time resolution of < 200 psec. By adding sense wires or by using copper-plated anodes on plastic, a position resolution of < 100 microns is expected.

9. Detectors for Nuclear Medicine

Work on the development of gamma-ray and neutron imaging detectors for nuclear medicine and neutron radiography has continued. In connection with these detectors, computer programs have been developed for the three-dimensional determination of the distribution of a gamma emitter within an object.



Hexagonal array of lead glass tubing used in drift chamber for detecting gamma rays by showers produced in the lead glass. This type of lead glass converter can be used both for high-energy gamma rays (50 MeV to 10 GeV) and low-energy gamma rays (0.1 to 2 MeV) by changing the hole and wall dimensions. (CBB 765-4207)

10. Visual Readout System

A system has been developed that provides for visual readout of "blind" CAMAC scalers on a standard CRT graphics terminal, without the need for minicomputer control. By keyboard, the user is able to select scaler channels to be displayed, identify each with a descriptive label of his own choice, and format a page with up to 20 scaler channels; 8 such pages can be defined. At the user's option, any page can be displayed in a "normalize" mode in which all scaling is stopped when the count of a selected scaler on that page equals an arbitrary keyed-in number displayed at the top of the page. The system includes a microprocessor controller, which can operate autonomously as a crate controller. It may also be used in conjunction with a modified, type-U CAMAC/PDP-11 controller, to operate as an auxiliary controller in the CAMAC crate.

11. Software Extension for PDP-11

The BASIC-language software package for the PDP-11 series computers, with which experimenters can do their own interactive programming, has been extended. A CAMAC/BASIC handler has been written to facilitate the programming of experiments implemented in CAMAC hardware. In addition, a BASIC handler for driving the Tektronix 4012 display CRT and for networking between small satellite computers and a larger host computer has been written. At present the Bioned PDP-11/45 is the host computer. This allows for downloading of programs, and sharing of larger memory, data files, and peripherals.

12. Charge-Coupled Devices

Charge-coupled devices have been studied with a view toward their use as analog storage devices in either single-channel or in optically sensitive array configurations. We have established that single channel devices can be used to 1 mV resolution with at least 200:1 dynamic range, and that the clocking frequency of these devices can be switched by at least 200:1 (e.g., 10 MHz:50 KHz) to provide time expansion during readout.

13. High-Speed Buffer Memories

The state of the art in high-speed buffer memories is being investigated for applications that require on-the-fly digitization of multiple

high-speed data points. The EMI detector at FNAL, for example, requires (1K-2K) buffers with ~ 30 nsec timing resolution.

14. Microprocessor Applications

Microprocessors hold considerable promise for data manipulation prior to storage. We are studying applications with presently available microprocessors, such as automatic real-time data correction per regularly updated calibration points. Careful attention is being paid to the capabilities of new microprocessors with the hope that the faster units may be usable for on-line decision logic.

15. Phototube Test Facilities

Phototube test facilities in Buildings 14 and 80 have been updated with improved hardware. The Building 14 facility has been improved especially to provide convenient use by other groups, and the capability of testing anode dark current above a selectable fixed threshold has been added.

II. THEORETICAL PHYSICS

Particle theory continues to be the major research activity of the Theoretical Group at LBL. In addition, the Group is heavily committed to accelerator theory and design.

A. Particle Theory

Research in particle theory encompasses strong electromagnetic and weak interactions and covers the gamut from formal axiomatic field theory to phenomenological model building and analysis of data. Hadronic processes and the new ψ particles dominated this year's research. Many papers dealt with various aspects of strong interaction dynamics, with ψ particles and color, and with SU(4) or higher symmetries, gauge theories and weak interactions. In addition, there were reports on quantum field theory, on S-matrix theory and related aspects, and many on miscellaneous topics.

1. Topological Expansion of Dual Models

The aspects of an approach to strong interactions, called the "topological expansion," has been explored. The inverse expansion parameter, which measures the density of hadronic levels or particles, is, in certain regions, sufficiently large to allow a tractable calculational procedure based on unitarity. Three previously independent strong-interaction models have emerged as different aspects of the topological expansion: (1) the multiperipheral bootstrap model, (2) the quark-antiquark model of mesons with Zweig selection rules, and (3) Gribov's pomeron calculus.

The topological expansion has led to relations between pomeron properties and the breaking of the Zweig rule. In this picture the leading meson Regge trajectories are accurately described as simple, quark-antiquark combinations (with exchange degeneracy and Zweig selection rules) for large t (mass squared), but as t diminishes the mixing of combinations becomes important in order to satisfy unitarity. One consequence is a large upward displacement at $t = 0$ of the leading isosinglet trajectory with even-charge conjugation. This trajectory is identified as the bare pomeron of Gribov's calculus. Its detailed predicted properties are in accord with experimental measurements of high-energy cross sections. Other isosinglet trajectories (e.g., the ω) are also shifted in a manner compatible with experiment.

The rate of decrease in mixing, with increasing t, is related to meson masses, and on this basis it has been conjectured that along unnatural parity trajectories (e.g., η and η') large mixing may persist to higher t than along natural-parity trajectories (e.g., ω and ϕ). To pursue such questions quantitatively, a Reggeon formalism for calculating the mixing has been developed.

2. Solution of Classical Field Theories

Much of our work has been concerned with

the extended solutions of classical field theories, and the quantization of such solutions. The main object has been to explore the proposal of Nielsen and Olesen for relating dual models to conventional field theories. This is based on the idea that the dual string is a representation or an idealization of a vortex of quantized flux in a superconducting vacuum. Strings of finite length require monopoles at their ends.

Some aspects of a model with non-Abelian gauge fields have been examined. Some workers consider such fields to be more relevant to strong interactions than Abelian gauge fields, and they also offer the possibility of eliminating the Higgs field. The main results are as follows: In SU(n), the number of units of quantized flux is only defined modulo n, so that quantized vortices can have m units of flux, where m is an integer between 0 and n-1. Magnetic monopole density is an invariant; it is subject to the Dirac quantization condition, and is only defined modulo n. In a superconducting vacuum, the number of monopoles minus the number of antimonopoles must be an integral multiple of n, if their energy is to be finite. Thus, if we set n equal to 3 and assign quark quantum numbers to the monopoles, we obtain a natural explanation of quark confinement. It is impressive to note that none of the assumptions leading to this result was introduced with a view to obtaining confinement.

3. Quantization of Field Theories

The crucial problem associated with vortices or other extended models is that of quantization. Most treatments of quantization start from the uninteresting region where the coupling is weak and the vortex energy is large. Results obtained elsewhere on the one-dimensional Sine-Gordon equation and its relation to the massive Thirring model avoids this difficulty but relies on perturbation theory. These results have been re-derived without using perturbation theory by expressing bare "soliton" operators as functions of Sine-Gordon operators. These soliton operators satisfy the field equations and commutation relations of the massive Thirring model. It is hoped that this approach can be generalized to obtain "vortex" operators in (3+1) dimensions and thus would allow a demonstration that such operators satisfy commutation relations and field equations similar to those of the second-quantized dual model operators.

4. Dual Models

A formula for the general S-matrix element in the interacting-string picture of the dual model has been found. The functional-integration formalism for the Neveu-Schwarz-Ramond model has been placed on a similar footing to that for the simple dual model.

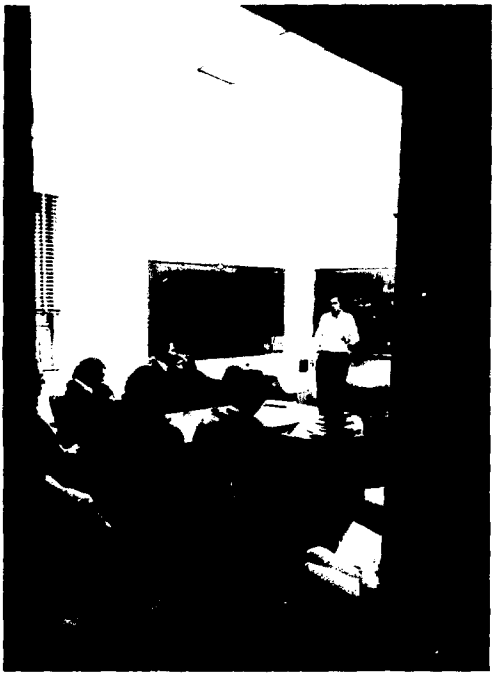
It has been shown that the second renormalization in dual models for $d = d_{crit}$ can be interpreted as a slope renormalization. The method that uses the string formalism is simpler and more direct than earlier work, and completes the demonstration that the perturbative unitarization of dual models is consistent at the one-loop level.

The problem of spontaneous breakdown in dual models has been intensively studied. The existence of such a symmetry violation in a certain class of dual models has been demonstrated.

5. Equivalent Field Theories

Work has been extended on the idea that many apparently different field theories may be equivalent. Such equivalences are deep views into relativistic quantum dynamics, and go hand-in-hand with approximate methods being

developed to solve field theories nonperturbatively. Earlier results for an Abelian model have been extended to the general non-Abelian case. Among the results are that: (1) in two dimensions, at least, every fermion theory has its boson equivalent; and (2) internal symmetry has its origin in quantum mechanics and topology. These findings may offer an understanding of internal symmetries in general. By using these methods it has been proved that Yang-Mills theories in two dimensions have all physically measurable currents. Models are important since they are considered the most likely for quark trapping in four dimensions.



Theoretical physicists meet frequently in "secret" seminars to exchange ideas. Ken Wilson, visiting theoretical physicist from Cornell, presents his work for their consideration. Geoffrey Chew (head on hand), Group Leader of Theoretical Physics, is among those present. (XBB 760 10552)

6. Model of Electromagnetism

Work has continued on a model of electromagnetism that results from the strong interactions by spontaneous symmetry breakdown of an Abelian or non-Abelian gauge theory. The spontaneous breakdown causes weak- and electromagnetic-strength coupling constants to appear in a model that had only strong couplings before the breakdown. We have studied vortex-

like solutions of Abelian and non-Abelian gauge theories as models for hadrons, and a study of the high-energy behavior of non-Abelian gauge theories has been made to find a field-theoretic model for pomerons and Reggeons.

7. Models for ψ Particles

Models for the new ψ particles and related phenomena have been under intensive study. When the known ψ particles consisted of two narrow resonance peaks and one broad hump, a model was constructed of the new particles, which introduced a fourth color. This was motivated by the energy dependence of the ratio, $R = \sigma(e\bar{e} \to \text{hadrons})/\sigma(e\bar{e} \to \mu\bar{\mu})$, and by the magnitude of the pole transition probability for emitting a photon. Though it is not now fashionable to assume integrally charged quarks, the fundamental idea is still quite alive.

When a class of experiments showed disagreement with the standard model, we explored the possibility that the new particles do not lie on Regge trajectories of normal slope ($\simeq 1$ GeV^{-2}). After the positive charge conjugation states were found around 3.5 GeV, it has become almost certain that they do lie on Regge trajectories, but their slope is still unknown. Two-psion production processes would be enhanced strongly in hadron-hadron collision, if their Regge trajectories have a slope much shallower than 1 GeV^{-2}. A numerical estimate was made for the two-psion production cross section.

8. New Class of Weak Interactions

The early absence of charmed mesons and the apparent violation of the selection rule that Δ Charm = Δ Strangeness led to the speculation that a new class of weak interactions may exist, which can be embedded in the standard model of gauge theory without violating renormalizability.

After we made the accurate measurement of the angular parameter α of inclusive pion production in e^+e^- annihilation, the inclusive pion data were examined to see if they were consistent with the picture in which two kinds of partons, one light and the other heavy, are produced with nonvanishing transverse momenta. It was found that with $p_t = 0.2$ GeV^2 and the heavy parton mass = 1.8 GeV, all the inclusive data so far available are explained perfectly.

9. Model of Unified Gauge Theory

As the data have accumulated on dimuon production in high-energy neutrino reactions and on e^+e^- annihilation, many apparent difficulties have appeared in the standard model of unified gauge theory. Models that include right-handed currents do not seem to achieve much, and a recent result on neutral weak currents implies a preponderance of left-handed currents, although the evidence is not overwhelming. A version of gauge theory of weak interactions has been proposed with only left-handed currents, which avoids all of the potential difficulties. It involves one new mixing angle common to the leptonic and hadronic worlds, which, it is hoped, will be understood in the framework unifying the two worlds. If the standard model fails definitely, this model may be the simplest and most economical one.

10. SU(4) Breaking Effects in the Mass Formula

The second-order SU(4) breaking effects in the Gell-Mann-Okubo mass formula have been examined by using a current algebraic technique. The result has an important implication for any search for charmed mesons. Though the magnitude of these corrections depends on detailed

knowledge of spectroscopy, the sign of shifts was found with fair certainty.

11. Even-G-Parity Decays of the ψ (3.1)

Studies have been made of even-G-parity decays of the $\psi(3.1)$ to ascertain what can be learned about the underlying dynamics of the new particles. Their radiative decays have also been investigated to provide information about their SU(2) and SU(3) symmetry properties.

12. Eta Decays and Quark Charges

Other investigations have shown that the radiative decays of η and η' can yield information about quark charges. Because of their SU(3) singlet components, η and η' decays are uniquely sensitive to whether quarks have fractional or integral charges. We have made a systematic review of theoretical predictions, which can test the quark color hypothesis at energies below color thresholds. We have also studied the question of whether the nature of the semiclassical solution to a strong-coupling field theory is qualitatively altered by quantum fluctuations. This bears on the problem of quark confinement.

13. Structure of Resonance Couplings

A study of the analytic structure of dual and Feynman diagram models carried out elsewhere shows that Reggeon-particle amplitudes of the form $R+P \to P+P$ and $R+P \to R+P$ should satisfy finite energy sum rules (FESRs) that are closely analogous to those ordinarily written for $P+P \to P+P$ processes. Applications of these Reggeon FESRs to data led to quite successful and intriguing results for the magnitude and helicity structure of resonance couplings. In the cases studied in detail, it was found that the duality properties of amplitudes with external Reggeons imply very stringent dynamic conditions, which nevertheless are selfconsistent and in agreement with experimental data.

A general formalism for studying resonance contributions to FESRs developed elsewhere was applied to predict the helicity structure and relative strengths of all couplings RNN, RNΔ, and R$\Delta\Delta$, where R is an isospin-one, meson trajectory ($R = \rho, \pi, A_1$). The prediction is in good agreement with all the experimentally known couplings.

The analytic structure of the $R+R \to P+P$ amplitude has been investigated with the dual resonance model as a guide. We found that FESRs can be derived under certain conditions, which should be helpful for further understanding the structure of multiparticle amplitudes. Generalized to the $R+R \to P+R$ process, it also has important implications for the dual unitarization schemes that are now being pursued by several groups. A surprising by-product of this study was the discovery of a new Regge pole β in the B_6 amplitude. The slope of the β trajectory is half that of the standard α trajectory, and β gives the leading asymptotic behavior when $\alpha < -1$. The coupling of β to two particles vanishes. Hence it cannot be exchanged in four- or five-point amplitudes. This fact is one of the main reasons why the β Reggeon has been overlooked until now.

14. Neutrino-Hadron Collisions at Fermilab

In the first half of 1975 an analysis was made of the possible production of charmed particles by neutrino-hadron collisions at Fermilab. The conclusion reached was that within the context of the quark parton model the anomalous distributions could not be explained by the conventional charm model and "reasonable" quark distributions.

15. Pion Decay

New ways to calculate radiative corrections to charged pion decays have been investigated. This work was motivated by a recent report of a possible difference of two standard deviations between experiment and existing theory in the electronic branching ratio, and by plans to measure this ratio more accurately. Two models of pion decay were developed – both in the context of gauge theories. One treats the pion as an elementary particle and gives a result identical to previous theoretical estimates. The other treats the pion as a quark-antiquark composite and gives a result significantly closer to the new experimental number.

16. Multiparticle Dispersion Relations

Great progress was made during 1975 on developing multiparticle dispersion relations. This work is founded in earlier investigations in which the general formulas for discontinuities around physical-region singularities were obtained. However, those formulas were local formulas that expressed the discontinuities in the immediate neighborhood of a single singularity surface. For dispersion relations one needs global formulas that hold at all points and express the multiple discontinuities across all combinations of cuts that bound the physical sheet. Formulas have now been derived that express all of the multiple discontinuities of the six-particle amplitude across all combinations of normal threshold cuts. These normal threshold-cut multiple-discontinuity formulas are the basic discontinuity formulas in the sense that remaining ones can in principle be derived from them. Also, they give the principal contributions to the multiparticle, fixed-t dispersion relations. These global discontinuity formulas were derived originally from S-matrix principles, and were obtained later from the axiomatic field theoretic formalism.

17. Fixed-t Dispersion Relations

The discontinuity formulas have been used in the development of fixed-t dispersion relations for the six-particle scattering function. These multiparticle fixed-t formulas are dispersion relations in the n - 3 Toller boost variables, with the momentum-transfers t_i and Toller angular variables ω_{ij} held fixed. It has been discovered that multiparticle dispersion relations in these variables are much simpler than those that arise by using other natural variables. In particular, the complex singularities that lie in the physical sheet, and ordinarily make multiparticle-dispersion relations exceedingly complex, are all hidden, at least asymptotically, behind the normal threshold cuts. Thus the main contributions to the dispersion relations are controlled by the multiple discontinuities across combinations of the normal threshold cuts discussed above.

18. Development of Regge Theory

These new dispersion relations have been used to give a systematic development of Regge theory, starting from basic analyticity properties. Earlier derivations that start from Feynman diagrams are plagued with double counting difficulties.

19. Singularities of S-matrix

In the course of developing the analyticity properties needed for the dispersion relations described above, a general theory of singularities of the S-matrix has been developed. However, it does not cover certain exceptional points. Because of this deficiency of the general theory, we have found it necessary to

introduce an extra assumption, called the no-cancellation hypothesis, in derivations of physical-region discontinuity formulas. This hypothesis states that one can ignore singularities associated with nonpositive-α Landau surfaces that happen to touch or lie on top of the positive-α surface in question. This assumption is physically reasonable, but is ad hoc. By using the new results on the singularity structure at exceptional points, we have shown that the simplest of the usual discontinuity formulas, namely the pole-factorization theorem below the four-particle threshold, can be derived without using the no-cancellation hypothesis.

Attention riveted at a theoretical physics seminar, UCB graduate student Susan Moore takes notes while Prof. Charles Harper of Hayward State University listens.
(XBB 760-10551)

20. Noncausal Behavior of Indefinite *Metric Field Theory*

It has been shown that the indefinite *metric field theory* of Sudarshan and co-workers must exhibit striking noncausal behavior, due to the presence in the theory of massive stable particles that propagate backward in time.

21. Unified Theory of Nature

The information provided by Bell's theorem on the nature of the breakdown of classical ideas in the quantum realm has been analyzed. Quantum theory, though satisfactory from the pragmatic point of view, does not provide a unified theory of nature because in principle it requires a separation of the world into an observing system that is described by inexact classical concepts and an observed system described by quantum laws that are inaccurate due to effects of the environment that must in principle be ignored. Bell's theorem provides much more precise information about the breakdown of classical ideas than was available heretofore. It shows that a unified theory of nature must either permit superluminal information transfer, or violate another assumption called contrafactual definiteness. Models violating each of these assumptions have been constructed. One of these models, based on the ideas of A. N. Whitehead, has been developed in some detail and appears to provide a possible basis for a unified theory of nature.

22. S-matrix Approach to Electromagnetic Theory

The infrared problem in S-matrix theory has been examined. It has been shown that an effective S-matrix can be defined, which is physical in the sense that when it is folded into the wave functions of the non-infrared

particles and squared, it gives the transition probability. The infrared photons give no contribution to this effective S-matrix. This result, a generalization of the Block-Nordsieck result, holds to all orders, and does not neglect small terms in denominators that are close to zero. Also, it does not encounter certain technical difficulties that occur in other treatments. By defining a finite S matrix that incorporates all the effects of the photons, this work provides a first step toward an S-matrix theory that includes electromagnetic effects.

23. Axiomatic Field Theory

Within the framework of axiomatic field theory, the question of duality has been studied for Hermitian scalar fields as well as for more general field theories, including spinor fields. Duality (the condition that the commutant of the local von Neumann algebra for a space-time region R is equal to the von Neumann algebra locally associated with the causally complementary region R^C) was established for a Hermitian scalar field under certain reasonable assumptions as a general field theory with local spinor and tensor fields.

24. e^+e^- Annihilation

Electron-positron annihilation phenomenology has been stimulated by the experimental program at SPEAR. As a result, a codification of the initial-state radiative corrections in e^+e^- annihilation was developed, and is important for the analysis of the properties of narrow resonances like the Ψ's. A didactic paper was prepared that is useful for understanding spin-flip synchrotron radiation and the transverse polarization of electrons and positrons in storage rings.

25. Magnetic Monopoles

After the recent announcement of an observation of a Dirac magnetic monopole, a study of the characteristics of the electromagnetic interactions of magnetic monopoles as they pass through matter was made. An idea was also given for a practical detector of relativistic monopoles exploiting the differences in the state of polarization of Cerenkov radiation emitted by electric and magnetic charges.

26. Nucleon-Nucleon Polarization

An analysis of existing nucleon-nucleon polarization data at modest momenta (2 to 6 GeV/c) implies the existence of a low-lying trajectory with vacuum quantum numbers. Addition of this trajectory [with intercept, $\alpha_\sigma(0) \simeq -0.4$] to a conventional Regge-pole model gives good agreement with existing data on pn and pp polarization for $|t| < 1$ $(GeV/c)^2$ and up to 20 GeV/c.

B Accelerator Theory and Design

Accelerator theorists have continued a broad range of projects on the design of accelerator systems such as PEP (the Positron-Electron Colliding Beam Project), ESCAR (the Experimental Superconducting Accelerator Ring, LBL), and ISABELLE (the Intersecting Storage Accelerator at Brookhaven), as well as more fundamental studies of theoretical problems of beam dynamics.

Research on accelerators, done in close collaboration with experimental physicists and engineers, is for defining the parameters of a new facility, or for understanding and improving the behavior of existing accelerators.

Among various items designed is a heavy-ion accelerator for cancer therapy.

1. Lattice Design

Lattice design studies were performed for three storage ring projects: (1) A study carried out at CERN of a 400-GeV storage-ring facility emphasized experimental insertion design and sextupole correction methods. (2) Study on ISABELLE carried out at BNL investigated the feasibility of running the storage ring with one insertion modified for very-low-β collisions. (3) For the PEP program, studies were made of chromaticity control with sextupoles and the design of a system for obtaining longitudinally polarized beams for experiments.

2. Beam-Beam Limit

The major limitation in storage-ring performance is the so-called beam-beam limit; when a certain intensity is reached, the colliding beams cause each other to be violently unstable and either the stored beams are completely lost or the luminosity drops sharply. It is generally agreed that the limit is caused by a very complex resonance phenomenon, but the mechanism is not understood and there is no way to predict the performance of a new ring except by empirical rules accumulated from past experience. Efforts during the past year have included analytic approaches to specific aspects of the problem. Although these efforts throw some light on the phenomenon, its complexity is such that semi-empirical digital computer methods seem to be required. By use of a computer code that includes a more realistic description of particle motion than was attempted in the earlier investigations, it is hoped to reproduce the behavior of SPEAR I. Results so far are encouraging. If truly successful, the same procedure will be applied to PEP and PETRA (the high-energy electron-positron storage ring being built at DESY) in an effort to predict their performance.

It has been found in SPEAR II that even a single beam is subject to a serious increase in height at betatron frequencies that differ by integer multiples of the synchrotron frequency. A tentative explanation for this phenomenon was proposed by the SPEAR group, and LBL has participated in both theoretical and experimental aspects of the investigation.

3. Stability of Bunched Proton Beams

By early 1975, it was apparent that bunched proton beams are susceptible to very-high-frequency disturbances associated with discontinuities and cavity-like structures in the vacuum chamber walls. This effect is bothersome in the Proton Synchrotron and Intersecting Storage Ring at CERN and could be serious in ISABELLE. We have investigated the phenomenon using computer simulation and have also obtained analytic formulas for instability growth rates, which agree with these results. This work may yield stability criteria for chamber impedances as related to bunch properties.

4. Experimental Superconducting Accelerator Ring (ESCAR)

Analytic and computational assistance has been given to the LBL ESCAR project. The results of this work, moreover, may be considered useful for other accelerator and storage-ring projects, both with respect to design and to operation. These results also suggest the potential value of collaborative work concerning the TORMAC CTR device under development at this laboratory.

5. Particle Dynamics nd Electromagnetic Fields

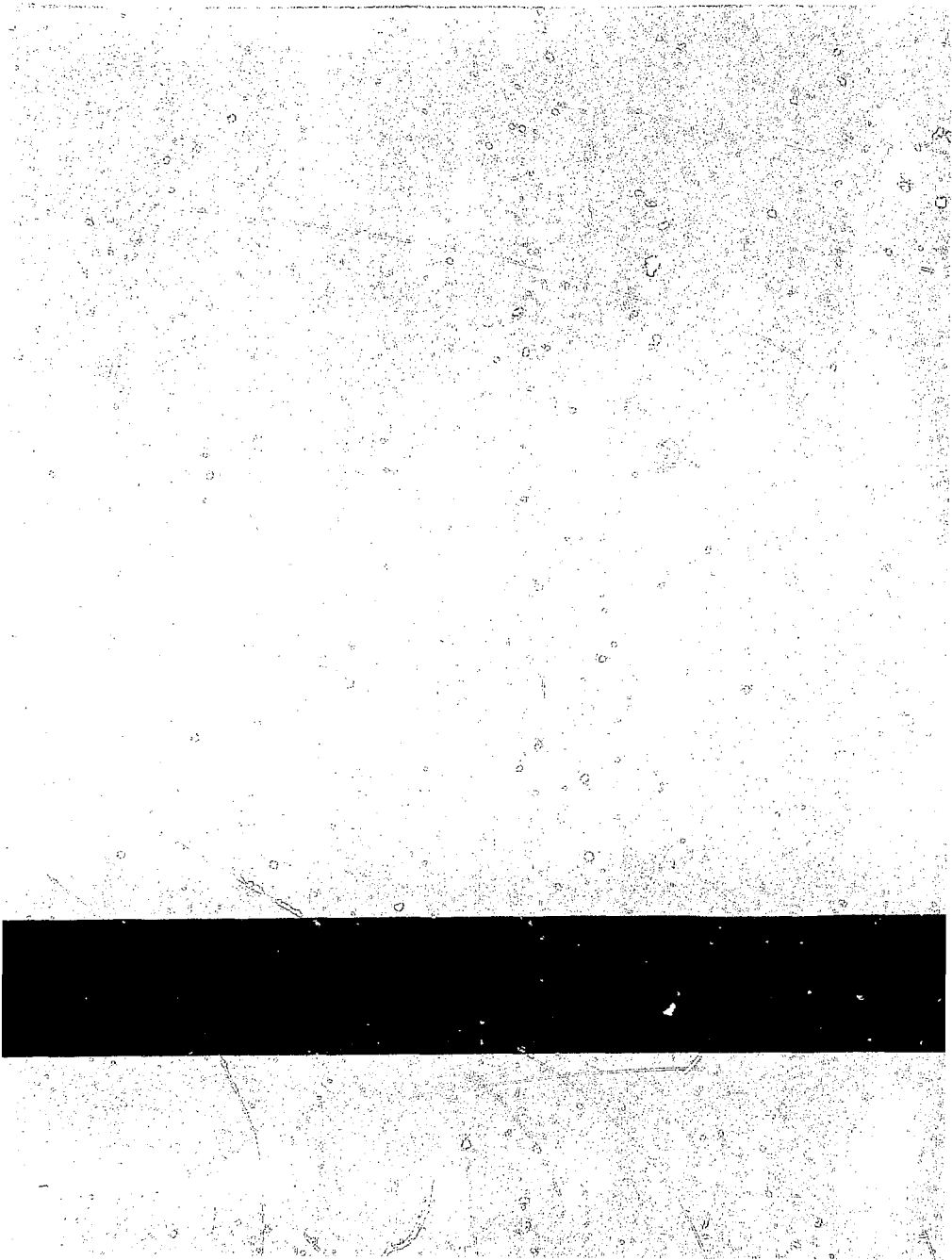
Work in this area has been chiefly concerned with the detailed character of electromagnetic fields and the dynamics of particles in such fields. The particle-dynamics studies have concentrated most recently on the situation in which particles are simultaneously under the influence of both (1) an applied ("fundamental") rf field and (2) the field induced by the particles in a passive parasitic "harmonic" resonant structure. Thus, relating to the "capture" process, we have studied the manner in which the applied rf must be built up in order not to lose control of the beam in the presence of the fields induced in the parasitic cavity. The utility and effectiveness of a phase-control servo on the rf drive during such an operation has been demonstrated. In addition we have investigated another type of instability that can develop under steady-state, applied-rf conditions with a passive parasitic resonant cavity again present. A large part of this work has employed computational "simulation" programs, and a part has been concerned with providing support to the effort to provide a theoretical account of the instability.

The magnet work has led to the proposal and testing of a method intended to improve the manner in which boundary conditions are treated. The boundary conditions are those at the outer edge of a region in which magnetic fields are being sought by means of a relaxation solution (for example) for the vector potential – as in computational programs of the TRIM family.

C. Miscellaneous

In atomic physics the major activity concerned single and multiple photon processes in atoms and molecules immersed in intense laser fields.

Research on the fluid dynamics of surface waves in deep water was completed. This work, concerning large amplitude waves and the approach to instability (breaking), is considered a new attack on a fundamental problem of physical oceanography.



III. COMPUTER SCIENCE AND APPLIED MATHEMATICS

The Computer Science and Applied Mathematics Department (CSAM) engages in research and development in a variety of computer science and mathematics disciplines. A balanced mix of 70 percent project-oriented work and 30 percent discipline-oriented research is maintained by funding from the U.S. Energy Research and Development Administration and other federal and state agencies.

The CSAM Department also works closely with the computer center staff, which runs and maintains the Laboratory's CDC 7600/6600/6400 triplex. LBL's center is one of the nation's largest unclassified scientific computer centers, serving federally-funded users nationwide over a sophisticated Remote Job Entry/Time Sharing system and the world-wide ARPA network. Research and development activities undertaken include the following:

- Data Management Systems. The special problems involved in managing large scientific, socioeconomic, and environmental data bases require advanced techniques in data management. Investigations of specialized hardware and software techniques for hierarchical and distributed data bases are proceeding. A general, transportable system is under development for distribution to several laboratories in the U.S. and England.

- Socioeconomic Environmental Demographic Information System (SEEDIS). The SEEDIS project includes a large integrated data base (over 10 billion characters) used for energy policy analysis and environmental impact studies by agencies throughout the U.S. The system provides interactive retrieval, analysis, and display of a wide variety of characteristics and statistics gathered from many collection agencies. Current research activities include techniques for integrating information collected by several sources, synthesizing data for specific modeling studies, and updating base data from auxiliary sources.

SEEDIS will be available to the ERDA-wide energy policy analysis and assessment program expected to begin in FY 1977. At LBL this program will involve not only LBL scientists and facilities but also a wide variety of UCB organized research units specializing in social, political, legal, information, and environmental sciences.

- Computer Graphics. The static and dynamic display of the results of information retrieval and analysis provide the user with a pictorial representation of results not possible with printed formats. Computer-generated maps, charts, graphs, and movies, often in color, usually created interactively, have proven the most effective way to communicate complex results. Current projects include a national, geographic information system, a graphical analysis system for decision making, a

*A glossary of relevant terms may be found in the Appendix.

device-independent graphics system, and a graphics modeling system.

• Computer Networks. Resource sharing over computer networks is one of the most exciting developments in the field. Unique resources that include hardware, software, and data bases can be accessed over a distributed network and provide full capability at all sites. The development of high-level protocols, common language interfaces, and distributed data management techniques will enhance the computational power available for every site on the network and provide a common pool of resources for the solution of regional and national problems. Currently, staff members from LBL are chairing the Investigator's Panel of the ERDA Network Experimentation Project. The Panel's mission is to provide a resource-sharing environment for ERDA-sponsored laboratories and universities. LBL also sponsored the first Berkeley Workshop on Distributed Data Management and Computer Networks.

• Management Information Systems (MIS). The retrieval, analysis, and display of information from a variety of data sources requires an integration of sophisticated techniques in data management, human-machine interface, and automated report generation. Current projects include a local MIS for managers in the LBL budget office, scientific research divisions, technical support groups, and personnel department.

• Computational Physics and Data Analysis. We provide program development and research support to the design and analysis of controlled thermonuclear reactors (e.g. TOKAMAK, TORMAC) and mirror machines; design and analysis of particle accelerators (e.g. PEP, ESCAR) through beam-tracing, space-charge, and magnet-design programs; and the analysis of experimental high-energy physics data.

• Mathematical Modeling. Our effort here is concentrated on the development of a linear programming system to be used in econometric models, a critical-path analysis program for project scheduling, a biomedical modeling system for compartmental models, and extension of a large hydro code to solve magneto-hydrodynamic problems.

• Programming Languages. This research centers on the development of structured FORTRAN-derived languages and proposed extensions to FORTRAN standards. Related work in systems-implementation languages is also under way.

• Applied Mathematics. Research is carried out in numerical and applied mathematics, with special emphasis on nonlinear elliptic differential equations, fluid flow, biomathematics, linear algebra, approximation, and applications to capillary phenomena and combustion processes.

• Educational Programs. Several pre- and postdoctoral programs are carried out in conjunction with the University of California at Berkeley. Graduate students and postdoctoral visitors benefit from the Department's expertise in computer science and applied mathematics.

A. Data Management Systems

1. A Berkeley Data Management System (BDMS)

BDMS is a hierarchical data-base management system specifically designed for efficient handling of numerical as well as character and bit string data. It has a data-base definition language that is very easy to learn, a powerful free-format data input language, and a sophisticated data-base editor. Its query language includes Boolean and relational operators, truncated and range searching, and the ability to save intermediate search results for later use. All capabilities of the system are available to the user as subroutines, so that specialized systems may be built upon BDMS. At LBL, BDMS is operable in both interactive and batch modes on the CDC 6400 and 6600, and in batch mode on the 7600. It can be easily transported to other operating systems and to non-CDC hardware.

An ad hoc working group on report generation was formed and met for several months to explore various approaches to the development of a generalized report generation facility that would interface to the data-base management system.

We have begun providing BDMS to other installations. In collaboration with Brookhaven National Laboratory (BNL), we are writing an interface to the standard CDC SCOPE operating system, and the system will be installed on the BNL computers. In collaboration with the University of Durham and the Rutherford High Energy Laboratory (RHEL) in England, the system was installed on the IBM 360/195 at RHEL.

A version of the sytem (BDMS-16) is being developed for use on 16-bit minicomputers such as DEC PDP-11s and ModComp IVs. The program was converted to a FORTRAN subset compatible with the compilers of most major manufacturers in order to enhance transportability.

2. Hierarchical File Management System (INTERAC)

Work has begun on INTERAC, a system designed to provide a standard and high-level method of reliable access to files (where "access" implies storage as well as retrieval). INTERAC is in no way concerned with the type or contents of files, nor is it designed for files that are routinely updated.

When used in its most general sense, INTERAC will allow data storage on all LBL devices (disk, PSS, MSS, and magnetic tape) and will retrieve them logically from the fastest device that is operational. This relieves users from needing specific knowledge of LBL storage devices. They may be assured that the INTERAC System will retrieve the stored data through a taxation of the entire storage resource, even if it means waiting for a tape to be hung. The INTERAC methodology involves an initial store on tape and then a "caching" to any combination of the online devices desired. (Files are eliminated from a cache by using a least-recently-used algorithm.) Interactive programmers are thereby allowed complete freedom in the use of LBL storage devices depending on such factors as the quantity of data involved, the amount of space available on each device, and user retrieval patterns.

INTERAC updates the index to the files each time they are accessed (stored or retrieved). This provides interactive programmers with statistics on user retrieval patterns of the files, including where the files are located and how large they are. INTERAC optimally provides standard summary and detailed reports on the index and each file in the index.

INTERAC also addresses the problem of eliminating data from a continually growing data base, which must eventually be limited. It allows the programmer to associate subsets of the files (e.g., by date and/or area) with particular tapes and MSS boxes. The index may be purged of all files associated with these tapes and MSS boxes when they are physically removed. A particular file may be purged from the index and PSS cache even though the entire set of tapes and MSS boxes associated with it are not eliminated.

3. Interlaboratory Working Group for Data Exchange (IWGDE)

The broadened ERDA mission in energy policy analysis and environmental impact assessment requires that the national laboratories use and exchange large amounts of computerized descriptive information and numeric data. These large data bases form the basis of regional and national studies in support of ERDA's energy and environmental policy formulation. Resource sharing and standardization of computer readable files and modeling programs for interlaboratory exchange will lead to significant efficiencies in carrying out those studies. To comply with these demands in a timely and cost-effective manner, the Interlaboratory Working Group for Data Exchange (IWGDE) was formed:

- to share expertise in computer-based systems for handling large data bases;
- to establish both short-term and long-term objectives for resource sharing and data management;
- to establish, test, and implement practical data-exchange standards;
- to examine the national laboratories' present data-management systems and data bases, and develop mechanisms for interfacing among these systems;
- to make long-term recommendations for a common ERDA data-management system;
- to recommend administrative guidelines for exchange of data and programs.

The Joint Program 189 form for this effort was submitted simultaneously by the seven major multiprogram ERDA laboratories: ANL, BNL, LASL, LBL, LLL, ORNL, AND PNL. The IWGDE was organized at a November 1975 meeting at LBL. Pepresentation in the Group was later expanded to include at least one computer scientist and one representative familiar with energy- and environment-related activities at each of the seven laboratories. The steering committee for Regional Studies Programs was added to the IWGDE distribution list to ensure that the RSP directors would be kept informed of the Group's progress.

The first task undertaken by the IWGDE was to collect summaries of existing data bases, modeling programs, and computer equipment at the seven laboratories. These summaries will provide a directory of resources and facilities for ERDA researchers.

The second task was to develop a data-exchange standard for ERDA. An extension was proposed to the ANSI Standard Interchange Format to provide for exchange of structural numerical data bases as well as bibliographic files, and subsequent modifications were suggested. The Level 0 ERDA Interchange Standard has been implemented at LBL, and we are in the process of developing a Qwick Qwery-to-ERDA Standard interface for providing selected socioeconomic data bases to ANL, BNL, LASL, and ORNL. This work should obviate the task of writing one-time conversion programs at each laboratory for each data base exchanged.

Work is proceeding on the development of transportable data management systems that can run identically on the various operating systems at the laboratories. The Berkeley Data Management System (BDMS) is being implemented at BNL and Rutherford High Energy Laboratory in England.

Details of these accomplishments are described in the IWGDE Annual Report for Fiscal Year 1976.

4. Training Facility Management Project

The Training Facility Management system, based on the STOFI Data Management System, maintains inventory, equipment characteristics and configuration, and documentation data bases for the civil service arm of the U.S. Naval Combat Systems Maintenance Training Facility. A batch interface to the complex report and update capabilities that is simple to use was created, and allows users to update, monitor, and generate reports from a remote terminal. Additional capabilities were added to the already existing interactive interface package, thus reducing user dependence on LBL programmers for file maintenance. Work was completed on users and operations manuals for the entire project.

5. Architecture of Data Management Computers (ADMC)

In this project we are exploring some new problem areas and techniques related to the extraction of subsets from a full data base, with emphasis on minimizing the cost of communication between terminal and central system. Current developments and trends in technology have reached a point where the majority of the processing related to typical data-base applications can be performed rapidly by using inexpensive processors. We expect that the use of such a processor embedded in a terminal will become the prevalent situation. For data-base applications, such an intelligent terminal could also have a small secondary storage unit, which is quite inexpensive. The primary function of the central system would then become the data-base manager for a multitude of such semi-autonomous terminals.

Some of the hardware components developed by the PRIME project at the University of California, Berkeley, were moved to LBL as the basis of system architecture research. The current system consists of several mass storage devices and processors connected by a crossbar switch. Currently a new processor (PDP-11/03) is being installed to serve as a data management processor, running BDMS-16. This system will form the basis of an experimental system for reliable data-management machine research.

B. Socio-Economic Environmental Demographic Information System (SEEDIS)

The development of the LBL Socioeconomic Environmental Demographic Information System (SEEDIS) over the past four years has provided ERDA with a valuable resource by which to carry out its broadened mission in energy assessment and environmental impact studies. Many LBL projects contribute significantly to the SEEDIS system by supporting research and development of retrieval, analysis, and display programs; others make use of existing software, but contribute new data resources.

The expansion of SEEDIS resulted in the acquisition and installation of data bases required for specific projects, and in the implementation and investigation of data retrieval, analysis, and display techniques. The new data bases acquired or developed this year by CSAM include:

- The complete set of annual Current Population Surveys for 1969-1975 (statistically selected samples of approximately 45,000 households, which contain information on employment by occupation, ethnic, and educational characteristics, etc.);

- Quarterly data on employment and wages, by establishment, for the eight western states for 1974, 1975, and first quarter 1976 (similar in content to County Business Patterns, but more current, comprehensive, and detailed;

- Population projections to 1976 by county from the Bureau of the Census;

- Employment Service data that gives characteristics of unemployed people in the labor force (including quarterly data for all states at the state level, and for Region IX by local area);

- An economic/environmental data base containing 150 variables for each county in the U.S., prepared from the Brookhaven Atlas on the Energetics of the United States;

- Estimates of 1972 U.S. employment (a) by industry and occupation, and (b) by state and industry, for use in input-output analysis.

In addition, other data bases were added to SEEDIS by staff from other LBL departments, including:

1972 U.S. Input-Output Table, 404 sectors
1972 California Input-Output Table, 404 sectors
1971 Energy Use, five energy types, 367 I/O sectors
County Business Patterns, complete, 1962-1972
1972 Census of Transportation
1968, 1969, 1970 I/O Tables, U.S., 87 sectors
1967 I/O Tables, nine Western states, 367 sectors
MERES Environmental Data Base
Bechtel Data Base of Energy Technology Coefficients
Brookhaven Energy Model Data Base
BNL-CAC Energy I/O Model
GRID Geothermal Data Base
CALERDI Data Base – (California energy-related research and development projects)
Dunn and Bradstreet File, 1972
Energy Conservation Data Base
Metropolitan Transportation Commission Data Bases

Under the direction of Carl Quong and Don Austin (1 to r, rear) the Computer Science and Applied Mathematics Department has become an acknowledged leader in the development of computer technology. For SEEDIS, the Computer Mapping System was developed in part by Harvard Holmes (right front), and is extremely flexible. The System uses census data to structure accurate maps of population distributions. Virginia Sventek does interactive editing. (XBB 753-1830)

The widespread use of SEEDIS necessitates constant communication within and external to LBL to avoid duplication of effort and to encourage maximum use of existing resources. Within LBL, CSAM department members regularly attend meetings of the Regional Studies Group (E&E Division) and the Information Research Group (Technical Information Department). Members of the LBL Computer Center staff also regularly attend CSAM meetings. Additional fruitful contacts are maintained with numerous other LBL groups, especially in the Energy and Environment Division. Outside LBL, CSAM's leadership role in the Interlaboratory Working Group for Data Exchange and the ERDA Network Investigators Committee ensures constant awareness of the availability of SEEDIS-related resources.

C. Projects That Use SEEDIS Data Base

1. Methodologies for Synthesizing and Updating Data Bases

Under subcontract to the Center for Advanced Computation, University of Illinois (through a National Science Foundation grant), LBL, by using several data bases from SEEDIS and other sources, has developed the methodology and calculated the estimates of U.S. employment for 1972. These data were required for input to the CAC Input-Output model studies that use the Brookhaven Energy model to evaluate the impacts of Federal policies for reducing dependence on foreign oil imports. These data are also being used in an ERDA-funded study of the impacts of the proposed California Nuclear Moratorium Initiative, and in a study for the California Energy Resources Conservation and Development Commission on the impacts of various state and Federal energy policies in California.

A related project involves the development of methods for updating selected items from the 1970 Census by using more current data sources (annual Current Population Survey, Population Projections, quarterly wage and employment reports, Current Business Surveys, etc.). The resulting synthesis, analysis, and integration techniques will be incorporated into SEEDIS, as will the auxiliary data bases.

2. Fuel and Energy Projects

As part of the Regional Studies Program, we initiated a project to analyze manpower constraints on energy plant construction and operation. Other projects include an analysis of short-term regional impacts of a coal strike, and an economic analysis of fuel and energy use in the United States economy. Data from SEEDIS and other sources were used in these studies.

3. Energetics of the United States Mapping Project

The Biomedical and Environmental Assessment Group at BNL contributed a large county-based file of environmental and economic data to SEEDIS, and used the cartographic data base and mapping system in SEEDIS to produce a set of 40 maps of the U.S. by county for their Atlas of Energetics of the United States.

4. Transfer of SEEDIS Data Base

The Inter-Laboratory Working Group for Data Exchange (IWGDE), supported by the Regional Studies Program (RSP) of the ERDA Division of Biomedical and Environmental Research, developed an extended ERDA Standard data exchange format to facilitate the transfer of information required by researchers at various Laboratories. SEEDIS facilities were made available to the other Laboratories over dial-up (telephone)

To identify land use patterns within a census tract, CSAM's computer system overlays a map of the Los Angeles Basin onto a picture of the area taken on a smoggy day from an earth satellite. The camera on the satellite used filters and film that are responsive to light, mostly outside of the visible range.

interactive and remote job-entry links, and over the ARPANET. In addition, selected SEEDIS data bases were mailed to ANL, BNL, and LASL in both the Qwick-Qwery formats (which required that specialized, one-time-only programs be written at each recipient site) and the new extended ERDA Standard format. This Working Group has made good progress in solving the resource-sharing problems of RSP and other ERDA programs in a general way, and provides a core group of experts who will continue to address future needs in this area.

5. Employment Information System

The Employment Information System (EIS) project seeks to standardize quarterly wage and employment data of business establishments for the eight western states and to build an information system to handle the Department of Labor data. These data form an essential component for estimating the Gross National Product, and are a valuable input to economic impact modeling systems. Currently the EIS project is studying strategies for time-series data structuring of the data base as well as efficient schemes for updating and guaranteeing data integrity.

6. SIRAP/REAP

The SIRAP (System of Information Retrieval and Analysis for Planners) project has completed an interface between the SIRAP portions of the SEEDIS data base, the LBL computer mapping system, and the SYMAP printer-plot mapping program. This interface will allow for rapid display of socioeconomic, demographic, or environmental data in geographic map format both at LBL and at remote sites.

We have developed the REAP system for user interaction and rapid retrieval of socioeconomic and demographic data for use by the U.S. Army Corps of Engineers and other governmental agencies. Data files of value to planners are installed at LBL in the SEEDIS data base, and on-line access to these data provides timely information to assist planners in evaluating the social, economic, and environmental impact of their civil works projects. Manuals to guide the user are continually updated to reflect the modifications and additions to the SIRAP/REAP data bases and programs.

7. Regional Management Information System (RGNLMIS)

The interactive retrieval program RGNLMIS has been developed to provide immediate access to information available in the Employment Security Automated Reporting System (ESARS) data base. Users at remote terminals can now identify, locate, and obtain the specific information they require in a timely manner. All Region IX statewide ESARS summary reports and the latest National and Regional Total reports have been installed at LBL. The RGNLMIS Users Guide provides guidance to assist users in retrieving the data from the ESARS data base, updated information on the content of the data base, and the current capabilities of the interactive retrieval system.

Redesign of the ESARS data base is expected to provide users with more timely access to the abundant amount of information concerning the employment statistics and welfare of the American people, which is collected under the ESARS program. The identification of the data items available in the source files and the determination of the data elements which should be in the output data base are the first steps in designing a useful data structure having the proper physical arrangement and interrelation of data items. Research is continuing on the programming logic necessary to aggregate the source files into an effective ESARS summary data base for use by planners

throughout the Employment and Training Administration of the Department of Labor.

The facility to display ESARS data of interest at a graphics terminal is now available. Tabular data extracted from the ESARS data base are transformed into bar and pie charts, line graphs, histograms, etc. for display using the CHART system.

8. ERDA Participation on the Federal Agency Council on the 1980 Census

Initial contacts were made with the Federal Agency Council on the 1980 Census, which culminated in a formal invitation requesting ERDA's participation as a member of that body. The Council, composed of representatives of approximately 90 federal agencies, provides an organizational channel through which federal agencies that make extensive use of decennial census materials can transmit advice to the Office of Management and Budget and the Census Bureau. The Council's efforts focus on broad aspects of the 1980 Census, including proposals for new questions, major changes in procedures or samples, and tabulation and publication plans. ERDA's expanded mission in energy policy assessment and evaluation of the social, economic, and health impacts of new energy technologies requires an increased role in influencing census policy issues and in keeping informed of developments relating to the census. By establishing this official tie ERDA will facilitate its participation on future working groups and subcommittees established by the Council. LBL, because of its extensive experience with the 1970 Census, will serve as staff support in coordinating ERDA input to the Council and its working committees.

9. Geographic Data Base

The Geocoding Subcommittee of the IWGDE began investigating the standards for geocoding geographical and political areas, for coordinate systems in use, and for exchange of geographic base files among ERDA sites. The Harvard University package POLYVRT was installed at LBL and we designed and implemented an interface module between LBL's MAPEDIT and POLYVRT. A test file was sent to ORNL for processing, since POLYVRT is running on IBM equipment there. In return, ORNL is to send a POLYVRT file to LBL to complete the initial testing of geographic file transfer.

10. Water Resources Project

A series of tables has been generated for the California State Department of Water Resources showing water use by manufacturing industries in California in 1970. The tables are patterned on a previous survey for the years 1957-1959. For each major Standard Industrial Classification and/or county, the tables present the water intake, use, source, recirculation, discharge, and potential acceptance of reclaimed water of approximatley 6000 reporting manufacturers, as well as an estimate of the total fresh water use by all 27,000 manufacturing industries in California.

11. LBL Interactive Resource Index (LBLIRI)

As a result of consultation with members of the Computer Science and Applied Mathematics Department, the Energy and Environment Division, and the Technical Information Division, we established initial guidelines and priorities for LBLIRI. A preliminary library of information on documents, programs, and data relevant to LBL SEEDIS has been assembled and is available in a BDMS data base. We intend that this data base will be expanded to include valuable documentation on data bases available throughout the ERDA laboratories. This information will be accessible to remote users, and will

provide a high level of interlaboratory communication.

12. National Technical Information Service (NTIS)

Because the systems and techniques developed in conjunction with SEEDIS, and the demographic and economic data bases installed therein are of general interest to the research community, we have implemented a mechanism to foster sharing of these resources. During FY 1976 an interagency agreement was executed between ERDA and the National Technical Information Service (NTIS), which provides government agencies, affiliates, and grantees of those agencies, and the public with access through NTIS to SEEDIS data bases, data, and programs for retrieval and display. Currently, a series of manpower reports developed under the sponsorship of the Department of Labor is available through NTIS for user-specific geographic areas. Users may also request special analyses that might require unique structuring of data within SEEDIS or data not available in a standard format.

13. Training in the Use of SEEDIS Interactive Systems

Following the development of SEEDIS and its systems for interactive data retrieval and analysis, which were designed primarily for use by persons who are not ordinarily involved with computers, the need for an educational program became apparent. Users guides are available for each retrieval and analysis system, and documentation written for the layperson has been prepared, describing the often puzzling procedures for connecting the user's terminal to the LBL computer. The users guides are being supplemented by videotapes that detail the intricacies and capabilities of each system. In addition, a set of workbook-like guides containing step-by-step examples are being prepared for new users of the SEEDIS system. A consultant is available in the CSAM department to help solve problems or answer questions that a user may have.

D. Computer Graphics

1. Computer Graphics and Interactive Programming Techniques

Our research in computer graphics is directed toward enhancing human-machine communication in the areas of data analysis, manipulation, and display. Graphic displays provide immediate comprehension of trends, clusters, and relationships in complex data. By expressing data transformations in graphic terms, the nonmathematical user can gain insight into the underlying structures of data.

2. Graphic Representation of Tabular Data

Development of CHART, an interactive analysis and display program for tabular data, continued. Most people have trouble assimilating even small amounts of data in tabular format; comprehension is much greater with the use of familiar graphic representations such as those found in newspapers, magazines, and technical journals. CHART uses a vocabulary of basic forms – lines, bars, pies, shading – which may be successively modified until a satisfying picture is obtained. Graphic manipulations that may be performed include table reorganization such as ranking on the basis of a particular row or column, data calibration and selection, scaling and binning, selecting graphic variables, and display annotation and

embellishment.

Limited data-analysis capability is also provided. Raw data may be systematically transformed into profiles by comparing rows or columns with a standard reference. Change, percent, or percent change from the reference allows objects to be compared across attributes when raw data values cannot be compared directly.

MATBOARD, developed in parallel with CHART, is a prototype program that has been designed to permit study of the feasibility of integrating data analysis techniques with graphic formats to aid decision makers. One particular class of graphic displays (matrix display) and one type of data analysis (dimensional scaling) are integrated within MATBOARD and offer an aid for two different cognitive tasks -- ordering and clustering rows and/or columns of a data matrix.

In addition, a bridge between RGNLMIS and CHART has been built as a first step toward supplying a data-retrieval facility for CHART. Given by a user-designed report template where tabular data values are designated by data descriptors, the two programs are used in tandem to retrieve and display the desired data.

3. Mapping System

The LBL thematic mapping system, CARTE, provides several types of displays based on geographic base files and geographically-coded data. CARTE was expanded to incorporate a variety of facilities for data integration and manipulation to allow the interactive analysis of geographic data by real-time displays of thematic maps.

Applied research has been the focus of developments in interactive thematic mapping. An exploratory interface to Fourth-Count Census data through BDMS was developed, and it greatly reduces user need for knowledge of data-base structure.

Display techniques appropriate for refresh or storage CRTs were developed, and the concurrent developments in GRAFPAC were made an integral part of interactive CARTE. Multiple windowing and three types of choropleth shading (character to centroid, parallel lines, cross-hatched lines) were implemented. These features allow the interactive user to compose a picture of the base map along with expanded subareas of interest, shaded as the user defines (emphasizing bins of interest, maximizing use of device features) with script titles. Thus the picture at the console is the same (within device limits) as that produced if a hard copy were made.

4. Diagrammatic Language Processors

PICASSO is a graphics modeling system. Models are drawn by the user as two-dimensional diagrams. These diagrams incorporate symbols that have been previously defined by the user and which are then translated into the linear (card image) languages of most analysis programs. This system was used as a basis for developing the CUPID graphics language processor for the relational data management system INGRES. The graphics editor module of PICASSO was implemented on the INGRES PDP-11 at UCB, leaving the complicated topological analysis and macro-processor modules resident on the CDC 6600. This provides a distributed computing environment with fast response to the interactive diagramming phase on an intelligent terminal, and transfers the complex operations to the large machine. A hard-wired link, established between the INGRES machine and the LBL complex, afforded network access to all these systems.

5. Relational Data-Base Management System Evaluation

LBL's geographic data-base index was installed in the INGRES system to help users explore and evaluate the efficiency of a relational data-base management system.

6. Generalized Dislay Routines

GRAFPAC is a set of device-independent routines designed to standardize programming for different kinds of display and graphics equipment. It is continually being improved to include both support for new equipment and special interfaces for software compatibility. GRAFPAC has also been extended to include the capability of displaying mixed hardware and software (vector) characters.

A high-level graphics system, IGS/NCAR, and the CalComp plotting subroutine library have been interfaced with GRAFPAC. The IGS/NCAR packages provide such high-level facilities as log-log plots, three-dimensional surfaces with hidden lines removed, contour plots, polar plots, etc. This is the first complete graphics system ever available at LBL.

Graphics output to multiple devices in a single job can be achieved conveniently by using TVOPEN.

E. Computer Networks

1. Network Implementation and Experimentation

By the end of FY 1976 we will have completed the implementation of full network facilities at LBL, including user and server TELNET, user and server File Transfer Protocol (FTP), and automatic FTP. Work on Network Control Program (NCP) and FTP protocols has produced a ten-fold improvement in the effective rate of data transfer – a significant aid in the experimentation process. Current single-hop transfers have been measured at 14 kilobits per second.

Experimentation over the network began in earnest this year as the other laboratories completed their implementation work. Experiments conducted in collaboration with about ten sites are described in the LBL ERDA Network Experimentation Project Status Report. The most successful of these includes the cooperative development of MINPACK with the ANL Mathematical Software Group, the exchange of experimental physics data in textual and graphical form with Rutherford Laboratory, cooperation in ELF II system development with BNL and NYU, and job export/import with MIT-LNS and UCLA. The data management system BDMS was improved and standardized to ANSI FORTRAN for installation on two additional network hosts (BNL and RHEL) in preparation for experiments in data-base sharing.

LBL established an ERDA Network Investigators Panel teleconference that uses the PLANET2 system developed by the Institute for the future. The teleconference is running on a PDP-10 at Bolt Beranek and Newman, Inc. in Cambridge, Massachusetts, and is accessible over both the ARPANET and TELNET. Participants include investigators from ANL, LBL, LLL, BNL, NYU, MIT-LNS, and ERDA Headquarters. It is expected that this teleconferencing medium will provide continuous interaction among the members of the ERDA Network Group, thereby considerably enhancing the network experimentation activity.

2. Regional Automation System

The Regional Automation System (RAS) study is a comprehensive evaluation of the

management information system used by regional and national offices of the Department of Labor for tracking employment and training programs, primarily under CETA (the Comprehensive Employment Training Act). The LBL study is focused on pinpointing operational and managerial deficiencies within the existing RAS procedures. To this end, LBL computer scientists have visited five regional offices as well as the Washington D.C. headquarters of the Department of Labor to survey existing operations. The study is intended to provide a set of detailed alternative plans for the improvement of RAS, ranging from minor modification of existing operations to replacing the existing centralized system with a distributed data-base minicomputer network operated from regional offices.

F. Management Information Systems

1. Technical Information Projects

The projects on technical information retrieval are carried out in support of the LBL Information Research Group. There are two major areas of effort: In Selective Dissemination of Information (SDI) there has been great progress in software modularization so that one computer system can be used on a variety of bibliographic data bases. This required development of generalized concepts for read modules and formatting modules. The second major effort has involved advanced techniques for handling bibliographic information. A batch version of the Thesaurus Management System has been completed, and an interactive version is under consideration. Bibliographic data bases have been combined and primarily converted to a common data-base management system, BDMS.

2. Management Information Projects

The projects carried out in support of the management of the Laboratory have served numerous managers including the departments concerned with personnel needs, the offices coordinating budget and technical support effort, and the managers of the research divisions.

The Budget Management System, used primarily by the division managers, had to be extensively rewritten because of changes in the Laboratory's accounting structure. The file structures were simplified and reorganized to facilitate anticipated future revisions. During this conversion process, the standard report generators were modified to use a uniform method for obtaining aggregate subtotals. Finally, the managers were allowed earlier access to monthly accounting data by initiating a file update from their terminals.

A new Support Effort Management System has been written that uses the same type of interactive dialogue as in the successful Budget Management System.

Two new series of reports were developed for the Budget Office: one is oriented to ERDA reporting requirements, the other consists of work sheets for eliciting budgetary plans from division managers. We have begun investigations for developing an interactive system to facilitate updating these plans.

Programs were written for the Personnel and Affirmative Action Departments to facilitate analyses of minority utilization, of reclassification, and of professional salaries. A data base was developed for the Visitor Arrangements Department by using DATABASE. The personnel tape was converted for use with the Qwick-Query report generator, which simplifies the generation of a wide variety of reports on an "at need" basis.

3. Space Analysis System

A space analysis system has been developed to aid in reassigning office and laboratory space. Details from a plant engineering data base on locations, and from the personnel tape on occupants were combined with collected data about the assignment of personnel to specific locations. The merged data base enables reports containing relevant space allocation information to be generalized easily via the Qwick-Qwery report-generation system.

4. ERDA/SAN Management Information System Projects

Initial studies are under way to provide the ERDA San Francisco Operations Office with a management information system for handling contracts, budgeting, and project management tasks. The system design will begin in FY 1977 and will be transportable to other ERDA sites for use by other operations offices. It will be based on a general data management system that can meet the continually changing needs of ERDA management.

G. Computational Physics and Data Analysis

1. Plasma Computations Group

The Plasma Computations Group is developing a modeling capability in simulating high-current space-charge limited beams that is applicable to source, accelerator, and fusion-device studies. This work is in support of the TORMAC, the neutral-beam-source development program of the LBL CTR division, and the U^{235} separator and high-current linac development programs of the Lawrence Livermore Laboratory. Several codes for use in this mission have been implemented, among which are the ion-source programs WOLF and BATES, and the electron trajectory program EGUN.

We are continuing the development of the WOLF code, with modification of the electron deposition procedure and improvements in the routines for optimization convergence criteria and trajectory tracking. The internal documentation of WOLF has been completed, and a user's operations manual is in preparation prior to distributing the program to the Argonne Code Center.

The WOLF code continues to be used to study the electrode geometry and extraction scheme for the separation of U^{235} and U^{238} isotopes by selective laser ionization. The design selected for the isotope separator now being fabricated at LLL is a result of the application of the code to the investigation of several different geometries.

A code has been developed for evaluating power deposition in high-energy neutral beam lines that consist of many converging sources. Our practical interest comes from wanting to inject neutral deuteron beams into fusion devices at energy levels of many tens of megawatts. For this we need detailed knowledge of power density profiles to determine practical aperture sizes, slit arrangements, and locations for beam dumps.

We have made calculations for a device to recover energy directly from the charged fraction of a hot, neutralized duoplasmatron ion-source beam. The EGUN code was used to investigate the behavior of the ion beam with cylindrical symmetry under several electrode configurations and modes of operation.

The preliminary design was completed for a high-current, 10,000 A linear accelerator. The beam is generated from a high-current diode source operating at two megavolts and accelerated to 50 MeV. With the program EGUN we

generated phase-space solutions for this source, which were used as input to the space-charge code TRANSPORT for evaluating the tune and spacing of the accelerating modules and solenoid lenses.

Several codes have been written by which to manipulate and analyze the experimental data from TORMAC. The raw data can be plotted or analyzed by fitting to a Gaussian or Lorentzian distribution to determine the amplitude and width of the spectral line shape. Selective acquisition of specific data can be made, and a least-squares fit of the spectrum performed, after removal of the instrument function. Plots of signal amplitude and width over the short duration time can also be made.

A code was written for the self-consistent solution of particle density and electric field in and around a one-dimensional plasma boundary. The results of this code are used as input to the WOLF program for proper simulation of conditions close to a plasma-emitting surface.

Our study continues on the extraction design for a high-current deuterium plasma source, for which the potentials, shapes, and electrode positions are being optimized for high-quality large-current emission. These sources will be used to heat and sustain CTR plasmas.

2. Muon Orbits in the CERN G-2 Ring

The effect of the gaps in the electrostatic focusing field on the muon paths in the G-2 ring was investigated. At the same time a study was made of the distortion of the closed orbits for particles with momenta off the design value.

3. Magnetic Shielding Design Computations

Extensive modifications were made to program JASON to allow one to calculate magnetic fields that have a fixed boundary condition. This refinement made it possible to study the design of magnetic shieldings for the Baseball-II-T Target Plasma experiment at LLL.

The modifications that were applied to JASON facilitated design of the magnetic shielding for the multiple beam source used in a modified version of the target plasma buildup experiment undertaken by LLL.

4. Beam-Beam Interaction

The computer program PEP, a beam-beam interaction program, has been used extensively to investigate beam distributions for weak-strong beam interactions in the presence of synchrotron modulation of both the longitudinal position and ring matching tunes. The basic program has been modified extensively to include the calculation of betatron functions that are functions of both position z and early/late timing. It has been determined that betatron envelopes for the strong beam-strong beam 1.5-GeV SPEAR machine give a dynamic strong beam that has the correct envelope. Beam distributions for this strong beam case have been simulated for the 1.5-GeV SPEAR machine and the results are presently being analyzed.

5. PEP/ESCAR

A program named CUR was used to calculate the fundamental modes of some parasitic resonant cavities in the PEP design. This project will continue, with the possible inclusion of the program SUPERFISH written by Klaus Halbach.

Calculations of magnetic fields and the harmonic components of vector potential were made for dipole bending magnets of the ESCAR project by using the program TRIM.

The magnetostatic program TRIM was modified to allow the use of a finite domain by incorporating a boundary condition that

reflects the fact that there are no external sources or sinks. The use of a finite domain allows a more effective use of the grid points in the iron and in the field region.

6. SPEAR ψ Particle Experiments

The kinematic fitting program SQUAW has been adapted for application to the data from the SPEAR electron-positron colliding beam experiments. In August 1975 the decay of the $\psi'(3700)$ particle into intermediate states (later named χ's) was convincingly demonstrated. This decay was first thought to result in two states, but improved resolution gained by analyzing the data with the SQUAW program has shown clearly that there are three states.

Data from both $\psi(3100)$ and $\psi'(3700)$ have now been analyzed by using this technique, which has helped to clarify the mesonic and baryonic decays of these particles. Of particular interest is the separation of λ-$\bar{\lambda}$ from χ-$\bar{\chi}$ final states, analysis of which has been aided by the fitting program.

Data collected and analyzed at SLAC were converted to CDC-7600 formats used at LBL for physics analysis. Recent discovery of a particle which decays to $K\pi$ and is believed to be direct evidence for a charm quantum number, was based on the processing of these data.

7. Computational Assistance to Nuclear Chemistry

Moments of inertia and magnetic moments of paired nuclei were computed and plotted. A plotting program suited to the needs of the nuclear fission group was begun. Consulting and general programming assistance was provided to the Nuclear Theory Group.

8. COBWEB and Other Ely Group Support

We continue to maintain the COBWEB system and its associated production programs.

A special measuring procedure was written for COBWEB to permit the measurement of film from the Fermilab 15-foot bubble chamber. This new procedure uses single-point digitizations, which define the ends of each track in an event. COBWEB then drives the stage to within 3 microns of the point to aid the measurer in picking out the correct tracks. An SPVB scan table has been put on-line, and a scanning procedure was written to digitize the endpoints of the tracks while the film is being scanned.

To study the data from the Fermilab experiments on 400-GeV/c protons in the 15-foot bubble chamber, the geometric reconstruction program TFVP was modified so that events of unusual configuration can be handled conveniently.

The project to develop a large superconducting solenoid for detectors at PEP involves design of a procedure to use the image plane digitizers to measure polaroid pictures of oscilloscope traces of signals relevant to the tests of the magnet. Programs to analyze and display the measured data are being written by using ERGON, a data summary and display system.

9. Automated Counting of Cell Clones with the Flying Spot Digitizer

The computer programs developed to count tissue clones were designed on the basis of two typical petri dish images supplied by the Tobias group last summer. A 90-dish sample of two tissue strains was digitized in February. This sample was photographed by using the new high-volume techniques; colonies had substantially different appearance from the initial data. Three digitizings of the film were made, at two

FSD threshold levels, in order to study reproducibility of counting.

The counts obtained from the runs and hand counts made by members of the Tobias group were compared. Since diameter is said to be the principal criterion for selection of the clones in the hand counts, diameter measurements from the three digitizing runs were compared. Reproducibility of individual colony diameters for constant digitizing threshold, as measured by differences from the mean of both runs, was excellent. Diameters were well correlated for different thresholds. Clone counts for the total sets made by visual and automated procedures had excellent agreement. Counts of about 10 percent of the individual dishes showed significant difference between visual and automated counts, although the automated counts of all thresholds agreed well internally, as did the visual counts. This suggests that visual counts, perhaps unknowingly, are subject to some additional selection criteria.

A study of the images that yielded significantly different counts was begun. Program modifications reflecting more subtle criteria than clone diameter alone are expected to result in satisfactory agreement of individual dish counts.

H. Mathematical Modeling

1. Biological Models

The model building and data fitting program, SAAM26, written by M. Berman and M. Weiss of the Laboratory for Theoretical Biology at the National Institutes of Health has been converted for use on the CDC 7600. The program contains some 250 subroutines and is being updated continually to reflect modifications by the authors. Currently under development is an interactive batch-submittal program for providing access to SAAM26 over the ARPANET.

2. Optimization

The GUMPS linear programming package is being used to solve a variety of problems by local users and those at remote sites including PNL, Brookhaven, and Argonne. Testing and modification continue. The post-optimal parametric routines have been improved. Input and restart procedures have been changed in an effort to reduce user errors.

PMG, the new interactive program to assist in project planning and management, is now available, without the scheduler, on the CDC 6600. It will soon be tested on the ModComp computer. We plan additions to the basic program in scheduling, graphics, and control capability. Assistance has been given to planners of projects including the SuperHILAC, Bevatron, ESCAR, and CTR construction.

Maintenance continues on SAP IV, a program for the static and dynamic analysis of linear structures.

FASTPATH, a geochemical simulation system from Kennecott Copper Corporation has been implemented.

We have written programs to examine, display, and fit solubility curve data.

An attempt has been made to find a simple expression which represents single electron time spread as a function of current pulse width for various photomultipliers.

3. HEMP

The HEMP program, originally developed by M. L. Wilkins at LLL, solves the conservation equations of two-dimensional elastic-plastic flow in the x-y plane or in coordinates with cylindrical symmetry around the x-axis,

and uses the method of finite differences and the Lagrangian formulation. The program has been implemented in FORTRAN for the LBL CDC 7600. A comprehensive revision has begun, which will add a graphics capability and improve HEMP's general efficiency. A new version of the HEMP Users Manual is under development and will reflect local changes and additions.

I. Programming Languages

1. Programming Languages Research

Control structure extensions to FORTRAN were surveyed, evaluated, and tested. In cooperation with the University of Southern California, a survey was made of over 50 FORTRAN dialects, directed to examining the control structures of the language. Based on a synthesis of these dialects, a proposal for compatible extensions of FORTRAN control constructs was published. The proposed changes were also tested within the framework of LBL's B4TRAN.

The systems implementation language BCPL was installed by the Real-Time Systems Group at LBL on several different types of computers (CDC, DEC, and ModComp). Work began on improving the efficiency of the generated code by machine-independent techniques, and plans have been developed for using it as the basis for implementing extended FORTRAN dialects.

Publication of a FORTRAN Development Newsletter was begun, to provide a forum for the many ideas and techniques related to FORTRAN enhancements. Six issues totaling some 80 pages of reports concerning known developments (including progress toward the forthcoming revised FORTRAN standard ANS X3.9-1977) and correspondence from developers of FORTRAN extensions were distributed to an average of 500 addresses.

2. META, Table of Isotopes Project

A production code was developed for checking table-of-isotopes data for proper syntax. Concurrently, a production code was developed for specifying syntax rules by using the syntax-oriented META language. More complete and sophisticated versions are now available, which are modeled on these two pilot codes.

J. Applied Mathematics Research

1. Capillary Phenomena

Work continued on the capillary-free surface problem. We obtained new analytic estimates for the shape of a pendent liquid drop, and with them proved preliminary asymptotic results for convergence to the singular pendent drop as the vertex height extends downward to infinity. Also, it was proved that a small capillary tube dipped into an infinite reservoir need not lift liquid higher than a larger tube, if the larger tube is not circular in cross section.

A comparative study continued on the relaxation and generalized conjugate gradient iterative techniques for solving numerically the capillary-free surface problem in two dimensions, including the possibility of corner singularities.

2. Mechanics and Biomathematics

Time-evolution was studied for the system of infinitely many particles interacting with the hard-sphere potential. A singular solution was found, which corresponded to the motion in a plane of a sphere reflected infinitely often from a boundary curve in finite time. We established necessary conditions for such singularities to occur.

Numerical and analytic studies of the nonlinear propagation phenomena in damaged heart fibers were completed. Experimental observations were explained in terms of physically meaningful parameters used in constructing the mathematical model. Extensions of the techniques hold promise in providing further understanding of the underlying biological mechanisms.

We have under study a model of skeletal dynamics, which is able to reproduce experimental data on the time course of blood-level, excretion, and skeletal content of bone constituents. Difficulties remain in finding experimental data on the relative amounts in the skeleton of apatite crystals of various densities.

3. Numercial Methods for Differential Equations

Our studies continued on the efficient use of fast direct methods for the numerical solution of separable elliptic equations on irregular domains. For the Poisson equation, the effect of boundary conditions on the frequently used capacitance matrix method was analyzed, and new techniques were developed.

The study of the generalized conjugate gradient method in combination with fast direct and other splitting techniques was extended to include nonsymmetric as well as symmetric problems. By so doing we further expanded the already numerous possibilities for application of this method.

An adaptive scheme was developed for solving two-point boundary value problems for ordinary differential equations. The scheme compares favorably with other methods for such problems, particularly problems with mild boundary layers.

4. Fluid Flow

Research continued in techniques for the numerical solution of problems in slightly viscous flow, which permit studies of the boundary layer separation and the effect of wall geometry on turbulence levels. We began work on the numerical study of the ergodic properties of fluid flows obtained by truncating the Fourier transform of the Navier-Stokes equations, in order to assess spectral approximations of turbulent flow.

Development of a technique for the efficient numerical solution of the Boltzmann equation was completed, and it was used successfully to study shock structure in one-dimensional rarefied gas dynamics. These techniques have collective application to the study of combustion chamber processes.

5. Numerical Linear Algebra and Approximation

In numerical linear algebra, advances have been made in the matrix eigenvalue problem. For the QR algorithm, a recursive shifting strategy has resulted in increased efficiency; and for inverse iteration, the behavior near multiple eigenvalues has been analyzed.

Work was completed on the study of bivariate function approximation by using complex cubic splines.

6. Mathematical Software and Consulting Services

Improvements and new additions were made to the mathematical software library in the areas of the numerical solution of ordinary and partial differential equations, linear algebra, minimization and optimization, numerical

quadrature, and random number generation. Mathematical consulting services in these and other areas were provided, and the project of preparing brief tutorial reports covering major areas in computational techniques continued. Cooperation was given to the community at large in the planning of general-purpose mathematical software projects concerned with numerical analysis.

K. Educational Programs and Visiting Staff

The Computer Science and Applied Mathematics Department provides supervision of graduate students in the Masters and Doctoral programs in applied mathematics and computer science at UC Berkeley. Four Ph.D. candidates (H. Holmes, B. Kitous, N. McDonald, K. Ang) completed their theses in computer science and engineering, and three in mathematics (R. Alexander, R. Miller, G. Sod). Three professors (A. Chorin, H. Baskin, M. Stonebraker) share joint UCB/LBL appointments, providing a rich source of exchange of ideas and experience.

This year our staff includes several postdoctoral appointees and visitors who are contributing extensively to computer science and applied mathematics research projects. They are A. Shieh, I. Karasalo, N. Chen, V. Pereyra, N. Albright, C. Risk, R. Finn, O. Widlund, M. Cauvin, and G. Ringland. In addition, masters theses by S. Chan, D. Dowden, W. Jones, and B. Zecher have been completed under the guidance of the CSAM staff. LBL's unique facilities and expertise provide an excellent training milieu, and this program is expected to grow.

IV. REAL-TIME SYSTEMS GROUP

The Real-Time Systems Group (RTS Group) works with project scientists and engineers to plan experiments and control systems that use computers. They provide dedicated project-oriented staff to work integrally with the research team during system development; and they provide routine systems support as well as system-development expertise organized along general functional requirements that are common to instrumentation and control systems.

Prior to the formation of the original RTS Group, there was an increasing variety of small systems developing around the Laboratory (minicomputers such as PDP-4, -5, -7, -9, -11, -12, -15; Data General Nova; Sigma-2). Formalization of the Group brought initial attempts at standardization with emphasis on ModComp (Modular Computer Systems) and PDP-11 (Digital Equipment Corporation Computer Systems).

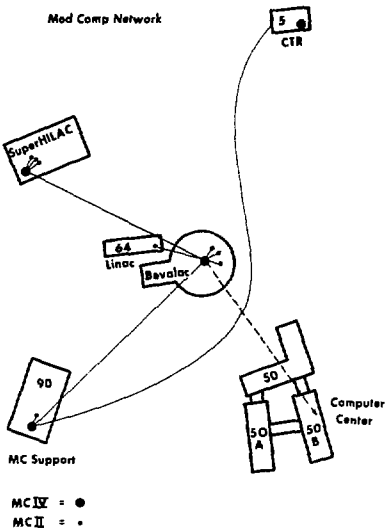
Recent computer facilities have now become standardized essentially into two major networks: one consisting of ModComp systems and the other of DEC PDP-11 systems. The ModComp network is set up primarily for control of the accelerators: the SuperHILAC, Bevalac, the Controlled Thermonuclear Reaction (CTR) project in Building 5, and the Linac in Building 64. The PDP-11 network provides data acquisition and analysis systems for research projects. Networking has shown itself to be a most practical approach. There are overall savings in cost, time, and convenience, as well as permitting central computing with a powerful facility.

For each major network there is also a support and developmental system where new hardware and software can be developed for application to other systems without interfering with operations. The ModComp developmental system is in Building 90. The counterpart for the PDP-11 system is in Building 46.

A. The ModComp Network

The Group's major effort at this time is the construction of control systems for the SuperHILAC and the Bevatron (when combined, the Bevalac). The design of generalized network control systems is structured on data bases so that as physical configurations of monitor and control points change, interactive editing of the data base will automatically and appropriately reconfigure the control system. Each accelerator control system consists of distributed real-time monitor and control processors that operate independently and asynchronously, but which are under the overall control of a larger central computer. This central computer will not only direct the activities of the secondary machines, but will manage all human-machine interactions through color displays and special function control panels.

The ModComp system to control the Bevalac is being installed in several stages. Phase Zero, the first stage, became operational in April 1975 and consists of one computer system



The ModComp network is set up primarily for the control of accelerators: the SuperHILAC, Bevalac, the Controlled Thermonuclear Reaction (CTR) project in Bldg. 5, and the Linac in Bldg. 64.
(XBL-765-2879)

at the SuperHILAC and one at the Bevatron. Although only the first of four phases, Phase Zero enables the SuperHILAC to operate in the timeshared mode. In timeshare, two injectors send pulses of different heavy ions interspersed in various combinations through the SuperHILAC at a maximum rate of 36 pulses per second. At the far end of the accelerator the pulses are separated: one pulse per second of the selected ion is sent through the transfer line to the Bevalac, the others are shunted into experimental areas at the SuperHILAC.

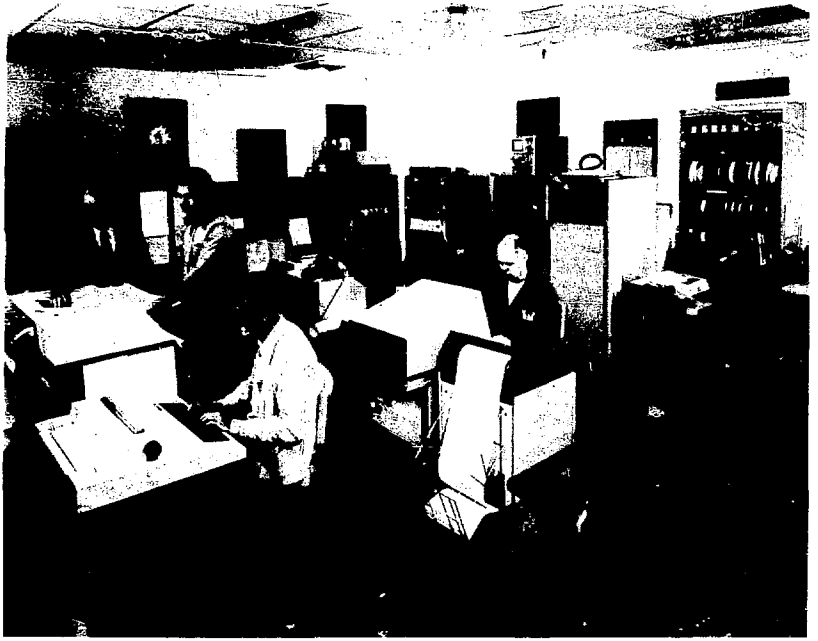
The two accelerators were brought up to Phase One in December 1975, with a two-computer network (MC IV and MC II) operating at each. Phase Two will come into action at the SuperHILAC in May 1976. At this time all the distributed real-time processors will be supported, and control will be extended to all machine parameters. When this system is proven, the Bevatron system will be changed to the Phase Two configuration.

Ultimately these two central computers at the accelerators, and the system support computer, will be linked together and to the computer center to provide all the computer support capabilities available at the Laboratory to the accelerator staffs.

Another component in the ModComp network is the 50-MeV proton linac in Building 64. Originally designed for injection at the Bevatron, it is awaiting a complete new data acquisition system for adaptation to ESCAR.

The Controlled Thermonuclear Reaction (CTR) Group presently has a ModComp II for data acquisition in two projects: the neutral beam test stand and the atomic physics experiments. The RTS Group designed the system to CTR requirements: they have had to provide a system that has the capacity to handle at least four remote experimental stations asynchronously and simultaneously that are up to 600 feet away and that can transfer data at a rate of at most 50,000 words per second between each experiment and the computer.

In the future is a medical accelerator designed to be built for patient use, which will have high reliability and can accelerate particles up through the "light" heavy ions (carbon, neon). Such a system will be highly computer controlled. The Group is presently doing a design and feasibility study on such a project, in particular, the beam delivery system for patient scanning, so that the accelerator will have a uniform dose distribution. This capability will require the handling of large amounts of data at a very fast rate and



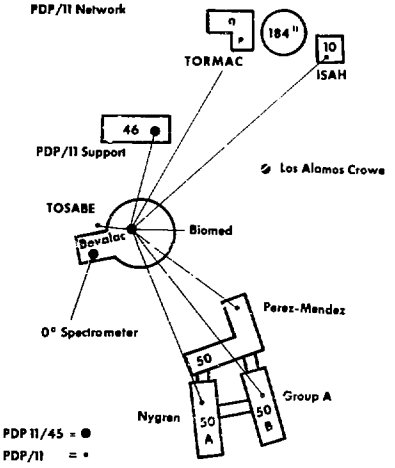
The ModComp room at the SuperHILAC. Here the ModComp II and IV units support all distributed real-time processors and control all machine parameters. The Bevalac has a similar control area.
(CBB 765-4161)

to a degree of accuracy never before attempted at an accelerator. This medical accelerator is of the type that could be installed at major hospitals throughout the country.

B. The PDP Network

The Biomedical Division PDP-11/45 computer at the Bevalac is the central system of the other real-time computer network. It is also used to study the experimental biological effects of heavy-ion radiation on animals, directed toward the eventual goal of patient treatment.

This computer system provides for concurrent data acquisition from instrumentation specific to the particular irradiation in progress and has a large complement of memory, disc, and magnetic tape drives. On-line analysis and graphics routines, excluding system support, are written entirely in FORTRAN or BASIC. The system support and data acquisition



The PDP-11 network has six remote stations, with Biomed's PDP-11/45 as the host computer. This system is designed primarily to provide data acquisition and analysis systems for research projects. By being part of such a network, the individual projects appreciate savings in cost, time, and convenience.
(XBL-765-2880)

routines accentuate the accessibility and usefulness of higher level languages for researchers.

In order for the PDP-11/45 to serve as the central host for this network, the Biomedical Division has established a working arrangement with the other divisions that their use shall be "transparent," that is, does not conflict with the host division's use.

At present this network also serves the CTR TORMAC Group, the Nuclear Science Division, and Physics, Computer Science and Mathematics Division. Currently six remote stations are connected, each consisting of a PDP-11/10 or similar machine with data acquisition and display devices. These small, inexpensive, and remote computers in the PDP-11 network serve a variety of research programs at LBL.

The RTS Group began the design of PEP's control system. This control system is extremely complex: the nature of the Positron-Electron Colliding Beam Storage-Ring Facility requires a control system to keep the beam in tune, and the control system must be subdivided to accommodate the real distances that would add excessive delay to the system's reaction time if it were controlled by only one central unit. Each of the six interaction regions will have its complete computer control system, which will in turn be connected by a high-speed serial link to two central computers in the main control room. These stand-alone units will permit local control, but during normal PEP operation the main control room operator will monitor and adjust beam parameters as needed. All work on PEP is in the system design stage, and final estimates of the complete control system have just been completed.

This Group has designed and implemented a monitor and control system with interactive graphics analysis capability for human treadmills at the Letterman Army Institute of Research in San Francisco. Like the accelerator control systems, the Treadmill Automation System (TAS) is entirely data-base driven.

Members of the RTS Group also serve as consultants to the Bay Area Rapid Transit District (BART). The District uses a Sigma-II-based computer system (Central Train Control Computer System) to provide system-wide train supervision. Failures of this system have been a major interruption to the operations of trains. The Group has investigated the problems of this system and has provided the District with recommendations to improve safety, reliability, and performance.

Members of the RTS Group, the BART Engineering Computer Systems staff, and the California PUC have been putting their heads together to find ways to improve real-time computer systems at BART. (XBB-763-2738)

The BART District uses 13 different computer systems for a variety of applications. The cost of supporting these computer systems (operations, maintenance, and development) is substantial. This is a problem at BART, in part because of the adverse impact on District operations when adequate resources are not available to support these computer systems. The RTS Group has surveyed all these computer systems and is currently formulating recommendations for medium- and long-range computer system planning at BART.

V. COMPUTER CENTER

The Computer Center provides an advanced level of computing service for the Lawrence Berkeley Laboratory's research groups as well as for a large number of users external to the Laboratory. The Center is functionally divided into four areas: systems programming, users services, hardware development, and operations.

The hardware currently includes a CDC 7600/6600/6400 computer complex, several smaller IBM computers, and a wide variety of peripheral equipment.

At the input/output counter Ray Gatti submits data on a magnetic tape to Pat Bean for computation work. In the background input data on cards are being submitted for computation also. (CBB-760-10411)

A. Systems Programming

The Systems Programming Group develops and maintains software for the CDC 6400, 6600, and 7600 computers and for a number of peripheral systems that contain minicomputers used as hardware controllers. Contrary to the practice at many CDC installations, almost all the system software in use at the Computer Center was either developed by the Systems Group or modified by the Group from CDC software delivered with the computers. This independence from manufacturer-produced software has enabled the construction of an integrated, flexible, efficient system tailored to the needs of the Center's users, as well as to the support of some specialized computer hardware (interactive, remote batch, mass storage, and microfilm systems).

1. Programming Languages

FORTRAN is the programming language of choice for most LBL Computer Center users. However, there is a continuing usage of the other supported languages: BLIMP, COMPASS, PASCAL, PL/1, and SNOBOL.

Substantial progress has been made in installing CDC's FTN Version 4 FORTRAN compiler. FTN4 is to be the primary compiler at the Computer Center, complemented by the University of Minnesota's MNF, a fast compiler with excellent diagnostic features. An intensive developmental effort has been directed to improving the compiler and library, so that they may include features commonly in use here with other compilers.

BLIMP is a structured FORTRAN-like language for system implementation and has subword

access; it was designed at LBL and completed in initial form. By combining modern concepts of structured programming with the ability to manipulate partial-word fields conveniently and efficiently, BLIMP is expected to offer great benefits in writing programs that are easy to understand and maintain. Several system codes have been successfully implemented in this language, and a number of anticipated systems projects will be coded in BLIMP.

2. Operator Systems

A new control-statement processor was written for the 6600 and 7600 computers to allow more flexible user control of job processing and to increase compatibility between the two systems. The 7600 permanent file system was totally rewritten to improve reliability and efficiency.

3. Peripheral Support Subsystems

A new print driver was installed to provide upper and lower case output. Modifications to the computer-output-to-microfilm system permit the user the convenience of mixing graphic and print output in the same frame.

4. Interactive Support

NETET, a file editing program conforming to the specifications of the ARPANET editor, was designed and implemented. LBL's support of its ARPANET connection became fully operational. Now users here may run at other ARPANET sites, and users at other sites may run here.

5. Remote Job Entry (RJE)

Over half of the batch processing workload of the LBL Computer Center enters and

The input/output station for the CDC 7600. In the center, on the CDC 6400, Boyd Holt assigns peripheral equipment for job execution, while John Powell watches. A magnetic tape carrying instructions to the computer is hung on the tape drive by Don Dumpit after having been selected from the racks of high-use tapes in the rear. At left Jesse Lopez verifies operational routines in the machine operator's guide. All are computer operators.
(CBB-760-10413)

leaves the system through the RJE system, which connects the center via dedicated and dial telephone lines to over 125 sites. The capacity of LBL's RJE system was increased by placing in service the COKE communications controller, which was built around a Computer Automation ALPHA/LSI minicomputer and is capable of handling up to 29 RJE lines. An additional COKE system was installed later in the year, allowing a leased Harris COPE controller to be discontinued.

6. Utility Programs

DUMP, an annotated memory-dump generator, was designed and installed. This program makes use of the load map produced by the link loader in providing the user with detailed diagnostic and traceback messages to help him locate the source of program errors. Unless otherwise

instructed, DUMP limits the displayed memory to only relevant portions, greatly reducing the volume of printed output.

B. Users Service

Staff consultants provide assistance to users so that they may effectively use the Computer Center hardware and software. This staff also supplies documentation support for the system.

The effort to provide a complete user description of our facility is bearing fruit. This year we made available many new chapters to the Users Handbook including staging, aids, and storage, and updated the previous information. Existing major manuals for the compiler FTN4 and MNF were modified to correspond to their use on our facility. A new users guide to the CDC product UPDATE was written to provide the unsophisticated users with an understandable manual.

Much was accomplished in the program library area: Edition five of the IMSL library was made available, as well as a new version of the CERN library and the Livermore STACK LIB.

Consultants Jerry Borges and Marjory Simmons trouble shoot a program for a user. This consulting service is available to all computer center users. (CBB 760-10423)

New utilities were written for dealing with nine-track tapes as well as with other tape conversion problems.

The consulting and training efforts continued to provide all of our users with assistance in solving the problems they encountered while using our computing center.

Efforts to develop an efficient working environment for a visually-handicapped consultant are progressing. A systems programmer has written a Braille conversion program in machine language – an intricately coded program that enables the computer to produce a printout in lines of periods to form symbols in the Braille alphabet. For creating the embossed image, a bracket with a piece of elastic stretched across it is attached to the line printer to receive the Braille output. With the pressure of the strokes set very high, the elastic provides a soft surface so that the images are embossed on the paper.

Work has been done to develop an interface for the computer and an OPTACON (optical-to-tactile converter).

C. Hardware Development

1. Overview

The Hardware Development Group develops special hardware systems and subsystems in support of the Computer Center. This development ranges from the simple interfacing of dissimilar hardware interface standards (such as the CDC/IBM Channel Adaptor) to full systems with many subsystem components (such as the COKE RJE system). These various developments are carried out in close conjunction with the Systems Programming Group from design conception through product completion.

2. COKE Remote Job Entry System

Since the installation of the CDC 7600, the RJE service has been handled by the University Computing COPE Controller. Although this device was initially satisfactory, demand for the 7600 soon outstripped the capabilities of the UCC COPE Controller. During calendar year 1973 and 1974 a search was done for satisfactory replacement of this system. A second controller was temporarily leased, Request for Proposals were called for from commercial vendors, and an evaluation ensued. The industry response was so inadequate as compared with the LBL requirement, that it was decided to develop an RJE front-end controller system internally.

A multiple minicomputer system was desirable for its characteristics of isolating protocols between minicomputers, minimizing single-processor crash impact on the system, and minimizing the amount of systems-programming development needed. So, a minicomputer subsystem was procurred. A subnetwork consisting of multiple hosts and multiple minicomputers was designed and developed to allow easy expansion of either hosts or minicomputers (as line and protocol expansion was needed). Also, a multiple-line synchronous-line controller was developed to allow each minicomputer to interface up to 29 lines at sustained speeds of 9600 bits/sec.

A software system was developed by the Systems Programming Group to handle the CDC 200 UT RJE protocol in the minicomputer and to interface multiple minicomputers to the CDC 6000 computers.

The system development was completed in early 1975, and the lease [illegible]PE Controller was given up. All 200 UT users were moved from LBL's COPE Controller to the COKE system. In late 1975 the COKE system was upgraded with a second minicomputer, and we expect a third will be added in late 1976 or early 1977.

3. CDC/IBM Channel Adaptor

By late 1973 it had become obvious that CDC peripheral I/O equipment was substandard to and more costly than that available to the IBM computer user. It was determined that an ideal situation would be to have an adaptor that allowed convenient interfacing of IBM input-output controllers to CDC 6000 and 7600 channels. To that end, design discussions were held with Brookhaven National Laboratory about the possible capabilities and desirable features of such an adaptor. It was decided to survey the commercial marketplace with a Request for Information about this device. The results were discouraging; essentially only one vendor responded positively and subsequent evaluation of that product showed it as undesirable as a subcomponent for the projected LBL application. Thus an effort was initiated in early 1975 to develop an adaptor capable of interfacing IBM Block Multiplexor and Selector control units to CDC 6000 and 7600 I/O channels.

Currently an STC 6250 tape system is being leased for evaluation to aid in debugging the CDC/IBM Channel Adaptor.

Future plans for the LBL Computer Center rely heavily on the capability of the CDC/IBM Channel Adaptor to allow upgrading of disk, tape, and mass storage systems to keep pace with the fast-moving computer industry, and to lower overall operating costs of the Computer Center by taking advantage of the higher cost effectiveness of the IBM-compatible peripherals.

4. RECC Interactive Terminal System

The Computer Center has relied heavily on the interactive front-end system called RECC (remote equipment control computer), which was developed by the Hardware Development Group in 1970. The RECC system has expanded steadily in the ensuing years, and it now controls 224

At the remote electronic computer controller (RECC), computer operators Jan Nelson and Don Dumpit run diagnostic checks on the equipment performance. The RECC acts as a traffic controller for all the remote terminals on the hill and those on the system within a radius of 150 miles that connect through RECC to the main computers. (CBB 760-10415)

live ports at speeds from 110 to 9600 bits/sec. Forty of these 224 ports currently are accessible by telephone with speeds of 110, 150, 300, 1200/150 and 1200/1200 bits/sec being supported in this mode.

The RECC system is used for terminal access to the timesharing system SESAME, to special interactive tasks, to the job-status system for batch users, and to interface Computer Center peripherals more easily and cheaply than by unique channel interfacing. Examples of this are label and routing printers for the COM system, tape cache labelers, punch and plotter system routing labels, and the paper tape punch development now underway.

New developments are being planned to upgrade the RECC system capability by developing a multiple microprocessor communication front-end system called MICROBUS, which will allow high speed (250 K bits/sec) terminals to interface to the Computer Center. This will allow many new forms of peripherals and networking to be supported by the Computer Center.

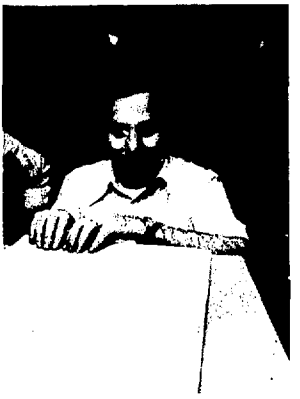
5. Terminal System for the Blind

In 1974 the LBL Computer Center hired a blind person to be a computer consultant in the Users Services Group. No aids were available to allow him to use the computer, so a small effort was undertaken to use the old DEC PDP 8/e computer and his personal OPTACON device for computer-generated tactile-sensitive output.

The OPTACON is a portable device (the size of a medium calculator) that has a tactile sensory pad of 6 by 24 vibrators for the blind person's finger, an optical scanner that is hand movable across a printed page, and the necessary electronics to convert the scanned dark line images to an equivalent vibrating image on the sensory pad. The Hewlett Packard Instrumentation group had developed a way of using the OPTACON for blind persons working on their component manufacturing line. With this conceptual idea (from HP), a special device was developed to allow the PDP-8 to control the OPTACON directly so that interactive output from the Computer Center could be output through the PDP-8 and generated directly onto the OPTACON sensory pad.

A specially modified Braille line printer was then purchased and integrated into the "blind" terminal so that documents and more lengthy output could be handled by the blind operator in his traditional way (he has relied on Braille most of his life), while the direct interactive use of the computer would still be through the OPTACON output capability.

Blind operator at sensory output terminal.
(XBB 757-5021)



Blind operator reading braille output.
(XBB 757-5022)

A keyboard is also supplied with the OPTACON output device for the operator to use for hand input to the computer. One interesting feature of the OPTACON output device is that it has a 16 by 24 display grid of light-emitting diodes to allow sighted observers to see the character that the blind operator is feeling.

The Blind Terminal is now fully operational and is an indispensible aid to an unsighted person who uses a modern computer system. Some improvements, such as voice output may be made in the future.

6. Short-Haul Modems

Due to the large amount of interfacing of batch and interactive terminals that has occurred at LBL, extensive line-driving capabilities are needed for COKE and RECC to function. These line drivers are called modems (modulate/demodulate). To this end many different techniques have been developed, which are not available commercially, to allow high communication speeds at long direct-wire distances. The dual-drive, high-current driver for teletypes has allowed many minicomputers to interface with each other, and with their terminals around the site, even though these are not always connected directly to the Computer Center. A synchronous short-haul modem has been developed, and is in extensive use by the Computer Center and others around the LBL site.

Developing these short-haul modems has provided experience that has been valuable to LBL scientists and engineers. It is expected that this expertise gained will greatly aid LBL physicists at the PEP facility to connect both in real time and interactively to the LBL Computer Center so as to maximize the human resource regardless of where the experiment is done.

7. Full Print Page Cathode Ray Tube

It has long been recognized that printing all output on 11 by 14 printer paper can be wasteful, and much effort has been made by the national laboratories to find useful alternatives for minimizing this waste. Microfilm systems (called COM) are most commonly used. In fact LBL was the first to produce microfiche output by interfacing a Stromberg Datagraphix 4460 directly to the CDC 6000 system at the Computer Center in 1973. This system currently prints three million pages per month on 48x microfiche.

The Datagraphics 4460 COM (computer output microfiche) has three cameras for producing film in 16-, 35-, or 105-mm sizes. They are laser-aligned permitting accurate interchange. George Kapus is cleaning the lenses. The user thus has the option of obtaining his data in paper form, microfiche, or any of three sizes of "movie" film.
(CBB 760-10417)

Still, this has not been enough. SLAC has pioneered the interactive use of computers by high-energy physicists and much output is searched interactively on Selectric typewriter terminals at a rate of 15 characters per second (cps). One hundred twenty cps graphic terminals are also used. The SLAC concept is very useful, although the terminals are far too slow. Also, paper output (such as on a Selectric) is not needed if the speed of a CRT-type terminal is high enough (9600 bps or higher) and one can occasionally get a hard copy when it is needed.

The problem is that the commercial interactive keyboard/CRT terminal was developed for timesharing users who are not necessarily tied to 132-column (136 for CDC) by 66-line formats as the scientific batch community has been. Thus these alphanumeric CRTs have been limited to 80 characters by 24 (or 40) lines. Certainly the more expensive Tektronix, storage-type, CRT terminal can suffice, but its capability exceeds that needed by most of the user community and the characteristics of the storage tube erase are maddening. So the Hardware Development Group has developed a new style, interactive keyboard/CRT terminal.

The PAGE CRT incorporates an inexpensive ($196) raster scan TV that has been integrated with a Motorola 6800 microprocessor and a keyboard. The CRT is 15 inches and has two modes: the page mode with a 136-characters per line by 66-line format, and the view mode with an 80-character by 40-line format. The modes are changeable by a single stroke of a special key on the keyboard.

The M680 microprocessor will allow great flexibility in the use of this terminal as it is expected that special applications can be coded directly into the PAGE CRT. Also, it will allow a very high-speed interface to the new MICROBUS RECC upgrade system so that the 8976 characters viewable in page mode may be output from the computer in a fraction of a second (250 thousand bps).

The prototype PAGE CRT is expected to become operational in July of 1976. Current thoughts about developing this kind of terminal include having private floppy disk drives on

the PAGE CRT to allow a user to have totally offline WYLBUR- or SESAME-type interaction to the main computer, then to use the high-speed line to the Computer Center for file transferring when needed. A small graphics capability with a user specifiable character set will also be experimented with (256 by 256 point graphics).

D. Computer Operations

These operations include the activities of the computer operations and keypunch staffs, whose function it is to provide day-to-day functional effort and to insure efficient and expeditious production.

The training program being conducted by the Computer Operations Group aims at professional upgrading of the individual and the group. The main goal of the training program is to achieve technical competence in the LBL Computer operating system. Development is mapped in four phases of instruction: introduction to operations, basic operator level, intermediate operator level, and advanced operator level. Individual or group instruction is also offered in safety, communications, programming, basic skills, presupervisory skills, supervisory skills, and electives. Training records are kept up-to-date, and annual interviews of all operations personnel determine the level of training achieved and the kinds of additional courses that are desirable.

The aims of Operations are realized through the combined efforts of the Computer Operations Training Officer, technical experts, Operations staff, and with the aid of video presentations. Specific course content is provided by technical experts, while the Operations staff provides assistance in the form of writeups or transcriptions of videotaped classes. To maximize exposure of resources, video presentations are available twenty-four hours a day to Operations, and are also available for review. On-the-job training and formal and informal sharing of ideas also serve to meet training needs.

APPENDIX: GLOSSARY OF CSAM TERMS

ADMC – Architecture of Data Management Computers

ANSI – American National Standards Institute

ARPANET – Advanced Research Projects Agency Computer Network (international)

BATES – Ion source program

BDMS – Berkeley Data Management System

BLIMP – A programming language

CARTE – LBL thematic mapping system

CDC – Control Data Corporation

CDC 200UT RJET – The 200 UT is a particular type of terminal produced by CDC

CETA – Comprehensive Employing Training Act

CHART – An interactive analysis and display program for tabular data

COBWEB – A computer controlled, bubble chamber measuring system

COKE – A remote communication control

COM – Computer Output Microfilm

COMPASS – A programming language

COPE – A remote communication control

CSAM – Computer Science and Mathematics

CTR – Controlled Thermonuclear Reaction

CUPID – A high-level graphics query language for INGRES

CUR – A program used in the design of resonant cavities

Database – A collection of any computer-accessible information

DEC – Digital Equipment Corporation

DUMP – Annotated memory-dump generator

EGUN – Electron trajectory program

EIS – Employment Information System

ELF II system – PDP-11-based ARPANET front-end machine

ERGON – A data servicing and display system

ESARS – Employment Security Automated Reporting System

ESCAR – Experimental Superconducting Accelerator Ring

FASTPATH – Computes chemical reactions as a function of reaction progress

FTN4 – A FORTRAN compiler; the primary one at the Computer Center

FTP – File Transfer Protocol

GRAFPAC – A device-independent graphics system

GUMPS – A linear programming system with parametric capability

HEMP – Hydro Elastic Magnetic Plastic program

IGS/NCAR – A high-level graphics system

IMSL – An international collection of programs to do numerical analysis

INGRES – A relational data-base management system

INTERAC – Hierarchical File Management System

IWGDE – Interlaboratory Working Group for Data Exchange

JASON – Electrostatic field calculation program

LBLIRI – LBL Interactive Resource Index

Livermore STACK LIB – Efficient set of subroutines for vector operations on the 7600

MAPEDIT – System for automatic map digitization

MATBOARD – An interactive analysis program designed for managers

META – A compiler name used in syntax-analysis approach to data reliability

MINPACK – Collection of exportable minimization subroutines

MIT-LNS – Massachusetts Institute of Technology-Laboratory for Nuclear Science

MNF – A fast compiler developed by the University of Minnesota

MSS – Mass Storage System

NCP – Network Control Program

NETED – A file editing program conforming to the specifications of ARPANET

NTIS – National Technical Information Service

OPTACON – Translates visual images into tactile images

PAGE CRT – LBL-developed interactive terminal; allows on-line display of full page printer output

PASCAL – A programming language

PICASSO – A general, interactive, graphics, no-delay program

PL/1 – A programming language

PLANET2 – Teleconferencing system by the Institute for the Future

PMG – Interactive program to assist in project planning and management

POLYVRT – A conversion program between different cartographic data structures

PRIME – Hardware for the Computer Systems Research Project

PSS – Program Storage System

Qwick Qwery – A generalized retrieval and report generation system

RAS – Regional Automation System

REAP – Interactive retrieval system for SEEDIS data

RECC – Remote equipment control computer

RGNLMIS – Regional management information system

RJE – Remote Job Entry system

RSP – Regional Studies Program of the Division of Biomedical and Environmental Research

SAAM26 – Biological model building and data-fitting program

SAP IV – Structure Analysis Program

SCOPE – A standard CDC operating system for 6600 and 7600 computers

SDI – Selective Dissemination of Information

SEEDIS – Socio-Economic Environmental Demographic Information System

SESAME – LBL's principal interactive system

Short-haul modem – Communications adaptor for short distances

SIRAP – System of Information Retrieval and Analysis for Planners

SNOBOL – A programming language

SPVB – Bubble chamber film scan table

SQUAW – A kinematic fitting program for SPEAR

STC 6250 BPI tape system – Storage Technology Corporation; 6250 bpi is the density at which data is stored on the magnetic tape

STOFI – Data management system

SUPERFISH – A program for calculating the radio frequency of a cavity

TELNET – Virtual terminal protocol for ARPANET

Tormac – LBL fusion project

TRANSPORT – Space-charge code

TRIM – Two-dimensional magnetostatic computer program

TVOPEN – A subroutine within GRAFPAC

UCC COPE – University Computing Company operating system

UPDATE – An older file editing program

WOLF – Ion source program

WYLBUR – SLAC's interactive system

I. EXPERIMENTAL PHYSICS

A. High-Energy Physics

1. SPEAR - PEP - SLAC

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