LBL-5370

ACCELERATOR DIVISION

ANNUAL REPORT

January - December 1975

Lawrence Berkeley Laboratory
University of California
Berkeley, California

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UC-28 Particle Accelerators
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ACCELERATOR DIVISION

ANNUAL REPORT

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E. J. Lofgren

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Lawrence Berkeley Laboratory
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January - December 1975

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FOREWORD

The year 1975 marked a turning point for the Accelerator Division. A major reorganization changed the Division's operational outlook from a single focus to a three-dimensional scope. Bold schemes came to fruition, either by demonstrated production of new beams, as in the case of the Bevalac, or by Presidential and Congressional funding approval, for the exciting new Positron-Electron Project (PEP).

The reorganization of July 1, 1975 expanded the Accelerator Division to include the SuperHILAC, transferred from the former Nuclear Chemistry Division, and the 184-inch Synchrocyclotron, from the Physics Division. The consolidation of these two accelerators with the Bevatron under one operational structure offers the opportunity to combine efforts on common goals and problems, and to deliver beams for a variety of research purposes at energies from a few MeV to 2 GeV per nucleon.

The roles of the Bevatron and the SuperHILAC remain virtually unchanged, and include a strong, unified approach to efficient Bevalac operation. The 184-inch, on the other hand, has now been dedicated to sole use as a medical accelerator. The development of protocols for treatment of cancer in selected sites is being diligently pursued with the 184's 900 MeV helium ion beams, while the treatment of human patients with pituitary diseases continues as before. With full scale cancer treatment trials expected to begin at this machine in 1976, the 184-inch has taken on an intriguing new identity.

The successful and reliable operation of the Bevalac in the latter half of the year were welcome testimony to the world's first production of high intensity, high energy heavy ion beams. The system, which links the SuperHILAC as an injector of high intensity beams into the Bevatron, has opened an entirely new realm of nuclear science and biomedical research. The concurrent installation of computer control at both machines makes possible time-sharing of beams from the SuperHILAC, resulting in minimum disruption of that facility's experimental schedule. A proposal to upgrade the injection potential at the SuperHILAC and to install an ultra-high vacuum liner within the Bevatron ring would permit the acceleration of every naturally occurring element up to uranium.

Authorization and funding of PEP, the LBL-Stanford 15 GeV colliding beam machine, is tremendously rewarding. With initial funding allocated in Fiscal Year 1976, and 25 million in construction monies for FY 77, the project is well underway. Design work has been concentrated on the magnet lattice and magnet models, and monitoring and control systems as well as other major aspects of the structure. The crucial considerations in designing the facility's experimental areas were examined by the 1975 PEP Summer Study participants.

Last year, too, work progressed on the Experimental Superconducting Accelerator Ring — ESCAR — which is to be built next to the Bevatron. Although funding of this project is not yet at the desired level, the design and construction of the superconducting ring magnets and their cryogenic system, and the cryogenically pumped high vacuum system have proceeded apace. After extensive testing of several models, a pulsable superconducting magnet was assembled with excellent field quality and low loss.

The Superconducting Program made strides in its work, most of which has been directed toward developing the dipoles and superconducting cable for ESCAR. But the group also has expended considerable effort in evaluating superconducting materials and solenoids created by others within LBL.

In all, the year has been a full and satisfying one. Our staff, both those directly and indirectly employed by the Division, have performed with dedication and excellence. The indications for the future, based on current activities and innovative proposals, are bright indeed.

ACCELERATOR DIVISION

Contents

ACCELERATOR OPERATIONS

ADVANCED ACCELERATOR RESEARCH AND DEVELOPMENT

ACCELERATOR OPERATIONS

H. A. Grunder

Group Leader

Bevatron/Bevalac

R. Force and *H.A. Grunder* in charge

R.V. Aita, J. Alonso, R.L. Anderson, E.A. Benson, D.A. Bentsen, J.P. Brannigan, R.W. Brokloff, A.H. Brown, D.M. Cowles, K. Crebbin, E.E. Demartile, H.M. Ellison, R.S. Everett, C.S. Feole, R. Force, J.R. Guggemos, D.W. Hickman, J.M. Johnson, O. Jones, J. Kalnins, C. Leemann, F.H.G. Lothrop, R.M. Miller, W.W. Olson, J.M. Palmatier, D.D. Pohl, R.E. Purvis, R.M. Richter, D.W. Schmeyer, J.W. Staples, E.W. Stewart, M.M. Tekawa, J.E. Tommaney, G.E. White, K.E. Williams, C. Weber, E. Zajec.

The Bevatron/Bevalac is operated, maintained, and continually improved as a national research facility for studies in nuclear science and in biology and medicine. Recent modifications have brought the 21-year-old synchrotron to the threshold of tremendously exciting new studies as the world's most powerful heavy-ion accelerator.

In its Bevalac configuration, the machine capitalizes on the coupling of the SuperHILAC to the Bevatron via a 175-meter beam line. The SuperHILAC acts as an injector to provide the Bevatron with high-intensity beams of ions as heavy as argon. At the same time, the SuperHILAC is capable of delivering heavy-ion beams to its own group of experimenters through a computer-linked, time-share system of operation.

Research efforts using the Bevalac have included a broad spectrum of nuclear science and cosmic-ray-simulation experiments, as well as intensive studies in biology and medicine aimed principally at diagnostic techniques and preclinical therapy studies for some forms of cancer.

OPERATION AND PROGRAMS

Severe budgetary limitations hampered the research programs of the Bevatron/Bevalac this year. For the first four months there was no operation. The next 4 months saw operation at 13 shifts per week, with another 2 shifts per week devoted to maintenance and machine studies. The final four months of the year were spent with operation at 19 shifts per week and maintenance and machine studies at 2 shifts per week. The additional 6 shifts resulted in an immediate 45% gain in the amount of time available for the research programs, and this virtually doubled the amount of research accomplished in any one week. The 21-shift effort was made possible by Department of Commerce emergency employment funds, which allowed the hiring of a few additional technicians. Their presence brought the operating staff just to the level which made full time operation possible, but by no means comfortable.

Research operations for the year were allocated roughly one-third to biology and medicine and two-thirds to nuclear science. Actual hours were 2486 for nuclear science and 388 for biology and medicine. The latter program, which is predominately devoted to heavy-ion research at the Bevalac, suffered from early difficulties with the Bevalac connection. However, the total number of research hours was not affected, since the nuclear science program could beneficially exploit the lighter ions produced with the Bevatron's own injector. The effective reliability of the Bevatron/Bevalac for the year was 90.4%.

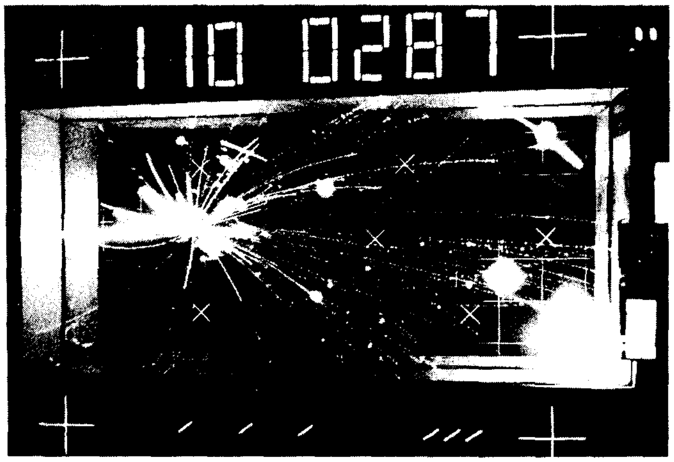
During the course of the year the Bevalac neon capability was improved substantially, and a good argon beam was delivered in December. The table below lists the ions available and their intensities.

Beam Performance - Intensity of Extracted Ions

Ion	Particles per pulse ($\times 10^{10}$)
Proton	200
Alpha	5
Carbon	0.2
Nitrogen	0.2
Oxygen	0.1
Neon	0.2
Argon	0.01

Nuclear Science Program

The Bevatron/Bevalac served 21 experiments this year, of which 5 were completed. Major experiments included surveys of heavy-ion fragmentation products (Experiment 162H: LBL, Heckman; UCSSL, Greiner and Experiment 205H: LBL, Steiner), diffractive dissociation (Experiment 209H: LBL, Kerth), space instrument calibrations, and scattering experiments (Experiment 168: UCLA, Igo; LBL, Perez-Mendez). The streamer chamber facility was used by a collaborative experiment (Experiment 228H: UCR, Poe; LBL, Schroeder and Steiner) to explore particle production and fragmentation by heavy ions. One of the most spectacular events recorded in the chamber is shown in Figure 1.



XBB 7511-8445

Fig. 1. Spectacular collision event. A 1.8-GeV/nucleon argon nucleus strikes a lead oxide target. Photograph is from a UC Riverside/LBL streamer-chamber experiment to study collisions of heavy nuclei at relativistic energies.

This multiprong event was produced by 1.8-GeV argon ions impinging on a lead target and gave rise to approximately 87 different tracks, each of them a charged particle. The large multiplicity of tracks indicates that virtually complete annihilation of the argon and lead occurred.

With the advent of the argon beam, several experimenters began to explore the possibility of providing experimental evidence to validate the Lee-Wick theory of superdense nuclei. B. Price of UC Berkeley, A. Poskanzer of LBL, and E. Schopper of Frankfurt Univ., Germany, were principal investigators on separate experiments (see also the Bevalac users meeting below).

Biology and Medicine Program

Thirty-three experiments were run for the Biology and Medicine Program at the Bevatron/Bevalac in 1975. Most of these were concerned with the effects of heavy ions (carbon through argon) in tissue. Relative biological effectiveness (RBE) and the oxygen enhancement ratio (OER) were measured for various cell systems exposed to several species of ion, and the late (delayed) effects of radiation were explored. Some experiments were done to relate space-flight data to a controlled ground-based experiment. Twelve of the experiments were completed this year.

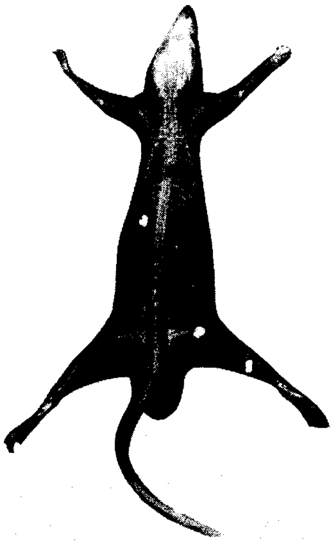
Diagnostic techniques are also being explored at the accelerator. C. Tobias of LBL and E. Benton of the Univ. of San Francisco used a Bevatron carbon beam and a Lexan stack as a detector to provide corroborative diagnosis of breast tumors in several patients. An illustration of the possible effectiveness of the technique is shown in Figure 2, which compares an x-ray of a rat with a neon radiograph of a rat. The x-ray used standard procedures. The radiograph used a series of Lexan foils to generate a three-dimensional image, and a single processed foil is shown as an example of the system.

Beam intensities at the beginning of the year were sufficient for preclinical studies, but insufficient for possible therapeutic applications. By the end of the year, intensities had improved to the point where radiation therapy can be done as soon as the preclinical problems have been solved.

ACCELERATOR AND FACILITY IMPROVEMENTS

Minibeam

A new biomedical research facility is being built on the roof of channel II of the external particle beam. This facility, called the "Minibeam," has been designed to observe directly the effects of a few ions traversing tissue. A vertically inclined beam line has been established which will allow heavy ions to pass through a microscope stage mounted on a vibration-isolated platform. Electrical isolation is also provided by means of a completely shielded room with special feed-throughs for power and signal cables. Changes



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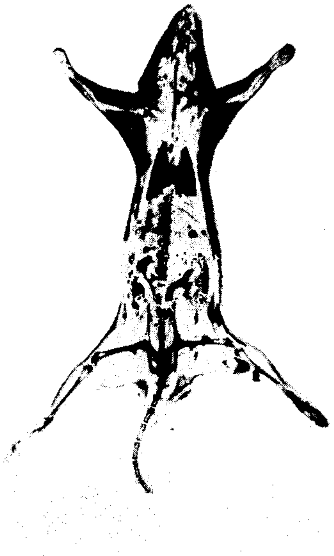

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Fig. 2. X-ray of adult rat (left) compared with a selected Lexan-foil radiograph of the same rat (right). The radiograph used 400-MeV/amu neon particles from the Bevalac to produce images in a stack of Lexan foils downstream of the rat. Dense features such as bone are imaged in the closest foils; organs become visible at more distance. The result is a high-resolution model of the density distribution of the specimen which is based on the variation in heavy-ion stopping power of the tissues.

in the galvanic potentials of cells and tissues with heavy-ion irradiation will be able to be recorded. This facility will be ready for use in mid-1976.

Computer Control

A major aspect of Bevatron/Bevalac improvements focuses on achieving a machine of great versatility, not only in terms of available beams, but also in terms of the time required to shift from one type of experiment to another. The goal is a half-hour changeover time, total, between worst-case experimental situations. The necessary tools to reach this goal are a set of modern small computers, a rapid-access data storage facility, and an interface network designed to set and maintain all the changeable parameters, from guide-field magnetic strength and repetition rate to beam delivery element controls.

This goal is being realized with the installation of a ModComp computer complex adjacent to the main control room of the Bevatron/Bevalac. A central processor will supervise the operation of several task-oriented units, each of which monitors and controls a specific section of the accelerator facility. The central processor and one task-oriented unit have been installed and are now being used to control the transfer line — that part of the Bevalac system which carries ions from the SuperHILAC to the Bevatron — and one experimental beam line, beam 37. The major programming for the complex is being developed in conjunction with the SuperHILAC, where the same type of control and monitoring is also being installed.

Uranium Capability

The resounding success of the Bevatron/Bevalac as an accelerator of heavy ions through argon to relativistic energies led to a study exploring the feasibility of accelerating ions up to uranium. Two major improvements were found necessary. The first is an injector of high-intensity, high-mass ions, and the second is a high-quality vacuum in the transfer line and the Bevatron ring. A preliminary design for each of these has been undertaken, and funds have been applied for.

The new injector facility at the SuperHILAC would consist of a Cockroft-Walton unit followed by a Wideröe linear accelerator to produce particles of the proper velocity and charge state for acceptance into the first tank of the SuperHILAC. Vacuum quality at the SuperHILAC is satisfactory.

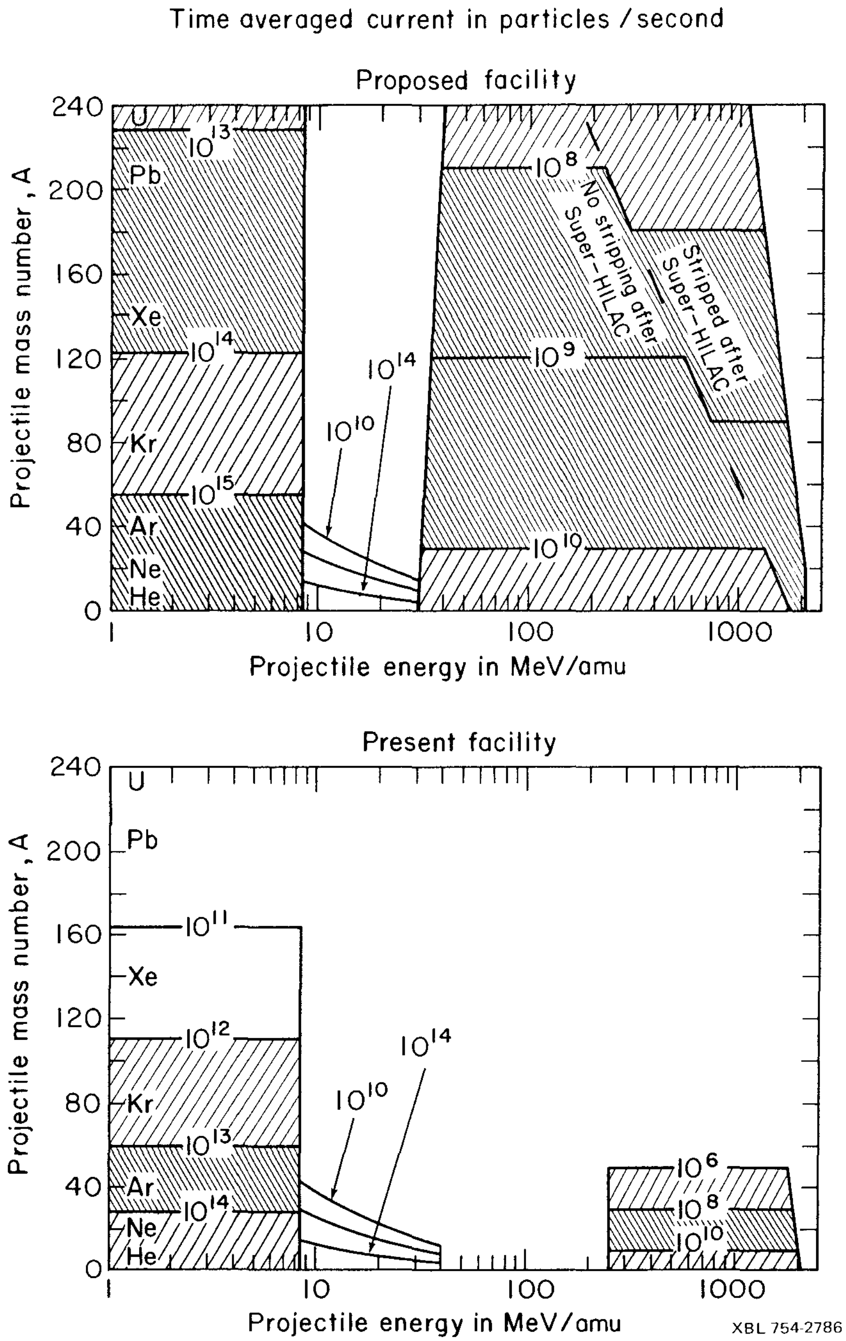

Fig. 3. Available heavy-ion beams from the present and proposed Bevalac-SuperHILAC facility. The major improvements will come from a new Bevatron vacuum liner and a new injector for the SuperHILAC.

Transport of the ions to the Bevatron would be through the existing transfer line, with some modifications required to handle higher mass particles.

The Bevatron's present vacuum system, which includes oil diffusion pumps, liquid nitrogen panels, and a gaseous helium panel at 20°K, is inadequate to accelerate the partially stripped very heavy ions to be transported from the Super-HILAC. The Bevatron vacuum must be increased 100-fold to the 10^{-9}-Torr range in order to avoid substantial beam losses due to recombination of the circulating ions with residual gas atoms. This can be achieved with the installation of a cryogenically pumped liner inside the present vacuum system. Measurements of the constituents of residual gases and calculations indicate that a pressure of about 2×10^{-9} Torr is economically achievable and will be satisfactory for uranium acceleration at the Bevatron/Bevalac. Figure 3 compares the characteristics of the heavy-ion particle beams at the proposed improved Bevalac/SuperHILAC with the present beam characteristics.

Heavy-Ion Spectrometer

As future improvements to the Bevatron/Bevalac extend its capability to accelerate heavier nuclei, expected heavy-ion experiments will evolve toward consideration of multiparticle final states, large-momentum-transfer processes, possible shock waves and related phenomena, and target and projectile fragmentation at intermediate and relativistic energies. Experiments of this nature will require construction of at least one heavy-ion spectrometer system (HISS) at the Bevalac.

Accelerator users, both within LBL and from outside users groups, have been solicited for their ideas and participation in order to specify the parameters of HISS. To define the physics objectives, two committees have been established: the Committee on High-Resolution Work and the Committee on Lower Resolution, Large Solid Angle, and Multiparticle Detection and Identification Capability.

USERS MEETING

A Bevatron/Bevalac users meeting was held at LBL on 15 February 1975. Approximately 100 scientists from U.S. universities and laboratories and from several European institutions attended. The program detailed the progress toward completion of the full-scale Bevalac complex. Past and present research work with relativistic nuclei was reviewed with an eye toward future second-generation experimental work at the Bevalac.

The physical science aspects of heavy-ion work were presented as well as the applications to biology and medicine. Recent speculations by T.D. Lee, W. Greiner, and others have suggested the possibility of observing new nuclear phenomena in high-energy, heavy-ion collisions. Professor E. Schopper (Univ. of Frankfurt) may have found the first direct evidence for the existence of these phenomena last summer when he observed possible nuclear shock waves produced at the Bevalac in the collision of an oxygen beam with a silver nucleus. Further experiments to test these ideas look exciting.

RESEARCH COORDINATION

With the development of more and more interconnections between the Division's three accelerators and their research programs, it has become mandatory to coordinate all machine and experimental operations through a single office. The Accelerator Research Coordination Office, located at the Bevatron, has been established to handle all accelerator scheduling to assure program compatibility for experimenters. The office staff offers expertise in nuclear science and biomedical experiments as well as other activities and services of interest to accelerator users.

PUBLICATIONS AND PRESENTATIONS

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J.J. Barale and *K.C. Crebbin*, Spill Control and Intensity Monitoring for the Bevatron-Bevalac External Particle Beams, LBL-3371, presented at the U.S. National Particle Accelerator Conference, Washington, D.C., March 1975; IEEE Trans. Nucl. Sci. NS-22(3), 1052 (June 1975).

J. Barale, R. Force, H. Grunder, J. Guggemos, G. Lambertson, C. Leeman, F. Lothrop, R. Morgado, R. Richter, D. Rondeau, F. Selph, J. Staples, M. Tekawa, and *F. Voelker*, Performance of the Bevalac, LBL-3366, presented at the U.S. National Particle Accelerator Conference, Washington, D.C., March 1975; IEEE Trans. Nucl. Sci. NS-22(3), 1672 (June 1975).

M. Clinnick, J. Greer, J. Guggemos, R. Kilgore, and *D. Rondeau*, Digital Controlled Frequency for Synchrotron Acceleration, LBL-3370, presented at the U.S. National Particle Accelerator Conference, Washington, D.C., March 1975; IEEE Trans. Nucl. Sci. NS-22(3), 1261 (June 1975).

J. Cuperus and *R. Morgado*, A Multi-Wire Chamber System for Heavy Ion Beam Monitoring at the Bevalac, LBL-3364, presented at the U.S. National Particle Accelerator Conference, Washington, D.C., March 1975; IEEE Trans. Nucl. Sci. NS-22(3), 1561 (June 1975).

H.A. Grunder, Status and Outlook for Heavy-Ion Accelerator Systems, LBL-3693, presented at the U.S. National Particle Accelerator Conference, Washington, D.C., March 1975; IEEE Trans. Nucl. Sci. NS-22(3), 1621 (June 1975).

C. Leemann, R. Morgado, and *R. Sah,* A New High Intensity K-Beam at the Bevatron, LBL-3369, presented at the U.S. National Particle Accelerator Conference, Washington, D.C., March 1975; IEEE Trans. Nucl. Sci. NS-22(3), 1484 (June 1975).

SuperHILAC

R. Nemetz and *F. Selph* in charge

A.C. Barnes, G.S. Boyle, G.M. Byer, N.L. Cash, R.C. Coates, B.F. Gavin, R.E. Gisser, M.I. Green, C.W. Hatch, L.B. Hill, C. Hitchin, B.M. Jeung, R.M. Johnson, J.F. Smith, D.A. Spence, R.R. Stevenson, H.K. Syversrud, M. Wolfe.

IMPROVEMENTS

The year was an eventful one for the SuperHILAC. An extensive effort to increase the reliability and voltage holding capabilities of Adam, the 2.5-MV injector, was completed in December 1974, and Adam was used to deliver krypton beams in January.

A new "puffer" valve system was installed on the Adam ion source early in February, in order to more easily attain the very low gas flow rates needed for running heavy ions. This was very successful.

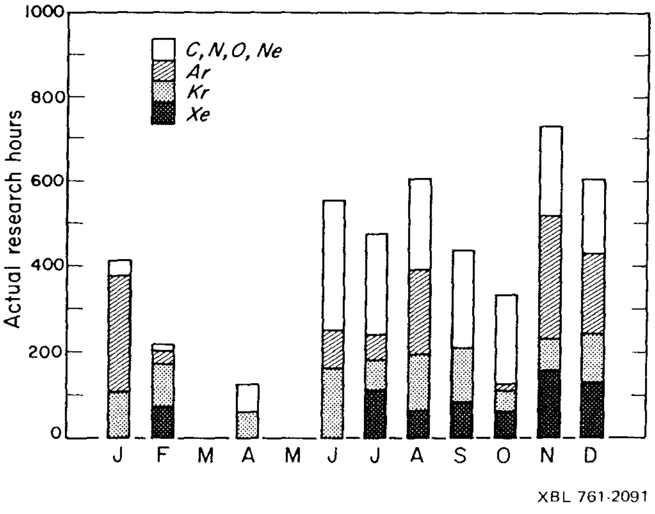
In November, tests were conducted with a ^{197}Au beam from the Adam sputter ion source. A new ring geometry was used for the sputtering electrode and resulted in three-times the output of the higher-charge-state heavy ions compared with the use of the simple cup electrode.

Modifications were begun in February to ready the SuperHILAC for computer control and time-sharing operation. The first ModComp units had just arrived. Computer interface hardware was installed to control and monitor the rf gradient and phase in the eight accelerating tanks and for the pulsed magnets. The required control room changes were so extensive that complete conversion was not attempted at the time. Instead, the existing control room was enlarged and modified to permit two control stations to be manned, and the major rebuilding was scheduled for the following year.

OPERATIONS

After operation in January and two months of shutdown, the machine was turned on, primarily for test purposes, for three weeks in April. Two beams were accelerated together for the first time. After this, the shutdown work was completed, and late in May the accelerator was ready to deliver beam to experimenters. During the remaining six months of the year the accelerator ran for experiments. From the start, it was clear that the time-sharing operation was much more difficult than any previous operation of the SuperHILAC. The operators had to keep abreast of many more parameters than before, and tuning was much sharper, with less room for error. For these reasons some beam intensities were frequently low in the first week of operation; however by September it had been demonstrated conclusively that beams of krypton and neon, both of adequate intensity, could be time-shared together.

Operations for 1975 are summarized in Figures 1 through 4. The number of actual research hours devoted to the ion species studied (Fig. 1) shows a general increase during the year. In Figure 2, the actual research hours and the scheduled crew time are compared. The crew time includes all of the time that the machine is available for use, plus scheduled maintenance.



XBL 761-2091

Fig. 1. Ions used for research at the SuperHILAC in 1975.

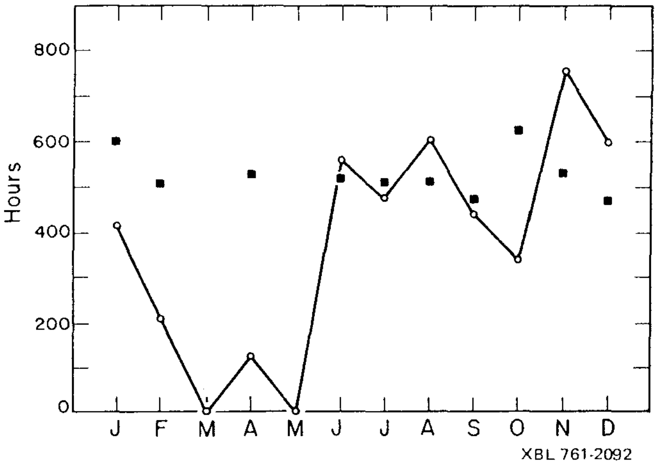


Fig. 2. Monthly accounting of research hours in 1975. Open circles are total actual research hours; closed squares are total scheduled crew time. March, part of April, and May were shutdown months.

The month of January represents "best" operation before the introduction of time-sharing Beam was delivered to experimenters for 70% of the available machine time; this is good "innage" time for a research machine such as the SuperHILAC, considering the necessity for source changes, the setups required for new ion species, and so forth. In contrast, in June, the first month with full time-sharing operation, the number of research hours exceeded the available machine time. This is simply a result of the multiplicity of beams available with time-sharing, which permits two simultaneous experiments.

November was an unusually productive month for research at the SuperHILAC. Beams of argon and xenon were time shared with acceptable intensities, as were beams of neon and krypton. The number of actual research hours logged in November was 733.5 out of a total of 484 hours that the machine was available for research; this meant an effective multiplicity of 1.52.

The ratio of actual research hours to scheduled research hours (Fig. 3) is here called research efficiency. If there were no breakdowns, unscheduled maintenance, or source changes, this ratio would be 100%. Most months it ranged between 70 and 90%, with two unusually poor months below 60%.

Some of the research hours are spent in setup; this includes such processes as getting equipment ready, switching monitoring from one beam line to another, and tuning. Thus the proportion of research hours in which the beam is on target, called here the target efficiency, is a useful indication of accelerator performance. It can be seen in Figure 4 that month by month, during the year, this target efficiency remained relatively constant within the range of 60 to 70%.

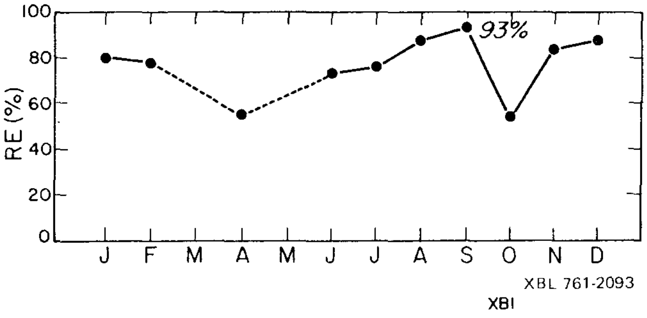


Fig. 3. The research efficiency (RE) of the SuperHILAC in 1975, expressed as the ratio of actual research hours to scheduled research hours.

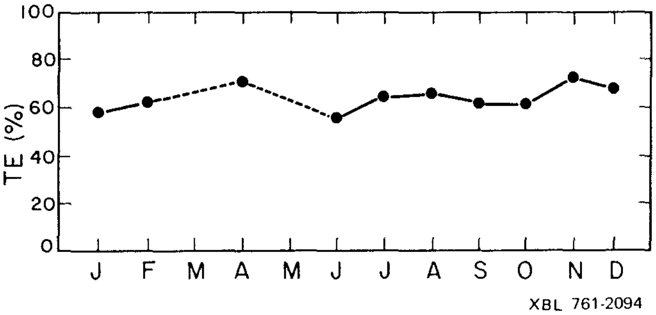


Fig. 4. The proportion of research hours in 1975 in which the beam was actually on target — known as the target efficiency (TE).

USERS MEETING

The first SuperHILAC users meeting took place 15 — 17 December 1975. About 40 scientists from other laboratories and universities in the U.S., Canada, and Europe came to the meeting, as did a slightly larger number of LBL personnel. There were several talks on the present and anticipated operation and capabilities of the accelerator. Another session treated instrumentation for heavy-ion studies — namely, recoil spectrometers, large-area detector arrays, time-of-flight techniques, and detector telescope identifiers. One session was devoted entirely to elastic, deeply inelastic,

184-Inch Synchrocyclotron

L. Kanstein in charge

J. MacMullen, F. Yeater.

The 184-inch synchrocyclotron is operated principally for the benefit of programs in LBL's Division of Biology and Medicine, including the medical therapy program under the direction of Drs. Joseph Castro and Charles Linfoot. Medium energy physics, formerly a mainstay of the 184-inch operating program, has been terminated as of 30 June, an action which was unwelcome but necessary in view of the funding priorities expressed at the national level.

On 1 July responsibility for operation and administration of the 184-inch synchrocyclotron was transferred from the Physics Division of the Laboratory to the Accelerator Division. As one of the three accelerators in the Accelerator Division, the 184-inch synchrocyclotron will continue its important role in LBL's contributions to the scientific community.

OPERATION AND PROGRAMS

For six months ending in June, the synchocyclotron was operated an average of 324 hours per month. Most of this time was for muon physics, some $p\alpha$ elastic scattering, and $pp \to pp\gamma$ experiments, along with cave and beam development for biomedical work. Other time was devoted to biology and medicine; the major thrust was pituitary therapy.

Beginning in July, machine operation was limited to no more than five shifts per week, which were used for biomedical therapy and development of a large-field alpha beam in the medical cave. During the second six-month period of 1975, diseases of the pituitary were treated with the small-field alpha beam, and several patients with large tumors were treated with the new larger beam.

PUBLICATIONS AND PRESENTATIONS

K.M. Crowe, T.F. Budinger, J.L. Cahoon, V.P. Elischer, R.H. Huesman, and *L.L. Kanstein,* Axial Scanning with 900 MeV Alpha Particles, LBL-3812, presented at the U.S. National Particle Accelerator Conference, Washington, D.C., March 1975; IEEE Trans. Nucl. Sci. NS-22(3), 1752 (June 1975).

K. Crowe, L. Kanstein, J. Lyman, and *F. Yeater,* A Large-Field Medical Beam at the 184-Inch Synchrocyclotron, LBL-4235 (August 1975).

ADVANCED ACCELERATOR RESEARCH AND DEVELOPMENT

T. Elioff and G. R. Lambertson

Group Leaders

Positron-Electron Project

T. Elioff in charge

T. Ahmadvand, R.T. Avery, R.A. Belshe, E. Berget, V. Brady, T. Chan, V. Cherniak, E.R. Close, J.S. Colonias, D. Curtis, V. Elischer, G. Eno, A. Faltens, A. Garren, S. Goss, J.T. Gunn, K. Halbach, E.C. Hartwig, L.T. Jackson, A.S. Kenney, A.A. Lake, J.J. Laslett, T. Lauritzen, D. Lippert, C. Macdonald, S. Magyary, R.M. Main, Y. Maruyama, J.B. McCaslin, V. More, P. Oddone, J.M. Peterson, C.D. Pike, D. Reimers, D. Rondeau, R. Sah, A.M. Sessler, L. Smith, J. Staples, B. Tafelski, J.T. Tanabe, R.H. Thomas, J. Zelver.

The Positron-Electron Project (PEP) is a colliding-beam storage-ring system that will be at the forefront of high-energy physics. It is a larger and higher energy version of the SPEAR storage ring, on which the most exciting basic discovery of the past decade, the unexpected ψ-particle family, was made.

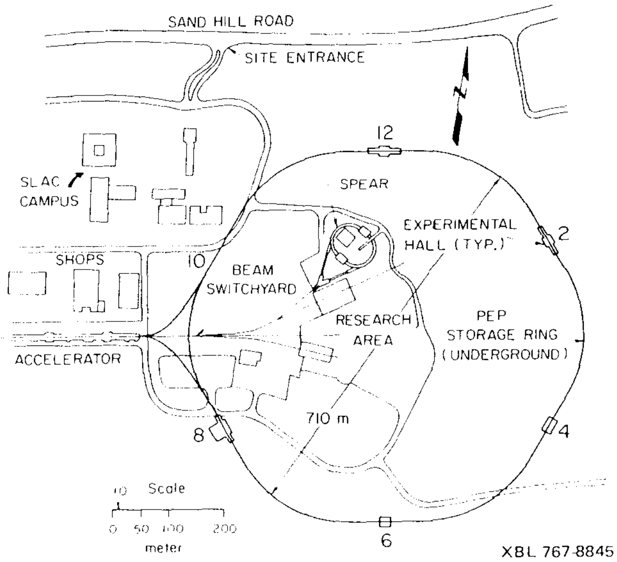
PEP is a joint undertaking by the Lawrence Berkeley Laboratory of the University of California and the Stanford Linear Accelerator Center (SLAC) of Stanford University. This collaboration was born informally in 1971 as a result of common interest both in the high-energy physics and in the question of whether such a high-energy ring system were feasible. By 1973 the feasibility was established, and a formal agreement signed by the Regents of the University of California and the Trustees of Stanford University provided the joint financial and management basis for the project.

A proposal to build an 18-GeV electron-positron storage-ring facility at SLAC was submitted to the Atomic Energy Commission (now the Energy Research and Development Administration-ERDA) in 1974. In 1975 the Congress voted, and President Ford approved, 11.9 million dollars in authorization and 2.9 million in construction funds for PEP in FY 1976. Later in 1975 President Ford recommended 25 million in construction funds for FY 1977 and full authorization at 78 million. Thus PEP has been formally launched and now is well underway.

TECHNICAL DESCRIPTION

The positron-electron storage ring is designed to operate at a maximum luminosity (reaction rate per unit reaction cross section) of 10^{32} cm^{-2}sec^{-1} per interaction area at 15-GeV beam energy and at greater than 10^{31} cm^{-2}sec^{-1} luminosity between 5 and 18 GeV.

The average beam current required at maximum luminosity is 92 mA in each beam. It will be concentrated in three small, equally spaced bundles in each of the counter-rotating beams. Thus collisions between the two beams occur only at six points in the ring, which will be at the centers of the six straight sections shown in Figure 1. Five of these six interaction regions will be housed in experimental halls of various designs where the high-energy-physics experiments will be carried out. The ring has 12 sections in all, 6 straight and 6 bending; the straight sections are numbered 2, 4, 6, 8, 10, and 12.



XBL 767-8845

Fig. 1. Layout of the PEP ring superimposed on an aerial schematic of the SLAC site. The straight sections of the ring, which contain the interaction regions, are numbered.

The sixth interaction region, in section 10 (northwest), is intended mainly for experiments in accelerator physics and possibly some high-energy physics on a modest scale.

The magnetic guide field that maintains the two beams in the hexagonal ring is an alternating-gradient, separated-function lattice, in which uniform-field bending magnets alternate with focusing and defocusing quadrupole magnets. Each of the six arcs of the ring has 16 regular lattice cells with about a 45-degree betatron phase shift per cell both horizontally and vertically. Each of the straight sections has about a 360-degree phase shift in each direction and is 117 meters long. The total circumference is 2200 meters.

The storage ring is to be filled with electrons and positrons from the 20-GeV linac at SLAC and it is situated in a tunnel just east of, and some 11 meters below, the linac. This powerful and versatile linac can fill the storage ring throughout its operating range in a matter of minutes — a time short compared with the typical beam lifetime in the ring. The beams from the linac are brought to the storage ring along two curving transport lines, which each terminate in a straight section of the ring. The electron line terminates in section 8 (southwest) and the positron line in section 10 (northwest).

The high-energy physics involved with electron-proton interactions is fully as interesting as that of electron-positron interactions. To ensure the future capability of electron-proton colliding-beam research, the PEP system is being designed so as to preserve the possibility of adding a superconducting 200-GeV proton storage ring in the tunnel at a later time.

PROGRESS IN 1975

Theory

A basic limitation in achieving high luminosity in a colliding-beam system is the beam-beam interaction, in which each beam produces a focusing action—or shift in the betatron tune—on the other beam. This effect is being studied by means of computer simulation calculations. It has been found that various effects associated with synchrotron oscillations (modulation of vertical and horizontal tunes, early/late arrivals) can lead to substantial growth of transverse amplitude under certain conditions and may explain the observed beam-beam limits.

A beam bunch when traversing an rf accelerating cavity tends to excite the cavity in its fundamental and higher modes. The energy loss to the fundamental mode is easy to anticipate and to include in the basic design of the acceleration system. The higher-mode losses, on the other hand, are usually difficult to anticipate and can cause significant heating and loss of power. In general, wherever the beam encounters a discontinuity in the vacuum system, it will suffer such higher-mode losses. If one uses a semiempirical expression for the losses observed in the SPEAR-II storage ring, it appears that for the presently assumed radiofrequency (453 MHz) and power level, there must be a bunch-lengthening by a factor of about 3 in order to achieve the design current at 15 GeV.

Lattice Structure

The magnet lattice in the PEP storage ring underwent several significant modifications during 1975. The number of quadrupoles was doubled so as to produce a focusing system of 96 cells, each with 45 degrees of betatron phase shift, in place of the previous 48-cell, 90-degree system. This change in focusing is needed to allow full coupling between the horizontal and vertical betatron motions without undue increase in the required vertical aperture. According to recent beam observations in the SPEAR storage ring, such field coupling must be allowed for. These observations also indicate that the PEP aperture allowance is conservative. In SPEAR, the required aperture is measured to be ± 6 σ_x horizontally and ± 6.5 σ_y vertically (σ_x and σ_y being the maximum horizontal and vertical rms beam widths), whereas in PEP the aperture allowance is ± 10 σ_x and ± 10 σ_y plus 10 mm horizontally and 5 mm vertically for possible closed-orbit errors.

The 96-cell lattice has another advantage. Computational studies of the beam dynamical effect produced by the sextupole magnets required to control the chromaticity (variation of betatron frequency with particle momentum) show considerably less vertical beam blowup with the 96-cell system than with the 48-cell system.

Another significant change in the lattice design was the addition of a "wiggler" magnet system for beam-size control at operating energies below 15 GeV. These dipole magnets "wiggle" each beam at three points in the ring (without perturbing the orbits elsewhere) and thus cause extra electromagnetic radiation at these points, the reaction to which is used to produce the desired beam size. This means of beam size control simplifies operation because it allows just one standard lattice configuration to be used throughout this energy range. (At energies greater than 15 GeV other configurations will probably be used.) The wiggler system alleviates a severe injection problem that had existed in the previous low-energy lattice configurations, in which an excessively large aperture was required for satisfactory injection. The wiggler technique also decreases the radiation-damping rates and thus shortens the filling times over most of the operating range. The time for the beams to become polarized also is shortened by use of the wiggler system.

Another change in the lattice is the introduction of two low-field (200 gauss, maximum) bending magnets at each end of each straight section. This decreases the characteristic energy of the radiation spectrum that can reach the interaction regions at 15-GeV operation from 45 to 3 keV and thus lessens that background problem considerably.

A system was designed to rotate the polarization of the electron and positron beams from the vertical direction in the arc sections of the ring to the longitudinal direction at one interaction region. This rotation system uses low-field, vertical bending magnets located outside of the 20-meter-long interaction region. New quadrupoles, centered on the vertically displaced beam line, solve the matching problems and maintain the same luminosity and other parameter values as in the standard configuration.

Beam Transport and Injection

A transport lattice was chosen that allows independent tuning of the transverse and longitudinal phase spaces, so as to be able to match into a variety of lattice configurations in the storage ring. Optically each transport line is three 360-degree achromatic sections and is made up of 24 quadrupole and 18 dipole magnets. This choice produces a relatively small aperture requirement (at most ± 2.5 cm for a momentum spread of ± 0.8% in the beam) and a minimum overall cost. Most of the magnets are fairly conventional, and preliminary engineering design has begun. However, the initial and final bending magnets in the transport line are of the iron-septum (Lambertson) type and will require careful design so that the leakage fields outside the septa will not be large enough to perturb nearby beams.

A layout for the beam instrumentation in the transport line was chosen. The design philosophy and technology by and large follows that developed for the SPEAR transport line.

The incident beam will be injected into the storage ring near the point in the ring where the dispersion function is zero (which happens to be approximately the same point for all of the lattices considered). This choice is optimum both with respect to the vacuum aperture required everywhere in the ring and with respect to the required strength of the "kicker" magnets (the fast magnets that serve to switch the incident beam onto a desired orbit within the vacuum chamber). A kicker magnet design is evolving. The favored concept at present employs a ferrite magnet shielded from the beam electromagnetically by a thin screen and separated from the high vacuum in the ring by a ceramic chamber.

Injection into the lattice configurations planned for 5- and 7.5-GeV operation proved to be difficult, primarily because of the relatively large dispersion functions used to hold up the equilibrium beam size at these low energies. The acceptance in energy spread was limited to ± 0.1 to ± 0.2%, whereas the incident beam has a spread of ± 0.5%. This difficulty led to the invention of the wiggler system, which controls the beam size without the use of large dispersion functions.

Rf Systems

Experience with a very similar system in the SPEAR storage ring has shown the desirability of controlling the accelerating voltage so as to avoid synchro-betatron resonances especially when the beam energy is being ramped. This control calls for a 20% range of adjustment in the klystron voltage.

An experimental klystron (Figure 2) produced the desired goal of 500 kW under pulsed conditions and at an efficiency of 63.5% (design goal is 70%). The magnetic focusing profile is being modified. For full-scale testing of the klystrons, an 850-kW power supply is being built, and a 500-kW load has been completed.

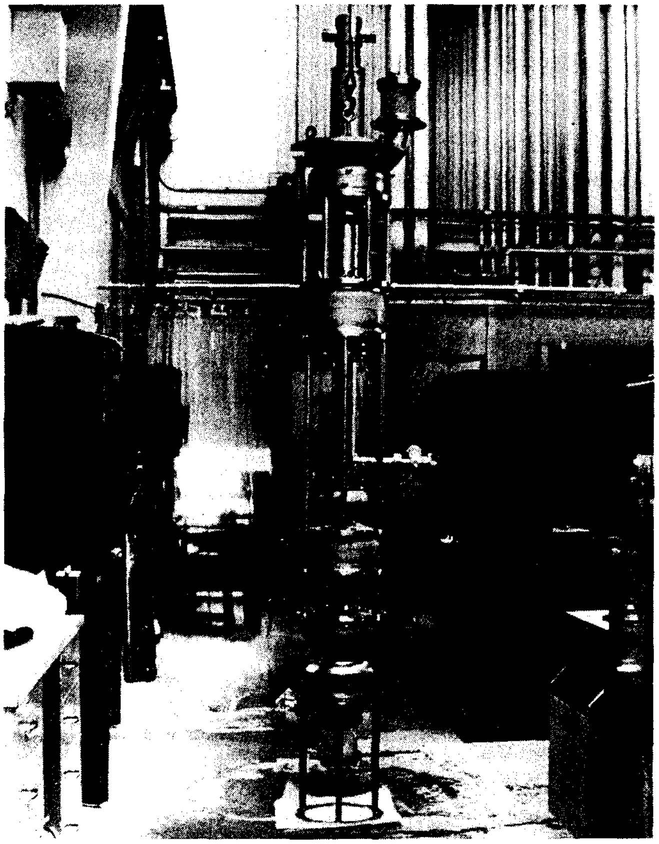


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Fig. 2. Experimental PEP klystron.

A low-frequency acceleration system was studied because of its potential for reducing higher-order-mode losses and as well as overall power requirements. It was found that the 353- and the 125-MHz systems were comparable in construction costs, but that the 125-MHz system would require considerable development time and money.

Magnet System

Normal Quadrupole: Several designs have been pursued for the quadrupole magnet in the normal cells of the lattice, and several models have been built to evaluate fabrication techniques and the magnetic profile. Magnetic measurements showed all of the multipole strengths to be less than 0.1% of the quadrupole strength at the pole tip except for the 12-pole strength, which was about 0.2%. The betatron-~~time~~ tune shifts produced by these magnetic impurities are considered acceptable. Among the several designs considered, a relatively low-current (and low-power) model has been chosen, and a final design is underway.

Insertion Quadrupole: A model of the larger quadrupoles to be used in the insertion regions (i.e., straight sections) of the lattice was built (Figure 3). Preliminary magnetic measurements indicated acceptable field quality, but they will be repeated because of a fault in the measuring gear. A second design has been necessitated by an increase in the required aperture.

Dipole Magnets: Tests of a model bending magnet with a 60-mm gap (Figure 4) revealed problems in detail with both the mechanical and the magnetic properties of the magnet laminations, even though the overall average magnetic properties were acceptable and agreed with those calculated theoretically. A new model with a 70-mm gap has incorporated changes designed to overcome these problems.

Magnet Power Supplies: The magnet currents will be regulated by "chopper controller" systems, in which the current to an individual load is fed from a large, coarsely regulated power supply in pulses at a rate of 1 or 2 kHz, and control is exercised through pulse-width modulation. A commercial prototype unit capable of putting out 1200 A at 300 V was purchased and tested.

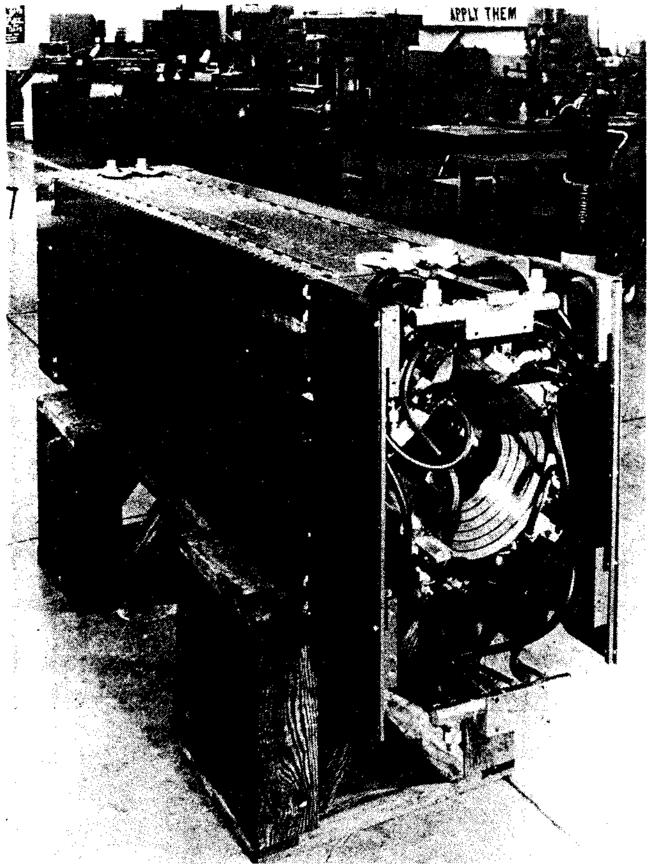

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Fig. 3. Experimental model of an insertion region (straight section) quadrupole.

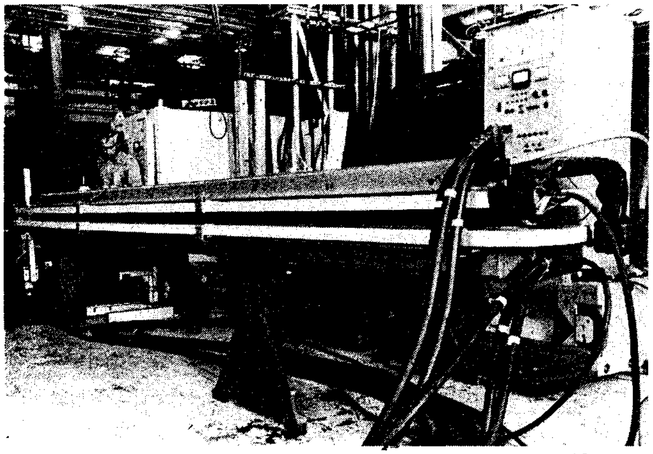

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Fig. 4. Experimental main-ring dipole bending magnet.

Although its basic operation was satisfactory, the degree of regulation achieved was not adequate. Alterations are being prepared to improve this performance.

Vacuum System

The typical vacuum-chamber unit will be a 14-meter-long aluminum extrusion that threads through two quadrupoles and two bending magnets. A cross section of the extrusion is shown in Figure 5. To minimize the required bore in the quadrupole magnets, efforts are being made to deform the extrusion from an oblong to a more nearly square shape in the region of the quadrupoles. Thus far, such severe deformations usually have ruptured the aluminum walls.

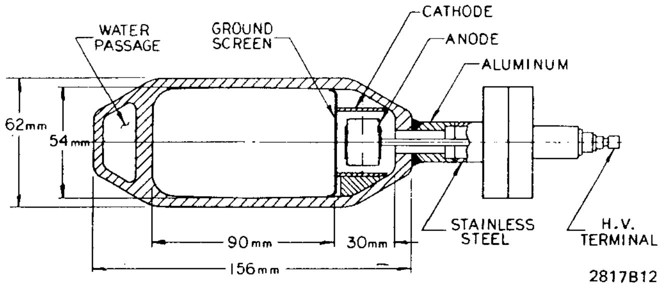

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Fig. 5. Cross section of a bend-magnet vacuum chamber.

Because of the energy lost by the beams when traversing a discontinuity in the electromagnetic environment, careful efforts are being made to make all transitions as smooth as possible. Each module is being measured for its higher-order-mode loss.

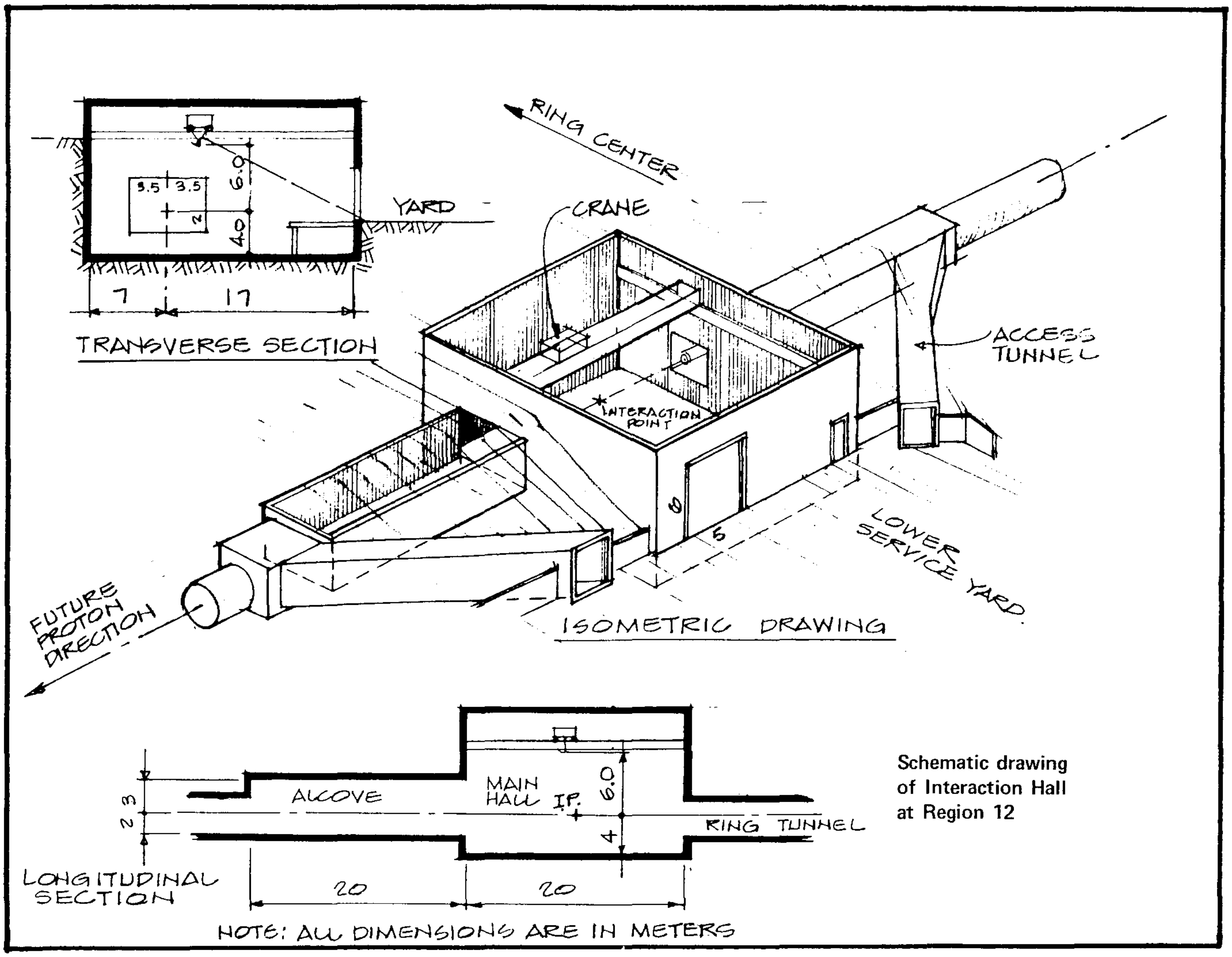
Survey and Alignment

Many surveying techniques have been reviewed and evaluated for use in the PEP ring and injection lines. The system that has evolved is divided into two portions: long-range surveying and short-range surveying.

The long-range survey will be based on 12 monuments inside the PEP tunnel derived from an above-ground survey by the U.S. Coast and Geodetic Survey. The horizontal accuracy is expected to be ± 2.5 mm. The vertical reference, which will be provided by a liquid-level system permanently mounted in the tunnel, should be better than ± 0.2 mm.

The short-range survey between adjacent monuments may use alignment lasers. Conventional optical instruments also are possible but involve larger labor costs and are slower. An automated inertial-guidance and laser system was evaluated but found inadequate.

Monte Carlo calculations of the closed-orbit distortions caused by the expected magnet



Schematic drawing of Interaction Hall at Region 12

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Fig. 6. Isometric view of planned structures at region 12.

placement errors indicate that the maximum distortions will be of about the same magnitude as the allowed aperture in each transverse plane. Thus, for initial operation of the storage ring some beam steering will probably be required.

Instrumentation and Controls

An overall plan for monitoring and control has been evolved. Data on magnet current, vacuum pressure, beam current, and so forth will be collected at data centers in each of the six interaction regions of the ring. These signals will be edited by a small computer and sent by serial link to the PEP control room, which will be integrated with the main control center of the SLAC complex.

The control system will use many small, dedicated computers. Fourteen of these will be connected to a central control computer, which will connect to the outside world.

The electron and positron beams will be monitored through the synchrotron light for beam-profile and bunch-length information. A dc toroidal transformer will measure the total beam current with an accuracy of 0.1 mA. Beam position will be monitored by a set of 4 capacitive buttons near the vacuum wall at about 80 points around the ring.

Site and Buildings

Plans for tunneling and site work are in an advanced state in preparation for the arrival of an architectural and engineering firm, who will do the final design of this part of the project.

A survey using 51 test drillings around the PEP ring showed that the site is free of serious tunneling problems and that there should be no great difficulty with ground water nor with swelling ground.

Experimental Areas

A great deal of effort has already gone into the planning of the experimental areas. Figures 6 and 7 illustrate the current concepts for an interaction area.

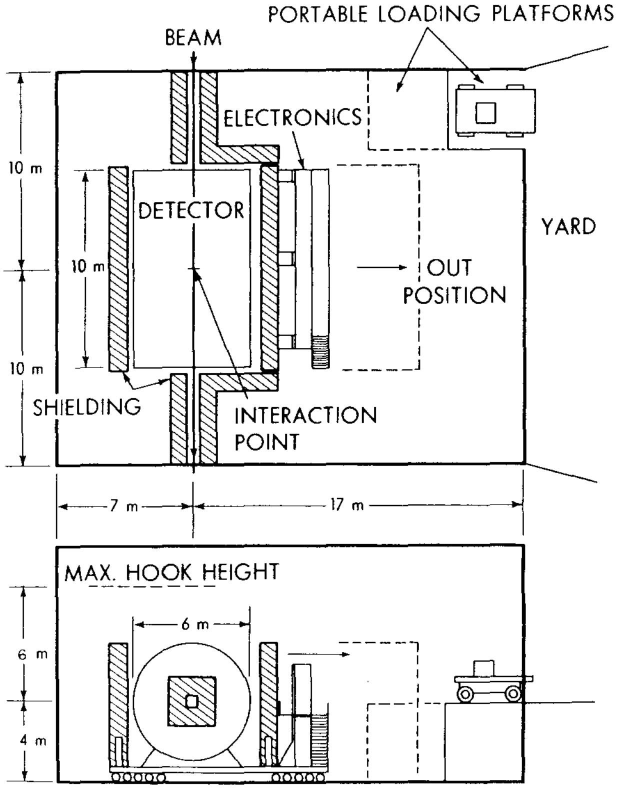

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Fig. 7. Possible experimental setup at region 12.

SUMMER STUDY — 1975

The PEP 1975 Summer Study brought together 60 physicists (selected from a larger number of applicants), including 11 from Europe and Japan. Working groups were formed to study, critically, many aspects of the experimental areas — the new physics to be explored; the detector concepts, especially those involving new technologies; the adequacy of the planned facilities; special experiments; and the possibilities of polarized beams. A 228-page Proceedings of the 1975 PEP Summer Study (LBL-4800) is now available.

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Superconducting Accelerator - ESCAR

Glen Lambertson in charge

R.C. Acker, T. Ahmadvand, R.V. Aita, P.C. Bean, F. Bierlein, A.R. Borden, V.O. Brady, R.A. Byrns, J.G. Carrieri, R.J. Caylor, W.W. Chupp, E.E. Demartile, W.F. Eaton, T. Elioff, A. Faltens, A. Garren, W.S. Gilbert, F.S. Goss, M.A. Green, E.C. Hartwig, D.D. Howell, E.H. Hoyer, D.B. Hunt, C.P. Johnson, A.H. Kleid, E.L. Knight, L.J. Laslett, I.W. Lee, D.R. Lippert, E.J. Lofgren, K.H. Lou, R.M. Main, R.A. MacGill, J. Meneghetti, R.G. Meuser, G. Newell, R. Peters, J.M. Peterson, C.D. Pike, W.L. Pope, J.B. Rechen, H.P. Riebe, D.F. Rothfuss, R.V. Schafer, L. Smith, J.W. Staples, J.T. Tanabe, F.L. Toby, F. Voelker, H.W. Vogel, R. Warren, E.R. Wellington, J. West, W.A. Wilson, R.C. Wolgast, J.A. Zelver.

The Experimental Superconducting Accelerator Ring, ESCAR, is a proton accelerator and storage ring with the express purpose of providing experience in building and operating this first functioning accelerator to use superconducting magnets and cryogenic techniques throughout. Through intimate collaboration with other laboratories, the experience gained will be used in planning future large accelerators which are based upon this new technology. With a nominal momentum of 5 GeV/c, ESCAR is large enough to be relevant for this planning and to be useful for other accelerator studies in its own right.

Design work for ESCAR began in July 1974 and has continued during 1975, but it has been neither necessary nor possible to pursue all systems with equal intensity because with restricted funding the construction will extend over a few years. The design and construction of satisfactory ring magnets, their cryogenic systems, and the cryogenically pumped high-vacuum system are the most innovative and crucial features of this experiment, so these have had the highest priority.

PLANT FACILITIES

ESCAR will occupy a site at the north end of the Bevatron external beam line shelter. The control room will be in existing Bldg. 64, near the 50-MeV proton linac injector. A new building, designated Bldg. 56, the Helium Services Building, will be constructed to house the compressors and cold box. Liquid helium will be produced here for ESCAR and for the Bevatron. Preparation of the site, placement of some shielding blocks for site stability tests, and provision of conventional facilities to the area will all proceed early in 1976.

INJECTION SYSTEM

The conventional bending magnets are fabricated but not assembled; the quadrupoles and solenoids have been designed. The layouts of the high-vacuum transition section and the injection straight section are complete but not fully detailed. Work on the injection system is held in abeyance at this stage to forestall redesign due to changing interface requirements with other systems.

BEAM DYNAMICS

The range of probable operating parameters has been explored using the SYNCH computer program. Initial tunes of $\nu_x = 3.3$ and $\nu_y = 2.3$ have been decided upon, but a wide range of other values can be accomodated. Transition energy may be varied from well above the design maximum beam energy to values within the acceleration cycle. The similarity between ESCAR and the CERN Booster Accelerator has been helpful in assessing expected performance and selecting control devices. Arrays of superconducting multipole windings within the main quadrupoles and at the quadrant symmetry points will control steering, chromaticity, and dispersion as well as field errors and beam resonances through the fourth order.

MAIN RING MAGNETS

The design, construction, and tests of a satisfactory dipole magnet have been the most active facets of the ESCAR effort during this year. The entire project depends upon a successful demonstration that pulsable superconducting high-field magnets with excellent field quality and low loss can be built routinely and with confidence. A full-scale dipole coil and compression ring assembly designated D3 was completed in June and tested in a vertical dewar in Bldg. 64 (Figure 1). This magnet developed a high resistance after a transition at 1496 amperes. Disassembly revealed a burned-out volume in the winding, probably due to a turn-to-turn short. This magnet, now designated D3b, was rewound with new superconducting cable and with meticulous attention to cleanliness and monitoring of coil parameters during the whole assembly. This coil was tested without iron in the vertical dewar (Figure 2); the first transition occurred at 1550 A, the 25th at 1948 A. It has been assembled with its horizontal cryostat and iron shield in Bldg. 58, where a magnet test facility is now set up. Tests will resume shortly. This design, with minor modifications, is satisfactory for ESCAR use, and parts are being fabricated.

Concurrently, more thorough superconducting cable inspection and cleaning processes have been put into operation, and a more positive

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Fig. 1. Assembly of magnet coil into its strengthening rings.

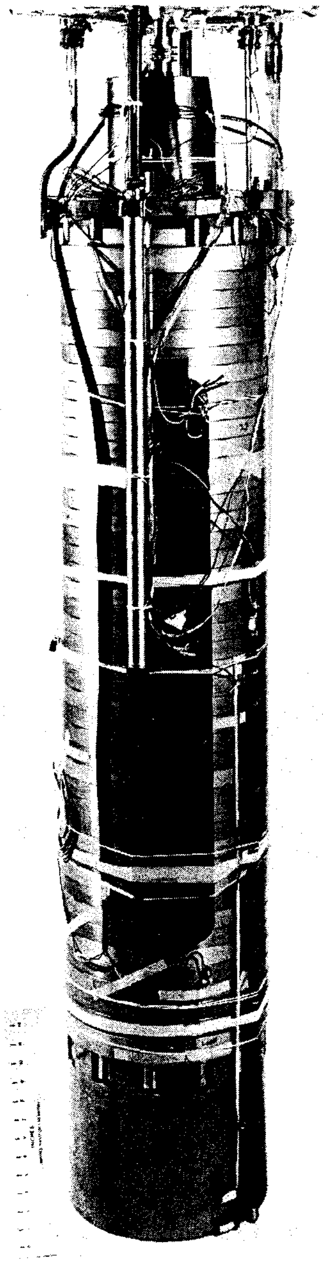

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Fig. 2. The dipole ready for installation in vertical dewar.

cable insulation scheme will be used. An improved system for transition detection and energy removal has been developed which can extract 80% of the magnet stored energy and dissipate it in an external resistor. There is thus less likelihood of burning out the conductor and less helium is boiled off, at the expense of a higher voltage across the coil.

Quadrupole magnets are in the design stage. They will utilize a "cold iron" design with four quadrupoles in a single cryostat. Superconducting windings for field and beam control will be included and will be formed on cylinders under and concentric with the quadrupole windings.

Power supplies for the dipoles are being provided by Fermilab. A supply has been used for tests with our dipoles and is satisfactory.

MAGNET CRYOSTATS

A prototype dipole magnet cryostat has been built, vacuum checked, cooled down with magnet D3b installed, and is ready for full-scale magnet tests (Figure 3). The iron return yoke is external to the cryostat, at room temperature. Cold helium-gas-cooled leads, tested to 2400 amperes, have been made and are part of the test setup. A set of magnetic measurement coils is mounted in the bore of the magnet, which is at cryogenic temperature. These will be used to check the practicality of determining the centering of the coil assembly in the iron yoke by means of strain gages on the suspension bolts.

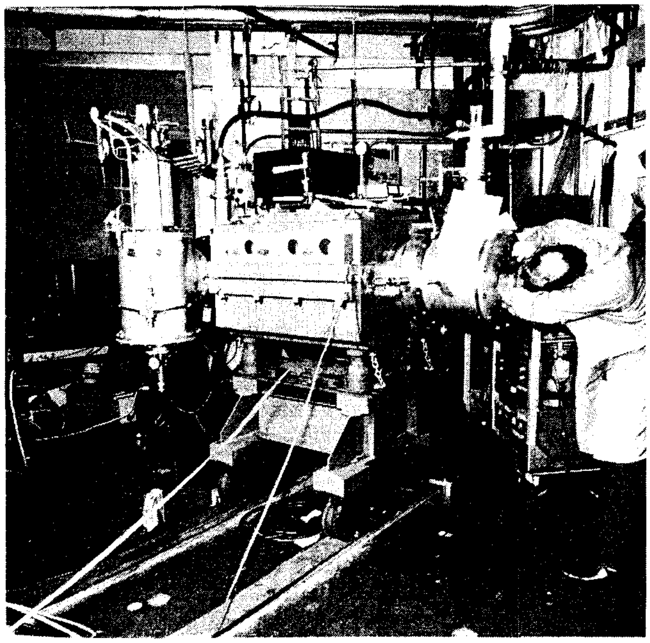

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Fig. 3. Dipole magnet D3b ready for full-scale tests.

MAGNETIC MEASUREMENTS

A set of nine precision coils on a rigid rotating structure with associated electronics has been built and used during testing of dipole magnets D3 and D3b. With this system, the strengths of multipole harmonics, through the 14th, of the basic dipole field may be evaluated with a precision of better than one part in 10^4 of the dipole field. Tests with magnet D3 showed that the desired field quality has been attained with our construction techniques, and tests with D3b at higher currents showed that the flexing of the compression ring structure of the magnet was as predicted. The end regions of the magnets are of comparable field quality to the central portions. Tests will resume shortly to measure field quality in the horizontal cryostat with the iron yoke and to transfer precisely the orientation of the dipole field to external optical alignment marks.

CRYOGENICS AND REFRIGERATION

The ESCAR superconducting magnets will be cooled by a two-phase helium fluid which passes through all magnets in series. Each magnet will be immersed in a pool of liquid helium, with space above the liquid for fluid flow. To further assure the adequacy of flow passages, adjustments of the cryostat design for the final production ring-dipole magnets have been made to provide a larger flow passage. Recovery of the distribution system following a quench is being studied

A separate helium circuit will serve the cryogenic vacuum pumping panels in the ring's straight sections.

The procurement of a cold box for the helium plant has been held up for a year by legal action by a possible vendor. Since the expected lead time on this item is 14 months, we have placed a "hold" on a surplus NASA helium refrigerator as a backup to prevent undue delay in cryogenic tests of ESCAR systems. The compressors and their motors are on order.

SUPPORTS, ALIGNMENT, SURVEY

The ESCAR site and injection line have been surveyed. Monument sites are being monitored for seasonal movement. The tape-tensioning device for the survey has been completed and tested. Magnet girders (procured from the Cambridge Electron Accelerator) are being modified for ESCAR. Four quadrupoles in one cryostat will be aligned on a single girder, then placed as a unit. Similarly, three dipoles in linked cryostats will be on a single girder. Air bearings to permit transport of a girder assembly have been designed. A lifting fixture for use with a crane is being designed. The detailed alignment grid has been calculated.

VACUUM SYSTEM

A cryogenically pumped high-vacuum chamber has been built and used for studies of the pumping of hydrogen and helium on CO_2 and argon frosts, and to determine the pressure rise due to small temperature changes. A cryogenic roughing pump has been designed and built and performs well.

The ESCAR vacuum chamber wall will be at liquid helium temperature throughout most of its length, and at that temperature it is the principal vacuum pump in the system. The straight sections will be warm, and where special gas-producing problems exist, such as the injection and rf sections, cryogenic helium-cooled panels will provide additional pumping. The problems of gas migration and of beam-induced gas desorption from the walls are being studied here and in other laboratories.

RF SYSTEM

The process of capture into rf buckets has been examined by computation, and a voltage-phase program has been determined. A ferrite-tuned accelerating cavity has been obtained from Brookhaven and will be modified for ESCAR use. Rf power supplies can be obtained from SLAC but will need modification to ESCAR frequencies for capture and acceleration. The requirements for an injection-line debuncher cavity have been outlined.

A continuing computational effort is investigating the effect of parasitic cavities and beam-tube discontinuities on the ESCAR beam, both during acceleration and as stored and bunched. Efforts to design components without adverse qualities are being applied to all portions of the vacuum vessel that can interact with the particle beam. The results of this study will be applicable to other accelerators.

MEETINGS AND REVIEW

Five members of the Accelerator Study Group attended the 1975 Isabelle Summer Study at Brookhaven in July. Five papers on ESCAR were contributed to the IEEE Particle Accelerator Conference in Washington, D.C., in March 1975. ESCAR was extensively reviewed by the ESCAR Advisory Group in November and the results of that review were presented to the High Energy Physics Advisory Panel (HEPAP) in December.

PUBLICATIONS AND PRESENTATIONS

R. Byrns and *M. Green*, The ESCAR Helium Refrigeration System, ESCAR-19 and LBL-3374, presented at the U.S. National Particle Accelerator Conference, Washington, D.C., March 1975; IEEE Trans. Nucl. Sci. NS-22(3), 1168 (June 1975).

W. Gilbert, R. Meuser, W. Pope, and *M. Green,* ESCAR Superconducting Magnet System, ESCAR-20 and LBL-3688, presented at the U.S. National Particle Accelerator Conference, Washington, D.C., March 1975; IEEE Trans. Nucl. Sci. NS-22(3), 1129 (June 1975).

M. Green, Computer Simulation of the Interaction of a Superconducting Magnet Good Field Region with a Particle Beam, ESCAR-21 and LBL-3373, presented at the U.S. National Particle Accelerator Conference, Washington, D.C., March 1975; IEEE Trans. Nucl. Sci. NS-22(3), 1881 (June 1975).

L. Smith, Betatron Equations in the Field of a Superconducting Dipole, ESCAR-12 (January 1975).

J. Tanabe, J. Staples, and *R. Yourd,* Design of the ESCAR Injection Beam Line, ESCAR-22 and LBL-3376, presented at the U.S. National Particle Accelerator Conference, Washington, D.C., March 1975; IEEE Trans. Nucl. Sci. NS-22(3), 1605 (June 1975).

R. Wolgast, Design of the Cryopumping Vacuum System for ESCAR, ESCAR-30 and LBL-3372, presented at the U.S. National Particle Accelerator Conference, Washington, D.C., March 1975; IEEE Trans. Nucl. Sci. NS-22(3), 1496 (June 1975).

Superconductivity Magnet Program

W. S. Gilbert in charge

R.C. Acker, A.R. Borden, W.W. Chupp, W.F. Eaton, D.D. Howell, E.L. Knight, R.B. Meuser, H.P. Riebe, F.L. Toby, and E.R. Wellington.

ESCAR

The major activity of the superconductivity program has been the initial assembly and testing of the ESCAR dipoles with the attendant development support required in the fields of superconducting cables, insulating and other special materials, magnet fabrication techniques, and magnetic-field measurement systems. The bulk of the staff, equipment, and laboratory space has been involved in the ESCAR program. This situation is expected to continue.

SUPPORT FOR OTHER PROGRAMS

Evaluations of multifilamentary Nb_3Sn superconductors, developed by the Materials and Molecular Research Division have been made using both short-sample test and time-dependent magnetization techniques. Physics Group A (P.H. Eberhard, et al.) have been developing large-scale, light-weight superconducting solenoids for use in particle detection at colliding-beam facilities. They have built a number of solenoids, up to one meter in diameter, and have tested them in our laboratory.

PUBLICATIONS AND PRESENTATIONS

R. Byrns and *M. Green*, The ESCAR Helium Refrigeration System, ESCAR-19 and LBL-3374, presented at the U.S. National Particle Accelerator Conference, Washington, D.C., March 1975; IEEE Trans. Nucl. Sci. NS-22(3), 1168 (June 1975).

W. Gilbert, R. Meuser, W. Pope, and *M. Green,* ESCAR Superconducting Magnet System, ESCAR-20 and LBL-3688, presented at the U.S. National Particle Accelerator Conference, Washington, D.C., March 1975; IEEE Trans. Nucl. Sci. NS-22(3), 1129 (June 1975).

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