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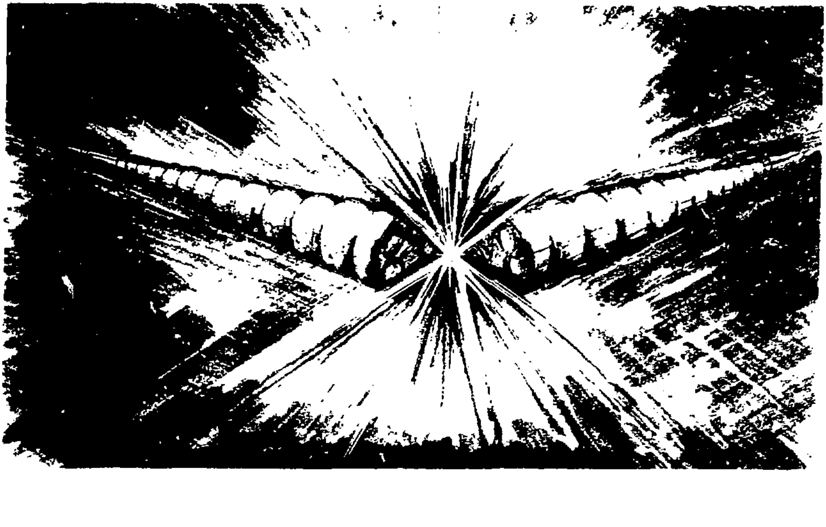
# ANNUAL REPORT
# ACCELERATOR DIVISION



January 1976 - September 1977

Lawrence Berkeley Laboratory
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January 1976 - September 1977

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# FORWARD

This report covers the period from January 1, 1976 through September 30, 1977. These twenty months saw not only the continuation of the Accelerator Division's established programs, but also the blossoming of PEP as ground was broken for major construction, and the introduction of a brand new effort in heavy ion fusion. A panel of distinguished scientists reviewed the Division's programs in May 1977, part of the annual peer review process. The status of the Division's many programs are detailed in the following pages.

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## BEVATRON/BEVALAC

Inaugurated in August 1974, the Bevalac passed its initial year and a half with a respectable record of research accomplishments, in spite of start-up challenges at the Bevalac and substantial modifications in progress at the SuperHILAC. During the period of this report -- January 1976 to October 1977, the emphasis at this national accelerator facility was to log as many research hours as possible. This goal was met with outstanding success, providing hard evidence of the reliability of the Bevalac connection. Out of a total of 9809 research hours scheduled, 8201 hours were run, for an efficiency of 83%. For 8 months of the 20, the machine was shut down; about half of the down time was due to budgetary limitations.

The established division of research time for the two major programs at the Bevatron/Bevalac was maintained: two thirds of the time is allotted to nuclear science and one-third to biomedical research. A special agreement between ERDA and NASA allocated 300 hours of beam time for NASA calibration studies. The machine operated approximately 80% of the time in the Bevalac configuration, using the SuperHILAC as the injector, with beams of lithium, carbon, neon, argon and iron. The Bevatron's 20 MeV injector supplied beams of protons, alpha particles, lithium and carbon for the remainder of the research time.

During the 20 month period of this report, a total of 48 nuclear science experiments received beam, 22 of which were completed in this time. Biomedical research, which typically involves short exposure times, represented 70 experiments, 29 of which were completed. About half the research time was devoted to outside national and international users.

Research time is assigned after research proposals are reviewed and recommended by either the *Biology and Medicine* or Nuclear Science subcommittee of the Bevatron/Bevalac Program Advisory Committee. These committees meet in the spring and fall each year.

The weekly and quarterly operating schedule for both the Bevatron/Bevalac and the SuperHILAC is coordinated by the accelerator operations staff. Although budget has severely constrained operations, a change from a one-week to a two-week operating cycle produced a modest increase in available research time. By running the machine for 12 consecutive days, then devoting two days to maintenance, start-up time is reduced, generating an additional two to three shifts per cycle for research.

## Beam Development

The repertory of experimental beams at the Bevalac grew by three, with lithium, carbon and iron joining neon and argon. The Bevalac carbon beam had been much requested because intensity of carbon out of the 20 MeV injector was fairly low. This beam, which was first delivered to experimenters in August 1976, has become a cornerstone of the biomedical program, since carbon and neon ions have emerged as two of the most promising beams for therapeutic use.

A lithium beam from the 20 MeV injector was produced in September 1976 for an experiment on cluster theory. Although not technically difficult to deliver, lithium had never been requested before. In June 1977, lithium was produced by the SuperHILAC's EVE injector, also for Bevalac acceleration but with much higher intensity.

In October 1976, after three days of intensive work, a 1.9 GeV per nucleon iron beam was accelerated in the Bevalac and extracted for several eager experimenters. This much-awaited beam, although low in intensity (several thousand particles per pulse), was employed for cosmic ray investigations for the 30 hours of its initial availability. In July 1977, a second iron run was conducted, with better intensity.

The continuous effort directed at improving the intensity of all Bevalac beams has yielded argon beams which now average $3 \times 10^8$ particles per pulse and neon of $2 \times 10^9$, with peaks even higher. Beams of argon +17 and neon +9 were also accelerated for development studies to look at charge-exchange problems and survival cross sections for partially stripped heavy ions. The tests of these hydrogen-like ions were very encouraging for the future acceleration of elements as heavy as uranium when the SuperHILAC's new injector and the Bevatron ultra high vacuum are available.

Additional beam development work concerned low energy -- 100 to 150 MeV per nucleon -- extraction studies. Considerable experimental interest has emerged in these energies which partially span the gap between the capabilities of the Bevatron's previous lower limit of 250 MeV per nucleon and the several MeV per nucleon SuperHILAC and 88-inch cyclotron. The 150 MeV/n beam has been used in the Biomedical facility, and the 100 MeV/n beam has been extracted and delivered down the septum channel to the beam 30-1 cave. Further studies will focus on integrating the extraction system with the future ultra high vacuum. A computer model is also being developed for use in designing an extraction system with improved efficiency and re- duced losses from large amplitude and low energy beams.

Ion Source Development

A duoplasmatron source optimized for heavy ions was employed on the 150 kV test stand to obtain a total current of 17 mA of xenon and 25 mA of argon collected 10 cm beyond the extractor. Measurements were made with a biased Faraday cup; a magnetic spectrometer and an 18 wire beam profile measuring system will be added to the test stand in FY 78.

The 750 keV proton injector became operational and has been used to evaluate beams of $H^{+1}$ and $^{20}Ne^{+1}$. The quadrupole strength limitation in the column and transport line prohibits tests of beams of mass greater than 20. Studies at the 20 MeV injector were aimed at more reliable and intense beams of carbon and nitrogen.

## Bevalac Transfer Line

Continued engineering effort on the computer control system for the Bevalac transfer line has resulted in consistently fast and easy tune-ups by the operating staff. The control system has been viewed with great interest by several other laboratories. Minor changes have been made in the transfer line hardware, such as installation of improved beam attenuators and beam centroid locating grids. A troublesome quadrupole doublet obtained from surplus is being replaced to enlarge the aperture at a critical point in the line to yield greater beam intensity.

## Bevalac Computer Status

Although installation of the ModComp computer control system at the SuperHILAC has been the first priority, substantial progress has been made in converting the Bevatron's PDP-8 control system to a ModComp architecture matching the SuperHILAC's. Hardwire connections from ModComp II's were made to the magnets of Beam 37, and several types of equipment status hardware have been interfaced to the system. Improvements were also made in operator control and display interfaces for the transfer line. Delivery of the Bevatron's ModComp IV-35 central processor is scheduled for FY 78.

## Nuclear Science Research

Research results from Bevatron/Bevalac experiments emerged at an impressive rate. The emphasis of much of the work involved searching for large density effects which conceivably arise from central nucleus-nucleus collisions. Although it is clear that a great deal of energy and momentum is deposited in these collisions, no unambiguous interpretations of the data have vet been developed to verify that non-normal, ultra dense nuclear material has been created.

Among the highlights of the major experiments (that is, those set up on the experimental floor for several months or more), is the work of the Poskanzer-Gutbrod-Stock group, an interna- tional collaboration between GSI, University of Marburg and LBL. Their measurements of the spectra of proton, deuteron, triton and helium particles emitted in nucleus-nucleus collisions led to the formulation of the "Fireball" model for proton emissions and for production of composite particles. With an enormous quantity of single particle inclusive data already produced, they are enlarging their instrumentation to permit a more com- prehensive measurement of all events.

Another major experimental group goes under the name TOSABE, standing for institutions at Tokyo, Osaka and Berkeley. Their work, again measuring single particle inclusive spectra, has produced new information of the production of pions with energies less than 100 MeV. This group has now been joined by scientists at Michigan State University.

The first results on negative pion multiplicity distributions by the UC Riverside and LBL collaboration using the Streamer Chamher, has evoked considerable theoretical interest, and a number of models have heen developed to inter- pret this data.

Nagamiya-Chamherlain, another international collaboration, has produced suhstantial data on the evolution of pions, protons and heavier particles at large transverse momenta. The spectra of protons they have observed, with typical temperatures ranging from 50-70 MeV, suggest that they originated in a hot source.

The LBL Heckman-Greiner group has continued their examination of projectile fragmentation in the zero-degree spectrometer. Expectations derived from their work indicate that projectile breakup increases with increasing difference in projectile mass and target mass.

In the area of light ion collisions, the LBL group represented by Anderson and Steiner has studied the fragmentation of light projectiles, principally deuterons and alphas, to test theories of projectile fragmentation processes. The concept of limiting fragmentation seems to hold at 1-2 GeV per nucleon. This group has also done the first research with beams heavier than alpha particles to study the production of pions at extremely high energies -- far above simple nucleon-nucleus collisions.

Further light ion studies by the Igo-Perez-Mendez group on proton-helium-4 and deuteron-deuteron elastic scattering has contributed much useful information for testing multiple scattering models.

## Nuclear Science Experimental Facilities Development

A Heavy Ion Spectrometer System, dubbed HISS, was proposed and approved for construction. This device will provide a large volume, high magnetic field for simultaneous momentum analysis of large angle multiple fragments. The core of the system is a superconducting dipole with a two meter diameter pole face and a one meter gap. By October 1977, substantial design work had been completed.

Another new spectrometer called SOP (Spectrometer of Odd Parts) was planned to replace the separated K beam line. The intention was to bring this facility, designed for beams below 250 MeV per nucleon, into operation during FY 78. However, delays in receiving the magnets, and a change in design of HISS to accommodate lower energy beams, have made SOP unnecessary.

Other improvements include the installation of multiwire proportional chambers inside the vacuum system at the east and south extraction magnets. These devices have been extremely useful for monitoring beam intensities below about $10^{10}$ particles per pulse, which is the functional limit for TV-scintillator paddles.

## Biology and Medicine Research

Operational efficiency for the biology and medicine program exceeded 80%. The stability of the Bevalac beam is a major factor in the continuing success of the radiobiological work, much of which is done with live targets, and with the radiography sessions, now conducted at two-week intervals.

Achievement of the first fractionation run in October 1976 represents a real milestone in the Bevalac biomedical program; the Bevalac carbon beam was delivered for a six-consecutive-day run at an outstanding 94% efficiency. Fractionation of a large radiation dose into several equally-spaced smaller ones allows biological repair mechanisms to minimize the radiation effect on normal tissue. It is technically difficult to accomplish fractionation because of the requirement to reproduce the same beam characteristics on a daily patient treatment schedule.

After the first success, a ten-day fractionation run was performed in June 1977, with equally fine results. This latter run signified an even greater accomplishment, since it was the first patient treatment at the Bevatron, culminating several years of intensive pre-therapeutic research at this facility.

## Biomedical Facility

Considerable progress was realized in the development of a human radiotherapy facility within the biomedical area. Cave I is being converted into Treatment Room I, with a commercial patient positioner (to be delivered in FY 78) and x-ray and laser location systems. A patient staging area, including waiting, changing, examination and preparation rooms, has been built adjoining the treatment room.

A beam flattening system is being produced to deliver the highest possible dose uniformly over the large diameter beams desired for radiotherapy. The system, modeled after the one created at the 184-inch cyclotron, uses scattering foils and occluding rings to achieve an overall uniformity of about 2% over fields of 10, 20 and 30 cm diameter.

Other improvements in biomed beam delivery are in progress. A fast beam cut-off system is being implemented to interrupt beam extraction within one millisecond when the desired total dose has been delivered to the target. Rapid beam switching between the treatment rooms is also being achieved by modifying the switching magnet power supply and control system. Pulse to-pulse beam routing between the rooms is essential for efficient use of beam time in biomedical situations, since set-up is much more time-consuming than treatment.

The Minibeam Facility was commissioned during this period also. This area, designed for microbiological radiation studies, is equipped with an optical microscope mounted on the beam line for in situ observation of cellular response to heavy ion bombardment. A typical desired spot size of 1 mm diameter is achieved with a 3 mm collimator at F1.

## MEETINGS

### SuperHILAC-Bevalac Joint Users' Meeting

Both accelerators have users' associations, each of which holds annual meetings. During February 17-19, a joint Bevatron-Bevalac-SuperHILAC Users' Meeting was conducted. The three-day conference, which consisted of general interest sessions and nuclear science and biomedical portions, was attended by 150 scientists, who considered the combined format very successful.

### Third Heavy Ion Summer Study

The 1976 edition of this week-long conference, which has grown steadily every year, saw participation by nuclear scientists from around the world. Lee Schroeder and Norman Glendenning arranged the program for this LBL-sponsored study.

## USER HANDBOOKS

New user handbooks were written and distributed for Bevatron scientists by the staff of the Accelerator Research Coordination Office. With the expansion of the Bevalac research program, two handbooks now exist: Nuclear Science, and Biology and Medicine. Each book covers much needed information on conducting research here, how to submit proposals, and operational data on accelerator capabilities and support services.

EXHIBITS, ETC.

The Accelerator Operations Group collaborated with DOE and the Smithsonian National Museum of History and Technology in Washington, D.C. to contribute to a new exhibit on the Historical Development of Accelerators and Detectors, which opened in Fall 1977.

KGO-TV in San Francisco filmed several sequences at the 184-inch cyclotron and the Bevalac Biomed Facility in Spring 1976 for a one hour documentary on new methods of cancer treatment. LBL's Dr. Joseph Castro discussed how patients were treated at the 184-inch for brain tumor conditions that require the use of large-field helium-ion irradiation. Dr. Kay Woodruff summarized pretherapeutic studies with heavy ions on animals at the Bevalac. The resulting film, titled "I used to have cancer," was aired in June of that year.

## SUPERHILAC

With the completion of substantial improvements and modifications to both the accelerator and experimental areas, the SuperHILAC achieved excellent research operation in fiscal 1976 and 1977. Operational efficiency was 79%, representing 7299 hours out of a scheduled 9255. The SuperHILAC was shut down for 8 months out of the 20 included in this reporting period; approximately half of the shutdown time was for budgetary reasons.

Time sharing of the SuperHILAC beams between two users (and occasionally three) has been very effective, especially since the Bevalac line can be operated simultaneously with all the other SuperHILAC beam lines. Customarily, a light ion (mass 18 or less) will be sent to the Bevalac, while a heavy ion is delivered to the SuperHILAC experimental area.

Twenty-five experimental groups used the SuperHILAC during this period. Of these about one-fourth are LBL based, one-half are from other institutions, and the remaining quarter are collaborations between LBL and other organizations.

The SuperHILAC Program Advisory Committee met three times to make recommendations to the Laboratory Director regarding allocation of research time.

## Ion Source Development

Recent source work at the SuperHILAC has focused on operational reliability and long life performance of ion sources. A newly constructed off-line duplicate Adam source facility has allowed the testing of sources for this injector and the debugging of mechanical and electronic improvements for subsequent accelerator use. Even injector source studies and improvements are conducted on the accelerator whenever possible.

Long-lifetime iron and calcium sources have been developed in the past year; each represents special challenges that were overcome to make these ions available for experimenters. Work continues on holmium and lead sources.

Considerable attention was paid to developing efficient collection and reprocessing techniques for calcium 48, a rare and expensive Oak Ridge produced ion which is much desired by SuperHILAC experimenters.

## Beam Development

Among the new beams developed for experimenters' were a titanium-50 beam, run principally to tune for a difficult calcium-48 beam, and iron-56, which was produced mainly for Bevalac users. Although iron had been accelerated at the SuperHILAC before, the new beam was fully stripped, yielding approximately 3% of 26+ ions. Short source lifetime over the first three-day run was the major problem. Further work on sources produced a much more successful iron run the next January. Iron has now become a standard beam in the SuperHILAC and Bevalac repertory.

SuperHILAC Facilities Development

During the spring 1976 shutdown of the SuperHILAC, an extensive rebuilding of the experimental area was begun. Beam lines E11 (Coulex) and E15 (Bevalac) gained separate ports at the M1 switching magnet, enabling these lines to timeshare beam for the first time. A new East Cave Area, with three caves and six beam lines was added, along with a new bending magnet to distribute beam among them. A new North Cave Area with three caves was also added, although the beam lines are scheduled for installation in the future. All beam lines have been equipped with improved vacuum pumping and more steering magnets. All control and monitoring of power supplies, vacuum valves, and Faraday cups came under computer control, supplemented by local analog control capability.

Rearrangement of the experimental areas has increased the efficiency of both experiment set-up and operation. Typically, one group now sets up its experiment as another group uses the accelerator. Remodeling of the experimenters' 'counting room' where the data is collected is slated for the next fiscal year; when that is accomplished, there will be adequate room to serve two major experiments simultaneously.

A 30-inch scattering chamber from Technolics, Inc. was installed at the end of beam E-73. This chamber contains two independent tables, each capable of 360° rotation, an out-of--

plane counter arm, and a sliding band for an external time of flight arm. This successful device is remotely controlled and monitored, with interface to the data-collection computer.

Many instrumentation improvements were also accomplished. The operators' energy monitoring system was simplified and expanded, and the Brutus spectrometer system, designed to supply experimenters with absolute energy measurements, was calibrated, debugged and routinely used. In the stripper area, an IR CCTV system was installed to non-destructively monitor beam position and size on the stripper foil. Several other electronic monitoring improvements were in the design and testing stage at the end of this reporting period.

The EVE injector high voltage power supply, which had long been dangerously overworked, was completely replaced in September 1977. The new supply has given no problems, and avoids the prospect of a total EVE breakdown.

Finally, a three-story annex to Bldg. 71 was constructed to relieve severe space limitations. The bottom floor serves an expanded machine shop, and the other two are devoted to experimenter and staff offices.

## SuperHILAC Research

The major research groups at the SuperHILAC average about 20-30 shifts of beam time, split into 2 or 3 runs, during a given 6-month scheduling cycle. About half of the beam time is used for nuclear reaction studies, and another 25% for Coulomb excitation and other particle-gamma studies with heavy projectiles. The other major types of studies are atomic spectroscopy of highly charged hydrogen and helium-like ions, and studies of the heavy transcurium nuclei.

Because of limited experimental areas at the SuperHILAC, the outside user nuclear reaction groups all use a single cave area. The primary facility in this area is a 30-inch diameter general purpose scattering chamber. In addition, a time-of--flight facility is available for experiments requiring mass information. The thrust of the nuclear reaction program at the SuperHILAC involves the study of equilibration of the various degrees of freedom associated with "deeply inelastic scattering," including measurements on the nuclear charge, mass, angular momentum transfer, and kinetic energies of the fragments emitted in the reactions.

The Coulomb excitation experiments involve looking at high spin states of good rotors and going up the ground band in back-bending nuclei. The measurements of the Lamb shift in hydrogen-like nuclei and the fine-structure splittings are severe tests of high-order corrections to quantum electrodynamics in a strong Coulomb field; measurements of the transition probabilities for certain forbidden transitions are tests of relativistic calculations for these highly charged ions. Finally, the heavy element groups are studying both the chemical and nuclear properties of isotopes beyond Cm, and hunting for the superheavy elements.

SuperHILAC Control System Overview

The SuperHILAC computer control system has been in operation since April 1975. The initial emphasis was to provide pulse--to-pulse time sharing for concurrent experiments at the SuperHILAC and at the Bevatron. With the achievement of this goal, the focus was shifted to speeding tuning by extending the scope of control and operating capabilities, improving system reliability, and shortening recovery time in the event of failure.

In April 1976, two computers were added to the control system and some 100 additional experimental beam line magnets were tied into the computer control network. Monitoring devices have been integrated into the control system as well. Many operator display features were streamlined and speeded up.

A major revision involved enlarging the control room to allow space for three control stations. Two of these stations are necessary for independent operator manipulation of two simultaneous beams, and the third station allows beam development work to continue.

USER HANDBOOKS

The SuperHILAC Experimenter's Handbook was published by the Accelerator Research Coordination Office. This new book contains relevant information on submitting proposals and conducting research at the SuperHILAC, along with data on accelerator and beam characteristics.

## 184-INCH SYNCHROCYCLOTRON

Since July 1, 1975, the 184-inch synchrocyclotron has been operated as a dedicated medical facility for LBL's Division of Biology and Medicine. The program of pituitary irradiations under the direction of Dr. Charles Linfoot continued, with 59 patients treated during the period January 1976 through September 1977. This therapy, considered the treatment of choice for Cushing's disease and acromegaly, makes use of the precise, pencil-point beam of helium ions to irradiate the pituitary gland.

A small amount of radiobiology work is performed at the 184-inch by LBL researchers. These studies represent a fractional percentage of the operating time of the accelerator, and they are conducted on a time-available basis.

Beginning July 1, 1975, the first patient trials for cancer therapy were launched at the 184-inch in a project headed by Dr. Joseph Castro in cooperation with the Northern California Cancer Program. To perform these treatments, a large field irradiating capability was developed. The emerging helium ion beam has a diameter of 5 to 7 cm, and a range in water of about 31.8 cm with the Bragg peak. For large tumor treatment, a scattering foil and two occluding rings are inserted in the beam to enlarge it to 20 or 30 cm diameter, depending on which of two scatterers is used. The Bragg peak is also extended to 6 to 14cm by means of precisely machined spiral brass ridge filters. The intensity of the beam is uniform to better than ±2% over 90% of the diameter.

To accommodate the enlarged patient load, now six per day, a 740 square foot patient receiving area was added to the 184-inch with the renovation of an existing modular building. The new facility contains a waiting room, two dressing rooms, x-ray darkroom, and radiologist's room, all on the same level and contiguous to the treatment room.

Another improvement was to the Accelerator Technician's Shop in Building 80. The enlarged machine shop is a multi-purpose facility which is also used for the design and construction of patient treatment collimators, immobilization devices and other equipment.

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## PEP

T. Elioff in charge

A. Altmann, R. Avery, W. Basinger, R. Belshe, S. Blair, R. Caylor, M. Chambers, T. Chan, C. Chavis, V. Cherniak, J. Chin, E. Close, K. Connelly, G. Cullen, D. Curtis, M. Donald, F. Duarte, R. Dwinell, T. Elioff, E. Eno, A. Faltens, W. Flood, A. Garren, S. Gil, S. Goss, E. Granucci, D. Greenway, K. Halbach, W. Hammonds, W. Harrison, E. Hartwig, C. Hitchin, E. Hoyer, T. Jackson, D. Jerko, C. Johnson, A. Kenney, A. Kruser, A. Lake, J. Laslett, J. Lavelle, T. Lauritzen, W. Lee, L. Leung, S. Lundgren, R. Main, A. Masana, V. More, R. Nissen, L. Nizin, P. Oddone, A. Paul, J. Peterson, C. Pike, R. Reimers, D. Rondeau, R. Sah, S. Sheperd, L. Smith, C. Sojourner, J. Staples, R. Tafelski, J. Tanabe, R. Thomas, H. Warnock, W. Wilson, O. Wong, R. Wright, J. Zelver.

PEP (the Positron-Electron Project) is a joint venture by scientists and engineers from LBL and SLAC. The six-sided storage-ring facility is currently being constructed at the end of the two-mile-long linear accelerator at SLAC. The completed machine will provide a storage ring in which counter-rotating beams of electrons and positrons will collide head-on at six points around the ring, with energies up to 18 GeV per beam.

During this reporting period, PEP construction geared up to full speed. Heavy construction was started, with deep excavations for the beam housing and experimental areas. Most of the major technical components, such as magnets, vacuum chambers, radiofrequency cavities, and instrumentation and control systems, were in production by the end of Fiscal Year 77.

A number of experiments had been proposed in expectation of an October 1, 1979 turn-on date, six months earlier than original projections.

Conventional Facilities

The PEP tunnel is 20 to 80 feet below ground, so a significant amount of excavation, earth moving, and tunneling has been necessary. PEP staff members developed preliminary conceptual designs and provided general criteria and specifications for this work. The detailed engineering, design, inspection and construction management functions have been the responsibility of the joint venture of Kaiser Engineers and Parson Brinckerhoff Quade and Douglas. Five-phased construction contracts were developed in order to optimize and maintain an expedient schedule.

The award of the Linac Junction Contract initiated the June 2, 1977 groundbreaking ceremonies. Actual work began with the SLAC linac shutdown on July 1, 1977. The contract involved excavating down the existing linac housing (some 40 feet deep in places), cutting through the heavily reinforced concrete walls of the structure and constructing approximately 300 feet of the PEP injection tunnels. Many complications were expected because of the proximity to existing utilities and structures. Time was a major problem because most of the work had to be, and was, completed by the end of October, during the scheduled linac shutdown.

Work on the Preliminary Site Work contract began in August 1977. PEP roads, drainage systems and fencing and rough excavation on the southwest portion of ring are part of this contract.

The largest contract is for Beam Housing -- the construction of all PEP tunnel enclosures (except the small sections completed in the Linac Junction Contract) and the heavy concrete portions of the interaction halls. This was begun in November 1977.

The Support Facilities Contract was scheduled for awarding in March 1978. This will include the major portions of electrical and mechanical utilities, as well as the steel framed parts of the interaction halls and all other above ground building structures.

The Final Site Work Contract, including landscaping, road piping and finishing touches, is scheduled for execution from January to June 1979.

## Technical Components

The PEP technical components and related functions are broadly categorized into the following systems: main ring magnets, magnet power supplies, injection and injected beam transport, vacuum, radiofrequency, instrumentation and controls, and survey and alignment. Many of the major components have now been developed and designed, with engineering models produced and tested. Production activities were proceeding at a rapid pace at LBL, SLAC and a number of outside companies which were fabricating parts.

Magnets:

There are some 700 magnets of almost a dozen varieties that must be fabricated and installed within the PEP main ring and the injection beam transport system. The largest are the nearly 200 main ring bending magnets, each of which weighs 10 tons and is approximately 20 feet long.

The coils for the bending magnets are being fabricated by outside suppliers, along with the main ring quadrupole cores. The "insertion quadrupoles," a larger type of focusing magnet to be positioned next to the interaction areas, are being constructed at LBL shops. These magnets will focus the beam to a minimal size at the interaction point. For this, an extremely high magnetic field quality is required, and magnetic measurements of production prototype units indicate that the required central fields have been achieved. Custom contouring of the end-pole tips is also necessary.

Injection System:

There are various specialized "splitter" and "kicker" magnets used in the injection process to first direct beam pulses away from the SLAC linac, then transport them to the PEP ring, and finally manipulate the beam particles for proper insertion to the PEP main ring. Approximately 1,000 electron bunches and 10,000 positron bunches will be directed from the SLAC linac during a period of several minutes to fill the ring. The beams will circulate for several hours before injection is repeated.

The cores and coils for the bending magnets and quadrupoles for the injection transport system are in production at several engineering companies. Kicker magnets, with ceramic vacuum chambers and thin metallic inner coatings were still in the design stage by the end of this reporting period.

Power Supplies:

A number of different types of power supplies are required for the variety of magnets incorporated in PEP. Purchased power supplies have already been delivered, and others have been designed and developed at LBL, with engineering models undergoing tests in the Bevatron area.

Radiofrequency System:

Twenty-four rf cavities are required for PEP, distributed at three regions around the ring. The rf system maintains the energy of the circulating beams by re-supplying the energy that is lost continuously from synchrotron radiation and various cavity losses. Seven of the aluminum cavity rf structures were being assembled at FY's end in preparation for high power tests.

The rf system operates at 353 MHz. New 500 kilowatt klystrons (12 are required) have been developed at SLAC to meet PEP needs. High-voltage power supplies were on order and the numerous electronic and control systems associated with the rf system were in different phases of design, testing and production.

Vacuum System:

The vacuum system consists of nearly 1.5 miles of specially extruded aluminum piping, with corresponding bellows and flanges and provisions for beam monitors, collimators, slits, and special instrumentation. The vacuum chambers in the curved sections of the ring are water-cooled to dissipate up to 3 megawatts of power from synchrotron radiation. Within the field of the bending magnets, the chambers have special sections for sputter-ion pumps.

The curved portions of the vacuum chamber are in production in 14.5 meter long sections.

Instrumentation and Controls:

Major systems in this category are communications, master oscillation and tuning, synchrotron light monitoring and other beam control and diagnostic instrumentation, vacuum system instrumentation, machine protection, personnel protection, rf and magnet controls and computer control. Seven peripheral computers are stationed around the PEP ring and will be connected to two larger central computers in the main control room. Both interfacing hardware and software are under development.

Survey and Alignment:

The quadrupoles must be positioned to within 0.2 mm accuracy relative to an ideal beam orbit to permit beam circulation. With the aid of an established array of primary survey monuments and a liquid level system around the PEP ring, engineers can rapidly determine the magnet positions using a special laser system with laser targets which they have developed and connected to magnet fiducials. This system has its own computer which will specify any corrective magnet positioning required.

Experiments:

Even though the first beam turn-on is still a ways off, apparatus for experiments is being created at an eager pace. In April 1977 the PEP Experimental Program Committee considered the first experimental proposals. Of the ten proposals, representing nearly 200 physicists from over 25 institutions, four were ultimately approved, two of which involved LBL scientists. A second round by the EPC was scheduled for January 1978.

MEETINGS:

The 1976 PEP Conference, sponsored by LBL and SLAC, was held at SLAC June 23-25. The Conference, which was held in place of the usual summer study, was one of many opportunities for potential users to discuss and be involved in PEP planning.

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## SUPERCONDUCTING ACCELERATOR - ESCAR

G. Lambertson in charge

D.S. Anderson, P.C. Bean, A.R. Borden, R.A. Byrns, J.G. Carrieri, R.J. Caylor, W.W. Chupp, W.F. Eaton, G.A. Gachis, S. Gil, W.S. Gilbert, E.C. Hartwig, E.H. Hoyer, C.P. Johnson, E.L. Knight, S.J. Knoll, L.J. Laslett, I.W. Lee, K.H. Lou, R.M. Main, R.B. Meuser, G.A. Newell, J.M. Peterson, U.A. Rabe, J.B. Rechen, R.V. Schafer, L. Smith, F.L. Toby, F. Voelker, H.W. Vogel, R.P. Warren, E.R. Wellington, G.W. West, W.A. Wilson, R.C. Wolgast, J.A. Zelver.

Construction of ESCAR, the experimental superconducting accelerator ring, progressed substantially during this reporting period. ESCAR's purpose is to gain timely, full-scale experience in the construction and operation of the world's first fully cryogenic proton accelerator. It is and will be an invaluable research tool in creating the next generation of very powerful accelerators already planned at several laboratories around the world. Superconductivity is the only technology that can minimize the escalating costs of real estate and energy that are required for these new machines.

When completed, ESCAR will accelerate protons from an existing 50 MeV linear accelerator to above 4 GeV energy. The device offers considerable flexibility for mounting accelerator experiments, allowing storage of tightly bunched high-current beams, and even acceleration of heavy ions.

The breakthrough represented by ESCAR is the use of superconducting magnets for all of the main accelerator ring's 24 dipoles, 32 quadrupoles and numerous trim coils. Although the technology required to build superconducting magnets has been advanced at many laboratories over the last several years, ESCAR is the first attempt to build a complete ring of reproducible, high quality superconducting magnets in an operating accelerator with all of the necessary support systems.

Headquarters for ESCAR is in Building 47, with the rest of the Advanced Accelerator Studies Group. The accelerator site is an area at the aborth end of the Bevatron experimental hall.

## Magnets

The magnets and other components of the ring are fabricated in the LBL Mechanical Shops. By October 1977, 12 of the dipole magnets had been completed and extensively trained and tested, with the parts for the next group of magnets being procured or constructed.

## Ring Installation

Two quadrant corners of ESCAR, consisting of six dipole magnets each, have been installed at the final ring site. Survey and alighment of these magnets of their support girders is complete. Each group of six dipoles is connected with a common bore tube, insulating vacuum jacket, nitrogen-cooled shield and helium circuit. Liquid helium transfer lines, based on the 20-foot test design, have been run between the ESCAR refrigerator and Quadrant IV.

## Cryogenics and Refrigeration

A new refrigeration facility, Building 56, was finished next to the accelerator ring. It houses the large helium refrigerator/liquefier which supplies ESCAR's refrigeration requirement of 1500 watts of heat removal at 4.2° Kelvin. Most of the cooling capacity is directed to maintaining magnet coils in the superconducting state, while the remainder is used to cool cryopumps in the warm straight sections between magnet quadrants. A mixture of gaseous and liquid helium will be circulated through all the magnet cryostats in series. This two-phase system, a unique feature in the ESCAR design, is expected to be ahle to remove more heat than alternate schemes.

After test runs of the compressors, some modifications were made and one compressor was replaced by the manufacturer. Tests of the refrigerator are set for November 1977 with the 12 installed dipoles as a realistic load.

## Vacuum

The fabrication of ESCAR provides an opportunity to operate an accelerator with vacuum chamber walls in part at 4.5° Kelvin. The condensation of gas on this surface will provide a pressure below $10^{-11}$ torr, as needed for modern storage rings. Instrumentation for the testing of the bore of Quadrant IV was in place at the end of the fiscal year. Auxiliary vacuum systems for insulation of the cryostats and transfer lines were being assembled.

## Electrical

Much of the electrical effort during this period has been on the helium refrigerator controls and instrumentation. Two dipole magnet power supplies have been tested with conventional magnet loads. Quench-protection circuitry has been fabricated, with testing in progress.

## Major Tests and Schedule

Test operation of the assembled system of 12 magnets cooled by the series two-phase flow is to proceed at the beginning of FY 78. More magnets will be added to the ring as they are produced, with completion of the main ring projected for 1979.

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1977 Particle Accelerator Conference, March 16-18, 1977, Chicago, Ill.

ESCAR Advisory Committee, Jan. 28-29, 1977, LBL.

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# HEAVY ION FUSION

D. Keefe in charge

J. Bisognano, S. Chattopadhyay, W. Chupp, A. Faltens, A. Garren, F. Goss, E. Hoyer, D. Judd, G. Lambertson, L.J. Laslett, C. Leemann, J. Meneghetti, D. Neuffer, S. Rosenblum, F. Selph, J. Shiloh, L. Smith, J. Staples, D. Vanecek.

The Heavy Ion Fusion Program at Lawrence Berkeley Laboratory, officially funded by ERDA in late March 1977, was spurred by indications that an intense heavy ion accelerator may offer significant advantages over laser or electron beam systems as an igniter in an inertial confinement fusion power plant. An ERDA Summer Study of Heavy Ions for Inertial Fusion was held in Berkeley in July 1976, and a study proposal, "Heavy Ion Fusion - Proposal for a Program at Lawrence Berkeley Laboratory," was prepared in September 1976. Argonne and Brookhaven laboratories are also involved in the national effort in heavy ion fusion.

The direction of research and development in the program at LBL has been to single out the novel problems in accelerator design that must be solved to achieve a pilot power plant driver of 1 MJ and 100 TW, and for the intermediate Heavy Ion Demonstration Experiment (HIDE). Among those challenges are the need for large charge per pulse (or high current) and high beam power on target. The required currents are one to two orders of magnitude beyond our present experience for heavy ions, and the power even more, which presents an interesting twist for the accelerator scientist who normally tries to provide the lowest possible beam power for experimental users.

An intensive theoretical program was launched to investigate the conditions for safe propagation of intense beam currents in focusing systems, such as continuous and interrupted solenoid lense systems, and quadrupole strong focusing systems. Using computational techniques, much new information has been generated on space-charge-dominated transport phenomena. Work with a new LBL particle numerical simulation code and an existing one at the Naval Research Laboratory progressed well.

The presence of the Bevalac as an operating heavy ion linac and synchrotron facility and the expectation of its imminent uranium ion capability offers an outstanding resource in staff expertise. Our unique experience in having built and operated an induction linac is also particularly applicable to this effort. We are now participating in studies of low-beta RF accelerating structures and ion sources suitable for heavy ion fusion. The requirements for an RF injector for HIDE are only a step away from those of the SuperHILAC third injector, soon to be constructed. Work on a multi-aperture ion source has progressed to the point of demonstrating currents of heavy ions suitable for HIDE, though not yet for a power plant.

An experimental program on intense beam propagation was initiated with heavy ions to avoid difficulties in extrapolating data from smaller experiments with lower mass particles. While multi-ampere beams of gaseous ions such as xenon have been produced at LBL with CTR sources, we decided to construct a large aperture contact-ionization source of $Cs^{+1}$ to escape gas load problems. A drift tube system employing pulse-power units accelerates a beam of about one ampere to 2-3 MV. A quadrupole transport system of some 24 magnets (12 periods) will be installed to study transport characteristics such as emittance degradation. Much of the required equipment has been borrowed.

Several scientists from other institutions in the United States and Europe have participated in the program for various periods of time.

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Workshop on Low-Beta High Intensity Accelerating Structures, June 1-3, 1977, LBL.

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