CEAL-1039

SEMI-ANNUAL REPORT

For the Period

JULY 1, through DECEMBER 31, 1967

K. Strauch,
Director

March 4, 1968

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
and HARVARD UNIVERSITY

CAMBRIDGE ELECTRON ACCELERATOR

CAMBRIDGE 38, MASSACHUSETTS

DISCLAIMER

The research work described in
this report was performed under
Contract AT(30-1)-2076 between
the U.S. Atomic Energy Commission
and the President and Fellows of
Harvard College.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY · HARVARD UNIVERSITY

CAMBRIDGE ELECTRON ACCELERATOR

HARVARD UNIVERSITY
42 OXFORD STREET
CAMBRIDGE, MASS. 02138

MASTER

CEAL-1039
Prof. Karl Strauch
March 4, 1968

SUMMARY

Part I summarizes the purpose of the contract, which is concerned with the operation of the 6-GeV Cambridge Electron Accelerator. Changes in the administrative organization of the Laboratory are also reported. Part II summarizes accelerator operation, and indicates that the total number of user-hours was 2741. Part III describes the general natures of the 30 experiments that were in progress or in preparation. Part IV lists the principal improvements made in the accelerator and in the associated facilities. Part V summarizes the progress made on Project Bypass, and shows that long-term storage up to 30 minutes at 3 GeV and multi-cycle injection affording a build-up factor exceeding 100 were accomplished successfully. Part VI deals with safety, and indicates that there were no lost-time accidents and no excessive radiation doses. Part VII deals with the Sixth International Conference on High Energy Accelerators, held at Cambridge, Massachusetts, on September 11 - 15, 1967. Part VIII lists publications resulting from work done at the CEA.

PART I - INTRODUCTION

This report summarizes work done under the Harvard - AEC Contract AT (30-1)-2076 during the six-month period from July 1 through December 31, 1967. The contract calls for the operation and maintenance of the CEA 6-billion-electron-volt synchrotron and for designing, procuring, installing, and operating various facilities essential to the experiments to be performed here.

Professor Karl Strauch of Harvard University became Director of the Cambridge Electron Accelerator on October 1, 1967, succeeding Professor M. Stanley Livingston who resigned to become Associate Director of the National Accelerator Laboratory.

The general policies of the laboratory are determined by a joint M.I.T. - Harvard "Executive Committee of the CEA", comprising the following:

From M.I.T.:
*Prof. Bernard T. Feld (after Oct. 1967)
Dr. Carl F. Floe
*Professor Jerome I. Friedman
*Professor Francis E. Low (until Oct. 1, 1967)
*Professor Victor F. Weisskopf
Dr. Jerome B. Wiesner

From Harvard:
Dean Franklin L. Ford
*Professor Sheldon L. Glashow (until Oct. 1,1967)
*Professor Francis M. Pipkin
*Professor Karl Strauch (until Sept. 1, 1967)
Mr. L. Gard Wiggins
*Professor Richard Wilson (after Oct. 1, 1967)
*Professor J. Curry Street (after Oct. 1967)

*Denotes member of Scientific Sub-Committee

In the months preceding September 30, scientific policies were established by a Scientific Committee which consisted of the Scientific Sub-Committee and also Dr. Robert K. Adair (Yale), Professor Richard H. Milburn (Tufts), Dr. Thomas L. Collins (CEA), Dr. M. Stanley Livingston (CEA), Dr. Gustav-Adolf Voss (CEA) and Mr. C. W. Wooldredge, Jr. (CEA).

As of October 1, 1967, the choice of the physics program became the direct responsibility of the Director. To advise him in the selection of the scientific program the new Director established a "Cambridge Electron Program Advisory Committee" (abbreviated CEPAC) that is to meet periodically, consider the various high-energy physics experiments underway or proposed, consider other major activities underway or under discussion, and advise the Director as to which experiments, etc., should be undertaken and their relative priorities. In addition to Prof. Strauch, this Committee includes the following:

Dr. Samuel Berman, SLAC
Professor Louis N. Hand, Cornell Univ.
Professor Louis S. Osborne, M.I.T.
Dr. Burton Richter, SLAC
Professor Julian Schwinger, Harvard Univ. (starting 2/1/68)
Dr. Gustav-Adolf Voss, CEA
Professor Steven Weinberg, M.I.T.
Professor Roy Weinstein, Northeastern Univ.
Professor Richard Wilson, Harvard Univ.
Professor Donald Yennie, Cornell Univ.
Dr. J. M. Paterson, CEA (Secretary)

The Committee held its first meeting on October 20 and 21, 1967. It reviewed the previously approved experiments and discussed some new proposals. As a result of these discussions the following new experiments were approved by the director:

1. 103h Compton Scattering at High Energy and Small Momentum Transfer (Brenner-Walker)

2. 116c Photoproduction of K^- on H at 20° (Yale)

3. 118d Photoproduction of μ-pairs to High Mass Values (Northeastern)

4. 118g Check of Iron Spectrograph (Northeastern)

In October, Dr. G. A. Voss, Assistant Director of CEA became responsible for the Operations and Development Division. Working directly under Dr. Voss, Dr. H. Winick assumed responsibility for Operations and Dr. J. M. Paterson became responsible for management of the experimental floor area and the coordination of the experimental program. Dr. G. A. Voss has a special responsibility for the design, construction, and putting into operation of the colliding beam facility, i.e., Project By-Pass.

Dr. T. L. Collins, on loan to the N.A.L. since the summer of 1967, resigned as Assistant Director of CEA as of January 1, 1968 to become Assoc. Director of Accelerator Division and Head of Engineering Services at the N.A.L.

Day-to-day priorities in assignment of 8-hour shifts of accelerator time to experimenter groups were determined by the CEA Scheduling Committee, which included the following:

From M.I.T.:	Dr. Raymond Alvarez
From Harvard:	Dr. James Walker
From CEA:	Dr. Gustav-Adolf Voss (through Sept. 1967)
	Dr. Herman Winick (starting in Oct. 1967)
	Dr. William A. Shurcliff, Secretary

A Long Range Planning Committee was formed in December 1967 to examine and plan the future needs of the Laboratory. This committee, consisting of 11 senior members of the Laboratory representing all main activities, meets once a month.

On December 1, 1967, a small Scientific Programming Group was formed for the purpose of providing computational support for the staff and users of the CEA. At present the group consists of one physicist, J. W. Koch, who joined the CEA in August 1967, and one scientific programmer.

PART II - ACCELERATOR OPERATION

During the half-year in question the accelerator furnished a total of 2741 user-hours. The number of user-hours furnished per month was as follows:

Month in 1967	Number of user-hours		
	Experimenters*	CEA Staff, for Beam Storage	CEA Staff, for Misc. Trials
July	0	0	0
Aug.	457	27	22
Sept.	467	8	44
Oct.	487	25	37
Nov.	575	12	46
Dec.	464	53	17
	2450	125	166

Grand total for six-month period: 2741 user-hours

*Here 40 hours of unscheduled parasite time used by Frisch et al have been included in each month in which the accelerator was operated. The Frisch experiment employed a very low intensity beam originating in a 2-micron-diameter fiber situated directly in the synchrotron ring; consequently no scheduling of his runs were required and the numbers of parasite hours used by his group was inadvertently omitted from the recent monthly reports. Likewise 15 hours of unscheduled parasite time used by Milburn et al in studying bremsstrahlung scattering at Straight Section 38 have been included in each month in which the accelerator was operated.

In accordance with plan, the accelerator was out of operation from June 28 through August 3, 1967, to permit construction (near Magnet 16) of a special passageway for the bypass beam of the colliding beam project, and to permit various maintenance and improvement tasks to be performed. Accelerator operation was halted again on December 20, to permit installation of bending magnets, quadrupole magnets, vacuum pumps, etc., of the bypass proper, and for various maintenance purposes.

Accelerator operation was improved in many ways in the six-month period in question, as explained in Part IV.

On 11/28/67, using the new linac, we achieved an intensity of 33 ma, which is higher than had been achieved before with this accelerator, and is well above the original design intensity of 21 ma.

PART III - EXPERIMENTS IN HIGH-ENERGY PHYSICS

During the six-month period in question there were 30 experiments in high-energy physics in progress or in various stages of preparation or completion at the CEA. These are described below, arranged in three groups according to whether use of machine time was (a) completed before the period in question, or (b) underway during the period in question, or (c) to start in a later period.

A. Experiments in which the use of machine time was completed prior to the six-month period in question.

Alvarez et al (M.I.T.) Experiment 108a: photoproduction of π^+ at large angles and measurement of angular distributions. In a previous period the investigators completed the experimental phase of a study of the photoproduction of positive pions, at laboratory angles of 90 to 160 degrees, by means of a 1 to 3 GeV photon beam incident on a liquid hydrogen target. They used a large deflecting magnet, several precision, wide-gap spark chambers, and other detectors. Data-taking was completed in May, and by December 31, 1967 the scanning of the film with the aid of the SPASS computer program was about 25% complete.

Some preliminary results were presented at the January 1968 meeting of the Am. Phys. Soc. in Chicago.

Bar-Yam et al (S.M.T.I. and M.I.T.). Experiment 13a: single pion photoproduction at c.m. angles of 30 to 90° on deuterium, using 3 to 4 GeV photons. During the period in question the group finished analyzing and reporting the results of the study. A summary of the results was presented at the January 1967 meeting of the Am. Phys. Soc., and further details were presented in Phys. Rev. Ltrs. 19, 40 (July 3, 1967). One noteworthy result was that the ratio of cross sections for production of π^- and π^+ is appreciably less than unity, being approximately 1/2 for certain of the energies and angles chosen.

Engels, Hand, Schivell, Paterson et al (Harvard, Cornell, and CEA). Experiment 101a: yield of photoproduced neutral kaons at 0 to 10° lab. A beam of 4.25 (or 5.5) GeV electrons was directed at a 1.0 X_0 aluminum or beryllium target, and the kaons photoproduced in that target, and emerging at laboratory angles of 0 to 10° from the forward direction, were studied by means of a spark chamber and scintillation counters. K_1^0 particles were regenerated from K_2^0 particles in a block of copper, and pions resulting from the decay of the K_1^0 were detected. The runs were made in January - May 1967 and the data were analyzed in subsequent months. The investigators found that the K_2^0 particles were produced in great abundance (from ϕ resonances, presumably) and with interesting momentum spectrum and angular distribution. They found that when 5.5 GeV electron struck a beryllium target, the flux of neutral kaons at 2.5° was 5.7 x 10^{-5} per steradian per incident electron. A short account of the results was published in Phys. Rev. Ltrs. 19, 1349 (Dec. 4, 1967), and a complete account is to appear in a thesis now being prepared.

Gettner, Weinstein, et al (Northeastern University). Experiment 118a: electroproduction of wide-angle muon pairs. The experimental phase of the work, which included wide angle production of muon pairs produced at forward angles of 4 to 10° lab by means of 4.9 GeV electrons and the exploration of the time-like form factor of the e-μ scattering process, was completed in a previous period. The analysis of results is still in progress. A preliminary account of some of the work was presented at the September 1967 SLAC Electron Photon Conference. Further details (e.g., calculations as to expectations) were presented in a June 1967 thesis "Photoproduced and electroproduced muon pairs" by P. Rothwell.

Hughes et al (Yale). Experiment 116b: $K^{\pm}$ photoproduction in hydrogen and the obtaining of evidence for baryon resonances with positive strangeness. The experimental phase of the work was completed in January 1967. It involved a search for evidence for hyperon resonances of strangeness +1 and strangeness -1, photoproduced by 3 to 6 GeV photons on hydrogen according to the interactions:

$$\gamma + P \rightarrow K^{+} + Y^{*} \qquad \text{and} \qquad \gamma + P \rightarrow K^{-} + Z^{*}$$

The K^- and K^+ mesons at 10° lab. were studied with the aid of a spectrometer comprising focusing magnets, momentum analyzing magnets, hodoscopes, and differential gas Cerenkov counters. The data showed evidence of the existence of several new resonances in the mass range 1800 to 2500 MeV, with strangeness +1 and -1. Some of the results were reported in Phys. Rev. Ltrs. 19, 255 (31 July 1967), and Phys. Rev. Ltrs. 20, 221 (29 Jan. 1968). Other results were presented by K. Strauch at the September, 1967, SLAC Electron Photon Conference and by V. Hughes at the September Heidelberg, 1967, High Energy Physics Conference.

Kendall, Friedman, et al (M.I.T.). Search for e' particle. The experimental work was done in 1965 and a summary of results is to appear in a forthcoming issue of Physical Review. The investigators conclude that they have no evidence of the existence of the postulated e' particle.

Von Goeler, Weinstein, Gettner, et al (Northeastern University). Photoproduction of baryon-antibaryon pairs. The investigators completed the reporting of results on photoproduction of baryon-antibaryon pairs by the reaction $\gamma + p \rightarrow \bar{n} + d$, using photons of 4 to 6 GeV energy. The experimental work, involving use of the Moby Dick spectrometer, was completed in 1966. The results imply antiproton and antineutron photoproduction cross sections generally similar to cross-sections found in earlier experiments. The present cross-sections are about two orders of magnitude smaller than predicted by Drell on the basis of a simple peripheral model, but are much more nearly comparable to predictions based on a recent modification of that model. An abstract of the results was presented at the September 1967 SLAC Electron-Photon Conference, and a summary of the results was published in Physical Review Letters 19, 922 (Oct. 16, 1967) by D. Earles, M. Gettner, G. Glass, Y. Laohavanich, E. von Goeler, R. Weinstein, and D. Garelick: "Photoproduction of Antineutrons and Antiprotons for Photon Energy Between 4.0 and 5.7 BeV".

Wilson, Mistretta et al (Harvard). Experiment 105a: determination of pion form factor through study of inelastic e-p scattering near the first nucleon-pion resonance. The investigators completed data-taking in the previous six-month period. They employed an external electron beam of 3 to 6 GeV energy, a liquid hydrogen target, and a two-arm spectrometer. One arm (Kontiki), which included a focusing magnet, arrays of scintillation counters, a gas-filled Cerenkov counter and a shower counter, detected the electron at 7 to 10° lab. The other arm, employing a sweeping magnet, a 144-element scintillation counter hodoscope, and a Lucite Cerenkov counter, detected the pion in coincidence with the electron. In the present six-month period the investigators analyzed all of the data on π^0 production, and much of the data on π^- production. The five main results of the work on π^0 are: (1) The cross-section fits well with a theory assuming only s and p partial wave amplitudes. (2) The cross-section is dominated by the cos (2ϕ) term, because of the almost 100% polarization of the virtual photons. (3) There are significant scalar transverse interference terms. (4) The γ-NN* transition form factor is consistent with either the magnetic nucleon form factor or with the exponential form factor proposed by Dufner and Tsai. (5) The electric quadrupole amplitude is between 5 and 13% of the magnetic dipole amplitude, in reasonable agreement with photoproduction experiments.

Wilson, Hanson et al (Harvard). Experiment 105c: determination of neutron form factor at low momentum transfer by an anti-coincidence method. The experimental work was completed in June 1967. The investigators used an external electron beam, a liquid deuterium target, and a coincidence method of detection and analysis. A checkerboard array of 144 scintillation counters determined the polar and azimuthal angles of the recoiling proton. The electron was detected by means of a spectrometer that included a threshold-type Cerenkov counter and lead-scintillator-sandwich shower counter. Data were analyzed on-line by the PDP-1 computer. At the end of December the analysis was still underway.

B. Experiments involving use of machine time in the six-month period in question.

Brenner, Walker, et al (Harvard). Experiment 103a: wide-angle electron pair study with tagged photons and a wide-gap spark chamber, to an invariant mass of 400 $(MeV/_c)^2$ (198 machine hours). The experimental method involved use of a tagged photon produced with the aid of momentum-analyzed positrons; the individual positron (of known energy) strikes a thin target and radiates by bremsstrahlung process; an open-sided tagging magnet (momentum analyzing magnet) and arrays of scintillation counters permit determination of the energy of the spent positron and, by subtraction, the energy of the bremsstrahlung photon. This tagged photon is put to use as follows: it is caused to strike a target of carbon (or liquid hydrogen) and produces here an electron-positron pair; an adjacent spark chamber shows the initial directions of these two particles, and a second spark chamber, situated within the large gap of a 200-ton H-type magnet, permits determination of the momentum of each particle; an array of 8-ft.-wide spark chambers with high-Z plates permits distinguishing electrons from pions. By the end of June 1967 the group had evolved satisfactory means of photographing tracks having different obliquities and very different brightness. Data taking took place in September and October of 1967. A total of 3000 electron-pair events at production angles exceeding 1.8° were recorded. Analysis is expected to be completed soon.

Brenner, Walker, et al (Harvard). Experiment 103h: study of small-angle Compton Scattering of Photons, at 2 to 6° lab, from protons. (150 machine hours). The investigators use tagged photons (of known energy, from 2.0 to 4.6 GeV) and measure the energy of the scattered photons by converting them to electron-positron pairs and determining the energy of these with the aid of a wide-gap spark chamber and the Jolly Green Giant magnet. The equipment is in place and trial runs were made in December 1967. Data taking is expected to start early in 1968.

Deutsch et al (M.I.T.). Experiment 111a: proton compton effect. (109 machine hours). Most of the experimental work on this study of γ-p scattering at 65° c.m. was done in the first half of 1967, but some additional data were taken (at energies of 2.0 to 2.7 GeV) in November 1967. The results were analyzed with the SPASS computer program. One central finding was that as the energy increases from 0.8 to 2.5 GeV the cross section decreases by almost two orders of magnitude. Up to 2.7 GeV the cross section shows no outstanding features. A preliminary account of the results was presented at the September 1967 SLAC Electron Photon Conference.

Frisch et al (M.I.T.). Experiment 8a: development of an internal beam tagging facility. (269 machine hours). To produce a stream of tagged, multi-GeV photons along Beamrun 12 1/2, the investigators employ a 2-micron-diameter quartz filament mounted near the center of Magnet 12. By remote control, the fiber is moved into the beam of orbiting electrons (without appreciably affecting it). An electron that strikes the filament and produces a bremsstrahlung photon has reduced energy and momentum and is deflected strongly by the magnetic field; the electron position is determined by means of a bank of 20 detectors situated near the downstream end of the magnet. Knowing the decrease in energy of the electron, an experimenter can compute the energy of the photon with an accuracy of about ±2%. The tagged photons pass into the Experimental Hall and are employed in photoproduction experiments. Because the fine wire used is so small, the experimenters can make runs at almost any time, without interfering with use of the machine by a prime user and other parasite users. In the previous six-month period the special vacuum chamber and mechanism for controlling the position of the filament were completed and tried out successfully. In September the system as a whole was operated successfully, producing $\sim 10^5$ tagged photons per second. The energy resolution was measured and found to conform to predictions (±2%). More recently, the facility is being improved by the provision of a ceramic (rather than an epoxy) vacuum chamber for use in Magnet 12. Also, a special "cross-over" vacuum chamber for a portion of the Bypass proper is being developed, to make Beamrun 12 1/2 compatible with the Bypass installation.

Fulmer, Dell et al (ORNL and CEA). Experiment 119: study of electro-induced and photo-induced spallation. (4 machine hours). The investigators exposed foils of uranium, iron, aluminum, and other metals to a 3-GeV electron beam as part of a study of electro-induced and photo-induced spallation. The analysis of fission products of iron was extended to include products with lifetimes as short as a few minutes. A summary of results, published in Physics Letters 26B, 140 (8 Jan. 1968), indicates that the graph of mass yields has two broad peaks with a shallow valley in the symmetric fission region. At the end of 1967 the investigators were preparing to expose additional foils of uranium, aluminum, and iron.

Hughes et al (Yale). Experiment 116c: K^- photoproduction in Hydrogen and confirmation of the January 1967 discovery of evidence for baryon resonances with positive strangeness. (25 machine hours). The group continued preparations for photoproduction and detection of K^- mesons at 20° lab (instead of 10° as in earlier work). They wish to ascertain whether the kinematic shift is in accord with that predicted for baryons having strangeness + 1. The equipment includes a liquid hydrogen target, two half-quadrupole magnets, two differential gas-filled Cerenkov counters, three momentum-analyzing magnets, and a scintillation hodoscope. By December 1967 most of the equipment had been tried out, and consideration was being given to changing to an angle of 15° lab, instead of 20°, in order that better statistics could be obtained. Data-taking runs are to start in March or April 1968.

Kendall, Friedman, et al (M.I.T.). Experiment 113a: study of elastic e, α scattering with the purpose of evaluating the short-range structure, or form-factor, of the alpha particle. (104 machine hours). The investigators use an external beam of 1 to 4 GeV electrons and a liquid helium target. The recoiling alpha particle is detected by scintillation counters, and the scattered electron is detected by a quadrupole spectrometer that includes wire chambers and scintillation counter hodoscopes. By December 31 a majority of the components were ready for use and data taking was expected to begin within a few months.

Kendall, Friedman, et al (M.I.T.). Experiment 113b: study of inelastic e,d scattering with the purpose of exploring the [illegible] disintegration of the deuteron near threshold and exploring the short-range structure of the n,p interaction at low energy in the n,p center of mass system. (104 machine hours). The investigators use an external beam of 1 to 4 GeV electrons and a liquid deuterium target. Essentially the same equipment will be used as for the e-α scattering experiment 113a described in the previous paragraph.

Luckey et al (M.I.T.). Experiment 109a: study of photoproduction in hydrogen of η° at forward angles. (419 machine hours) The photons resulting from decay of the η° are detected by glass Cerenkov shower counters mounted on a small spectrometer arm. The investigators obtained a large volume of data in November and December 1967 using 4 GeV photons; η° particles emitted at angles of 0 to 18° lab. were measured. The investigators have been preparing to take much additional data, early in 1968, at photon energies near 5.6 GeV.

Milburn et al (Tufts). Experiment 114a Part I: measurement of the polarization of the proton recoiling in $\gamma + p \rightarrow p + \pi^\circ$ events in which the pion is ejected at 65° c.m. (194 machine hours). The investigators employed (a) a small spark chamber and lead glass Cerenkov counters for detecting photons from the decay of π°, (b) a magnet and four small spark chambers for determining the momentum of the recoiling proton, and (c) a large spark-chamber, containing 61 graphite plates, for determining the asymmetry of scattering of the proton by the carbon nucleus. Data taking occurred in August, September, October, and the analysis of data is now underway.

Milburn et al (Tufts and CEA). Experiment 115a: study of the production of polarized photons with the aid of a laser. (75 machine hours). The investigators continued preparations for exploiting the method of producing polarized high-energy photon beams demonstrated on a pilot scale in 1964 and 1965. They will direct a very intense beam of polarized 2 ev photons head-on at the 6-GeV electrons in orbit in the synchrotron; the photons will recoil with energies as great as 800 MeV and will retain their original polarization. A very powerful ruby laser has been obtained; it provides 25 to 30 joules per pulse and may be pulsed once a second. The necessary glass Cerenkov counters are in place. To demonstrate that sufficiently low gas pressure may be maintained in the straight section tank to be used (#38), despite the presence of several glass windows there which make it impractical to use usual bake-out procedures, the investigators made many tests at the Straight Section 38 location and encountered no circumstances prejudicial to the success of the laser experiment. Data taking is to start by spring of 1968.

Osborne et al (M.I.T.). Experiment 109b: study of photoproduction of π° by polarized photons in hydrogen. (68 machine hours). A diamond crystal mounted on a goniometer in the synchrotron ring will produce the polarized photons, and another goniometer-mounted crystal (much larger, and of silicon) will serve as analyzer for use in evaluating the polarization of the beam. The photons resulting from decay of the π° will be detected by a Cerenkov counter hodoscope, and the recoiling proton will be measured by the Moby Dick spectrometer. The accelerator will be operated at about 6 GeV, and the polarized photons used will have energies of about 3, or possibly 3.5 GeV. The range of four-momentum transfer squared to be studied extends from -0.4 to -2.0 $(GeV/c)^2$. Data taking is to start in mid-1968.

Pipkin, Randolph, Tenenbaum, et al (Harvard). Experiment 102a: study of wide-angle electron pair production with greater accuracy than was available earlier. (407 machine hours). The investigators, seeking possible failure of QED at large values of four-momentum transfer, enjoyed many long and successful data-taking runs, using a multi-GeV photon beam and a carbon target. Detection was accomplished with two large spectrometer arms that included focusing magnets, scintillation counters, and gas Cerenkov counters. By the end of December 1967 a total of 5000 events, at electron-pair mass values ranging from 80 to 425 MeV, had been recorded and the task of analyzing the data was started.

Pipkin, Stanfield, et al (Harvard). Experiment 102f: continuation of study of small-angle scattering of electrons by carbon. (48 machine hours). This group, seeking additional information on the form-factor of the carbon nucleus, employs an external beam of 1.5 to 4.0 GeV electrons, a carbon target, and a single-arm spectrometer that detects and analyzes the scattered electrons. By the end of December the investigators were ready to take data.

Walker, Knasel, et al (Harvard). Experiment 104a: total cross-section for photoproduction of electron-positron pairs with low momentum transfer. (130 machine hours). The experimental work, involving photoproduction in carbon, aluminum, lead, and copper, was nearly complete in the preceding six-month period. In the present period a few additional runs were made, and the data were analyzed and reported in a thesis of December 21, 1967 by T. M. Knasel. The results indicate agreement of better than 0.1% between experiment and the most refined theoretical calculations for electron pair photoproduction. (The calculations were based on the relativistically covariant theory of pair production by Jost, Luttinger, and Slotnick together with the Dirac-Slater model of atomic structure). The photon energies were 1 to 4 GeV. The present work provides twenty-fold greater accuracy than had been achieved previously.

Wilson et al (Harvard). Experiment 105b: search for violation of time-reversal invariance in electromagnetic interactions involving strongly interacting particles. (152 machine hours). The investigators direct an external electron beam of about 6 GeV energy at an ethanol-water target (developed by Pound and others at Harvard) containing polarized hydrogen nuclei. They measure just the inelastically scattered electrons--by means of a single-arm spectrometer that includes scintillation counters, a Freon Cerenkov counter, and a shower counter. A small amount of data was taken in December, and the main data-taking runs were completed early in 1968. The results are now being analyzed.

C. Experiment in which the data-taking is to start in a later period.

Bar-Yam et al (SMTI, M.I.T. and CEA). Experiment 117a: study of photoproduction of charged pions on hydrogen and deuterium by polarized photons. A diamond crystal will be used as internal target (to produce the polarized photon beam) and the CEA pair spectrometer will be used to verify the polarization. The photoproduced pions will be detected by the Moby Dick spectrometer equipped with scintillation counter hodoscopes, wire chambers, and a gas Cerenkov counter. Data taking is expected to start in 1968.

Deutsch et al (M.I.T.). Experiment 111b: feasibility study for the determination of polarization of lambda particles produced in $\gamma + p \rightarrow \Lambda^{\circ} + \kappa^{+}$ by 2 GeV photons. The equipment includes a magnetic spectrometer, six spark chambers, scintillation counters for trigger and time-of-flight determination, and a water Cerenkov counter for pion rejection. The group finished most of the assembly of equipment, and data taking is expected to start early in March or April of 1968.

Frisch et al (M.I.T.). Experiment 112a: study of photoproduction of $2\pi^{\circ}$ resonances (f_o particles) with tagged photons. The investigators are using tagged photons from the internal beam tagging facility in Magnet 12; photon energy is known to within ±2%. The f_o particles are produced in a 0.1 X_o polyethylene target. The direction of the recoil proton is determined by means of a thin-foil spark chamber. To determine the directions of the four photons produced in the decay of the two neutral pions, the investigators find the locations of the resulting showers by means of a spark chamber containing thick iron plates that have an aggregate thickness of $7.3X_o$. Recent results from DESY indicate that the cross-section for f_o photoproduction may be much smaller than had been expected, but expectations are that the same picture will contain other interesting reactions, e.g., ω° photoproduction. Data taking began in March 1968.

Milburn et al (Tufts). Experiment 114a Part II: measurement of the polarization of the proton in $\gamma + p \rightarrow p + \pi^{\circ}$ events in which the pion is ejected at 90° c.m. The equipment, most of which is now in Area 4, is much the same as that used in the earlier experiment (No. 114a Part I) described on page 17. At the end of December 1967 this experiment was inactive--while the investigators were analyzing the data obtained in Experiment 114a Part I described above.

PART IV - EQUIPMENT AND FACILITIES

A. Accelerator

During the last half of 1967 we received and installed many new vacuum chambers of ceramic type. Twenty-one were in use by the end of July, eleven more were installed in October, and others were installed later. But although the ceramic segments of the chambers have performed perfectly, holding a very high vacuum ($\sim 10^{-9}$ torr) and showing no radiation damage, the metallic flanges, or bellows, connecting the segments developed small leaks. Many of the chambers had to be removed and repaired. We made a study of the possible causes of the leaks, and concluded that the flexibility of the joints, and their resistance to fatigue from vibration, was inadequate. Accordingly we (1) worked out a new and more compliant design of flange, and (2) installed chamber supports that reduced the maximum strains and amplitude of vibration. In September we arranged with the supplier to manufacture chambers with the redesigned flanges, and in November we received two chambers having the modified design. By the end of November we had on hand a total 32 ceramic chambers of old design and 2 of new design. Fifteen of the chambers were in use in the synchrotron ring. The defective chambers that were removed from the ring were repaired (at the CEA, in most instances). Thanks to the improved suspension system used, the lifetime of old chambers has been increasing. The chambers of the new design are being received at the rate of several per month. Of the three new-design chambers on hand and in use by December 31, 1967, all have performed perfectly to date.

We completed the installation of the new system of high-efficiency vacuum forelines and Welch turbo-molecular forepumps for the synchrotron ring.

We ordered from Westinghouse Electric Co. an ultrasonic degreaser for use in processing vacuum components to be maintained at ultra-high vacuum.

In August two of the coils of the 60-ton inductor of the magnet power supply failed and were replaced. Three new coils were received in September and we now have a total of five spare coils on hand.

A survey of height of the 48 magnets of the synchrotron ring was made in December, and showed that the heights had varied unequally by as much as 20 mils since the most recent re-leveling, done two years ago. (The heights were readjusted again in February 1968).

In October we installed four monitors of greatly improved type in the synchrotron ring, to monitor beam intensity and horizontal and vertical position of the beam. The new type of monitor, developed at CEA, is superior to the old type in many respects: it is far more sensitive; it has excellent discrimination against backgrounds of many kinds; it is virtually unaffected by prolonged exposure to radiation; it can be mounted within the flange at one

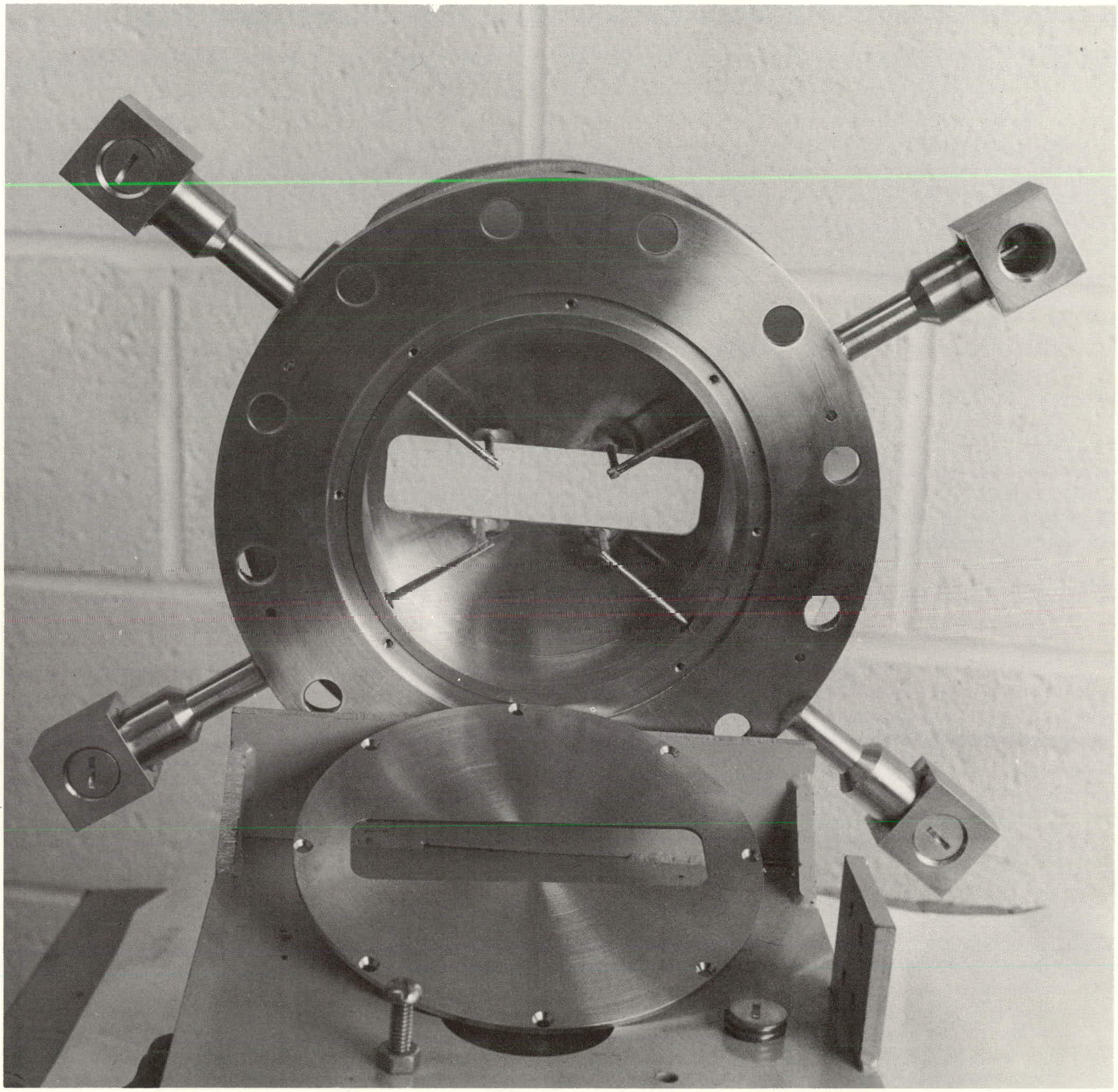


FIG. 1 Multi-purpose Monitor for the beam in an electron synchrotron. In this front view, an end plate and a plug have been removed to show the loops and their output.

end of a straight section tank and thus leaves the tank itself free for other uses; and it can be baked out together with the straight section. The device consists of four small pick-up loops flanked by an assembly of four hybrids which, by providing signals (at a frequency of 952 MHz, i.e. twice the accelerating frequency) proportional to the sums and differences of the signals from the four loops, furnish information not only on beam intensity but also on beam transverse position. The units installed in the ring in October have performed excellently and, in a few months, we hope to have eight such devices in use, to assist normal operation of the synchrotron and also to facilitate adjustments during storage mode and operation of the bypass system discussed in Part V.

B. New 120 MeV Linac

During July a team of engineers from Varian Associates, with some assistance from CEA engineers, completed the installation and tune-up of the new linac which had been ordered in June of 1965 for $864,000. On July 29, 1967, a 24-hour acceptance test was completed successfully. When operated in the chopped mode, furnishing one pulse out of six, the linac ran steadily while delivering 110 ma at 122 MeV. Measurements showed that 60% of the beam was within a momentum spread of 1%.

In October we completed the installation of the beam transport system for guiding the linac electron beam into the Circular Tunnel, bending the beam by about 100°, and inflecting it into the synchrotron at Straight Section 29. The transport system includes two

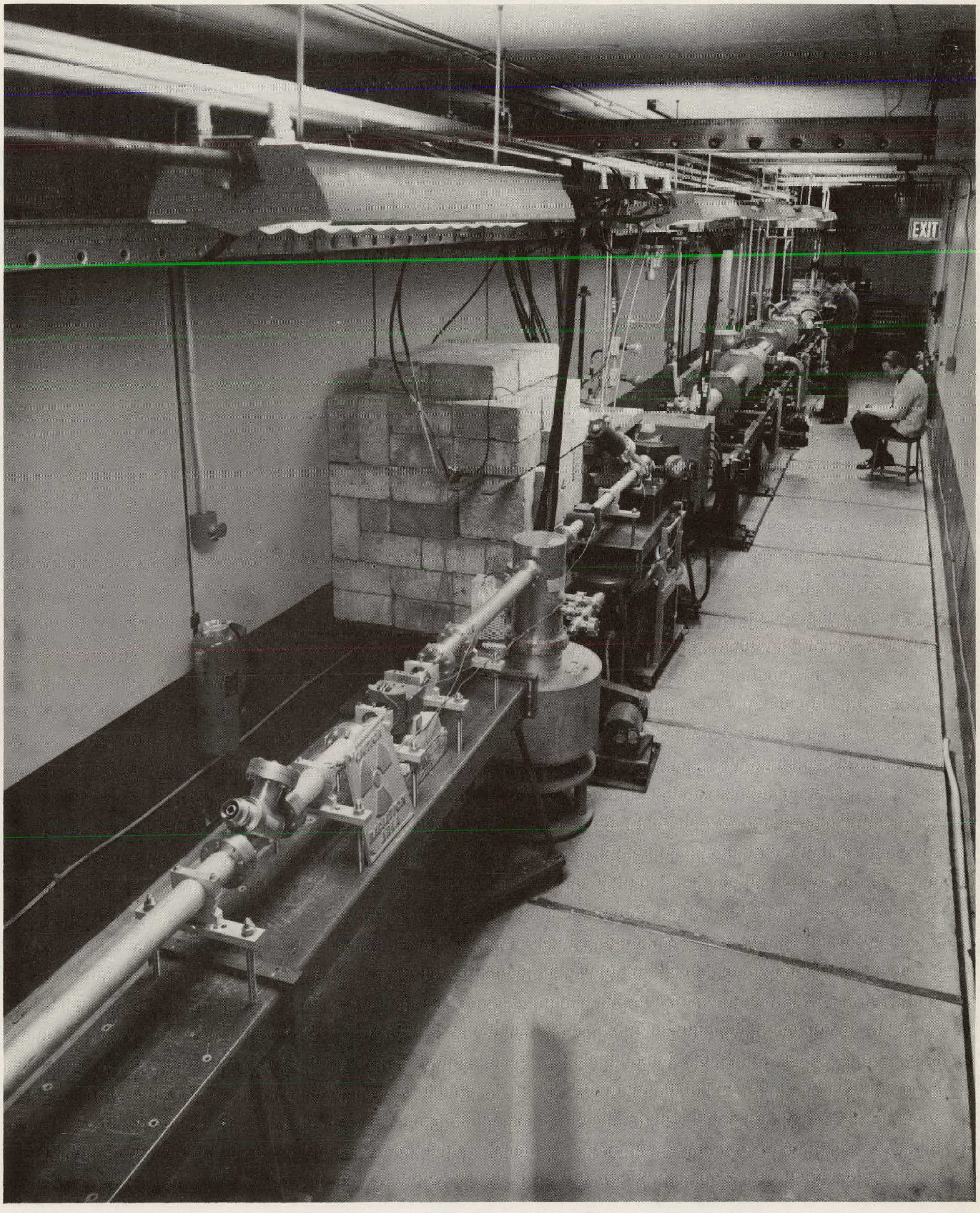


FIG. 2

50-degree bending magnets, various sets of quadrupole focusing magnets, steering coils, monitors, and a shutter for isolating the New Linac Tunnel from the Circular Tunnel. When the synchrotron is operated in normal manner, an on-axis, 10-milliradian inflector is used. The inflector is of gradient type, and has a turn-off time of 0.1 μs.

We subjected the new linac to many trials, and achieved good performance. The emittance ellipse, measured during a run at 130 MeV and 100 ma, was found to conform to specifications. One klystron failed and was replaced.

On November 21 we achieved the first successful injection from the new linac into the synchrotron ring. About 7 ma was injected at 125 MeV with an extremely high (about 85%) circumferential filling factor. On the following day we injected into the synchrotron while it was in cycling mode (see Part V).

On November 28 we succeeded, during normal injection from the new linac, in achieving an intensity of 33 ma of circulating current in the synchrotron ring. This is well in excess of the previous record at CEA (about 22 ma) and well above the design intensity of 21 ma. (33 ma corresponds to 1×10^{13} accelerated electrons per second)

In October we completed construction of a master linkage between (a) the interlock system for the new linac and its tunnel and (b) the interlock system for the old linac, the synchrotron, and associated tunnels.

C. New Engineering Building

In December we signed a $180,000 contract with the L. H. McIsaac Co. for the construction of an Engineering Building adjacent to the Experimental Hall and the truck ramp. The building is to be used by CEA support divisions in assembling and testing large equipments to be installed in the Synchrotron Area, the Bypass Area, or the Experimental Hall. The 40-ton crane for this building was ordered in October. The building is to be completed during the spring of 1968.

D. Support of Experiments

Much effort was given to routine support of experiments, installing new equipment to be used by experimenters in the various areas of the Experimental Hall, and removing equipment no longer needed. In particular, in July we installed a new spectrometer arm for the Kendall, Friedman group, and we received (for use by Pipkin et al) a $9,000. magnet vacuum chamber. In October we installed cabling for a new 1 MW supply to power large experimental magnets, e.g., the Jolly Green Giant magnet used by Brenner, Walker, et al.

In December we completed the rebuilding of the goniometer that is to support and orient a diamond in the orbiting beam, (to produce a polarized photon beam to be used by Osborne et al and by Bar-Yam et al in the Beam 10 Area).

In September we ordered a 10-watt cryogenic refrigerator that will permit direct cooling of hydrogen targets without recourse to helium. In December we completed setting up a test ring for evaluating the cryogenic performance of such equipment. Also, we developed an improved cryogenic valve that greatly reduces the hazards associated with use of liquid hydrogen as target material in a thin-walled container.

To demonstrate the dangers associated with liquid hydrogen targets in thin-walled containers, and to point the way toward better design and better handling, we conducted a number of rupture and explosion tests at the Holliston, Massachusetts, proving grounds of the Fenwall Corporation. The tests were completed in December.

PART V - PROJECT BYPASS

Introduction

Work on Project Bypass progressed well in the six-month period in question.

As explained in previous reports, Project Bypass is a scheme for providing a colliding beam facility (for head-on collisions of electrons and positrons) that will provide excellent luminosity (1.5×10^{31} $(cm^2\ sec)^{-1}$) and uses the existing C.E.A. ring to accelerate and store both an electron and positron beam. Thus the expense and the long period of time required to design and build a separate storage ring are avoided. When completed and put to use late in 1969 or early in 1970 it will be the only high-luminosity electron-positron colliding beam facility in the western world capable of providing 6 or 7 GeV energy in the c.m. system.

Principle of Operation

In brief, the plan is to inject 100 MeV electrons into the existing 240-ft-diameter synchrotron ring in counterclockwise sense and inject 100 MeV positrons into the same ring in clockwise sense. Each of the orbiting beams will be only about 250 ft. long, hence will fill only about 1/3 of the circumference of the ring.

Using multi-cycle, off-axis injection, we will accumulate electron and positron beams having a peak intensity of 100 ma.

Vertical electrostatic fields will be provided to keep the two countercurrent streams of orbiting particles separated vertically -- except at the prearranged interaction station.

Special damping magnets will reduce the horizontal betatron oscillations which otherwise would increase without limit (because of the anti-damping effect of the quantum process of emission of synchrotron radiation). The damping of the horizontal oscillations is accomplished at the expense of some reduction in the (unnecessarily large) inherent damping of the synchrotron, or phase, oscillations. Thus adequate damping of all three modes of oscillations--horizontal, vertical, and longitudinal--is achieved.

When beams of adequate intensity have been accumulated in the ring, the a.c. component of magnet excitation will be turned off (in a few seconds) and the level of d.c. excitation increased until the two countercurrent beams have the desired constant energy. Any desired energy up to 3 or 3.5 GeV can be obtained. (Greater energy could be achieved if we were to provide a larger increase in rf power than is now contemplated).

We will then employ magnetic switches, the fast components of which will be pulsed to have field rise-times of about 100 ns, to deflect the two beams away from the south portion of the existing ring and into a 120-ft. detour that bypasses this portion. (The portion in question extends from Magnet 11 to Magnet 17, inclusive).

The bypass proper, served by direct-current-excited bending magnets, focusing magnets, and sextupole magnets for controlling

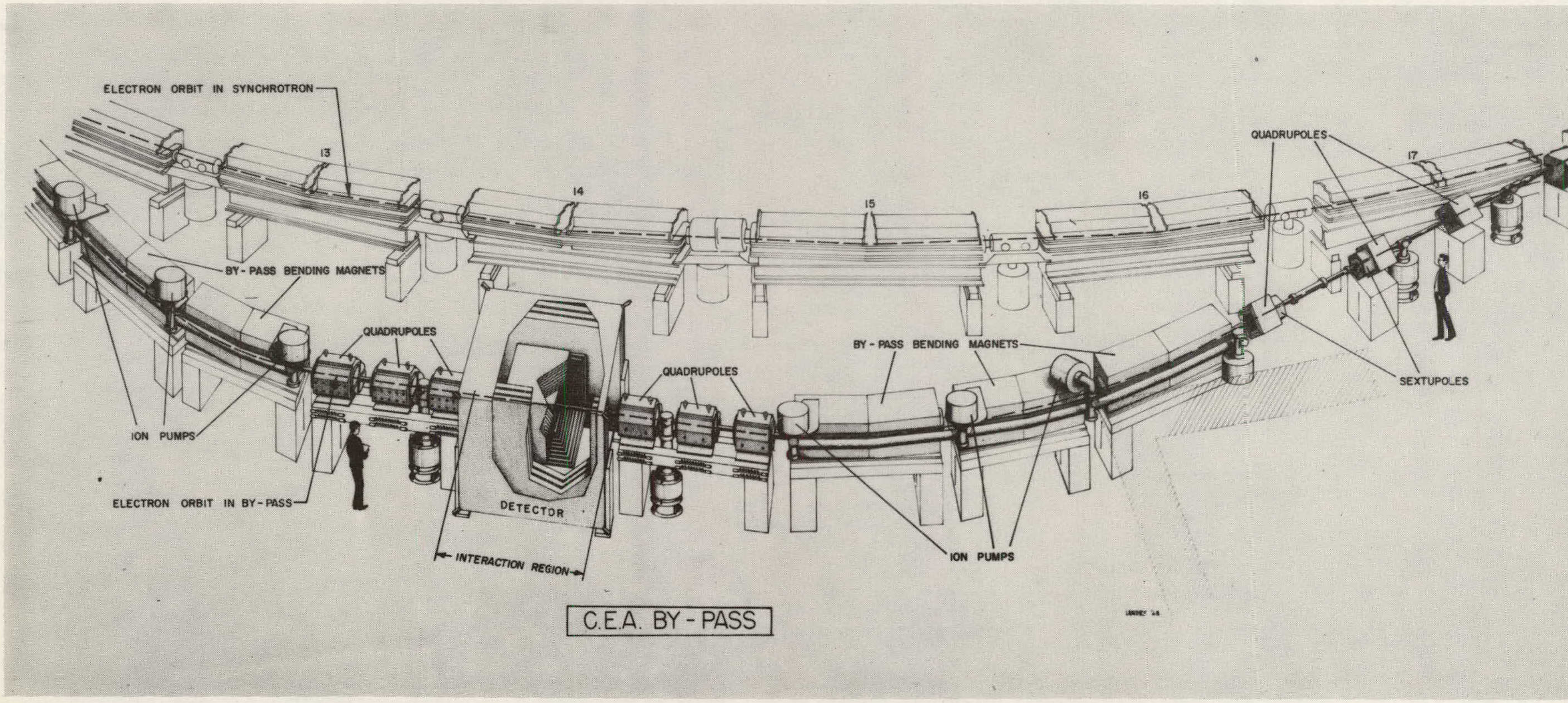

ELECTRON ORBIT IN SYNCHROTRON
13
14
15
16
17
QUADRUPOLES
BY-PASS BENDING MAGNETS
QUADRUPOLES
QUADRUPOLES
BY-PASS BENDING MAGNETS
SEXTUPOLES
ION PUMPS
ELECTRON ORBIT IN BY-PASS
DETECTOR
INTERACTION REGION
ION PUMPS
C.E.A. BY-PASS

FIG. 3

off-momentum particles, will provide an ideal setting for the head-on collisions. Extra-strong focusing, called low-beta focusing, will be provided here and will reduce the cross-sectional area of each beam by a factor of about 140; thus the efficiency of collision (the luminosity) will be increased by more than two orders of magnitude--to about 1.5×10^{31} $(cm^2 \text{ sec})^{-1}$, at 3 GeV. The low-beta focusing tends to minimize beam-beam interactions that might destroy the beams, hence tends to maximize the attainable luminosity.

An 8-ft-long clear space is left available near the center of the bypass, where the two beams collide head-on. Thus there is room for a large and versatile detection system having almost 2π geometry. The two beams do not cross here, but merely become briefly tangent and colinear; the colinearity is controlled by small horizontal electrodes just above and below the interaction region. Because the beams do not actually cross here, there is no conjugate recrossing point, and, again, the tendency for beam-beam interactions to occur is reduced. A particularly high vacuum (about 10^{-9} torr) must be maintained in the interaction region, to reduce the number of spurious events resulting from gas scattering.

To maintain the two orbiting beams, each of 100 ma and 250 ft. long, will require much rf power, in view of the steady loss of energy through synchrotron radiation. Approximately 100 kw of constant rf power will be required. (About 50 kw average is available today for normal operation of the synchrotron).

It is expected that the beam intensities will decay by a factor of two in an hour or two, if the gas pressure in a typical portion of the ring is of the order of 10^{-8} torr. Thus we will wish to resort again to multi-cycle injection of electrons and positrons every hour or two. To reestablish the 100 ma electron beam will take only a few cycles, hence only a fraction of a second. To reestablish the 100 ma positron beam will take several seconds, since the current accepted from the positron source is only about 0.1 ma.

The multi-cycle injection scheme, crucial to the accumulation of 100 ma peak beams of positrons and electrons, deserves further comment. During multi-cycle filling of the ring, we will use an off-axis injection accomplished with three kicker magnets and a septum magnet. The kickers, turned on in approximately 1 microsec., move the equilibrium orbit close to the septum magnet. The septum magnet, powered by direct current, produces a small deflection ($\sim$ 10 mr) of the newly injected 100 MeV particles such that they will cross the paths of particles already in orbit; the newly injected particles will have, initially, a large horizontal betatron oscillation amplitude ($\sim$ 15 mm amplitude). The kicker magnet is then de-energized and the distortion of the equilibrium orbit disappears. During the ensuing 8 ms of acceleration, the streams of new and old particles come closer together because of adiabatic damping and synchrotron-radiation damping. During the next 8 ms of <u>deceleration</u> there is adiabatic <u>anti</u>damping, but the synchrotron-radiation damping due to the damping magnet continues. The overall effect is that, in the 16 ms cycle time, there is damping in all three modes: horizontal and vertical betatron oscillations and synchrotron oscillation, and the two streams begin to coalesce to form a single stream. In the 16-ms cycle period, the multiplicative damping factor applicable to the two forms of betatron oscillation is about 0.7, and that applicable to the synchrotron oscillations is about 0.4. The coalescence process continues, of course, in subsequent cycles. But the important point is that, even in one cycle, the coalescence is great enough so that an adequate amount of phase space is freed to permit fresh injection of another pulse of particles.

Thus new pulses of particles may be injected every 16 ms, or 60 times a second, and one may expect to achieve a beam intensity build-up factor approaching 60 in a one-second interval--if the intensity does not approach whatever ceiling is established by rf power limitations or other limitation. In several seconds a build-up factor of the order of <u>hundreds</u> may be expected, if the ceiling is not approached. For electrons, injected at the rate of perhaps 10 to 50 ma per pulse, only a few pulses of multi-cycle injection are required; but for positrons, injected at a rate of perhaps 0.1 ma per pulse, several seconds of multi-cycle injection will be called for.

* * *

The bypass hardware and controls are such that, on a few hours' notice, the Operations Crew will be able to reconvert the entire facility for use in normal manner, to supply 0 to 6 GeV beams of electrons or photons to the various areas of the Experimental Hall.

Status of Components of Bypass and Results of Tests

The new linac, installed in July 1967 in the newly constructed tunnel adjacent to Radial Tunnel 26, has been operated routinely at the intended energy and intensity: about 100 MeV and 100 ma. Despite some small initial difficulties, it promises to run steadily and well.

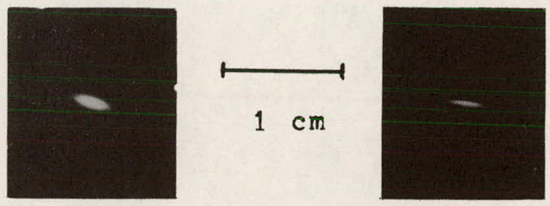
The positron source and accelerating linac were ordered on July 26, 1967, from Varian Associates for $494,000. This equipment will provide a maximum energy of 130 MeV; it will utilize an 85 MeV electron beam of 300 ma intensity and will produce a 0.82 ma beam of positrons, 50% of which are to be within a 2% momentum spread and an acceptance of 11.2 milliradian centimeter. Delivery is scheduled for the first half of 1969.

The equipment for bending the beam of 100 MeV electrons by about 100° has been installed and operated extensively. The off-axis septum-type inflector and the ferrite-core kicker magnet, also, have been used successfully in many trials. Expectations as to damping rates have been confirmed, and beam intensity build-up factors as large as 200 have been achieved. We built a synchronizer unit that insures that the two main kicker magnets will be energized at the proper time in the cycle, and will fire at the same instant within about 10 ns.

A novel type of beam-lifetime monitor, requiring only 1/2 sec. to measure lifetimes as short as seconds or as long as an hour, has been developed and used on many occasions. It involves use of a phototube to monitor the slowly declining intensity of visible synchrotron radiation emitted by the slowly diminishing orbiting beam of particles. The CRO or digital presentations of half-life values occur almost as quickly as one can adjust the parameters controling beam life; thus--while employing just one filling of the ring--an operator can make many trial-and-error adjustments and ascertain the effect of each. The new monitor has enormously simplified the task of understanding the various influences on beam lifetime and optimizing the control parameters.

Improved monitors of beam intensity and beam position, essential to reliable control of individual beams or a set of two counter-current beams, were developed and put to use. Details are presented in Part IV.

A highly successful means of determining the actual size and shape of the beam cross-section was developed in the fall of 1967 and demonstrated successfully in December. The cross section is photographed by means of synchrotron x-radiation (of about 1 A.U. wavelength, emitted by the orbiting particles themselves) photographed with the aid of a pinhole camera. The method provides eight



$I_{PFW} = 0$ A $\qquad I_{PFW} = 5$ A

STORED BEAM 3 GeV

FIGURE 4

Cross-section of stored 3 GeV beam of electrons as measured with x-ray pinhole camera making use of x-ray synchrotron radiation, Dec. 21, 1967, magnification 1.6. The two photographs show different amounts of horizontal-to-vertical cross-coupling of betatron oscillations. Two different pole-face-winding currents were used. The right picture indicated a beam height of 0.2 mm in a synchrotron straight section. The precision of height determination is estimated to be 0.06 mm.

times the optical resolution attainable using <u>visible</u> light emitted by the particles; the lobe-width of the visible light is simply too narrow to provide high enough resolution. Using the pinhole x-ray photography method we found that, under typical circumstances of storing 3 GeV electrons (and with a relatively high pressure of 10^{-6}torr) the height of the cross section is 0.2 mm, which is in accord with predictions and confirms our expectations of achieving, with countertraveling electrons and positrons, in a vacuum of 10^{-8} to 10^{-9} torr, a luminosity of the order of 1.5×10^{31} $(cm^2 sec)^{-1}$.

The development and procurement of vacuum chambers capable of withstanding the high intensity of synchrotron radiation and capable of providing a pressure as low as 10^{-8} or 10^{-9} torr has been discussed in Part IV. The chambers can be baked out at temperatures of about 175°C, and seem virtually unaffected by the prolonged exposure to nuclear radiations encountered in the synchrotron ring. There is room in the chambers for installing water-cooled strips placed so as to absorb most of the synchrotron radiation (which streams outward horizontally, and might irradiate the wall of the vacuum chamber sufficiently to produce gas by thermal evolution and also by photo-desorption).

We have found how to recondition our Drivac titanium-ion high-vacuum pumps so that, under no-load conditions, they will maintain a vacuum as high as 3×10^{-10} torr. By December 31 we had reconditioned a majority of the Drivac pumps. In the bypass proper we plan to use six General Electric Co. titanium-ion high-vacuum pumps, many of which were in place by December 31. A Westinghouse Electric

Corporation ultrasonic degreasing bath for cleaning components to be used at 10^{-8} or 10^{-9} torr is on hand and has been used successfully.

A power supply that will make it possible for us to supply 100 kw of 476 Mhz power to the rf acceleration system (as compared to the 50 kw average available at present) is now on hand and is to be installed in a few months.

In July 1967 the firm of Spencer, White, and Prentis completed the excavation of a special passageway, at the northeast end of the Target Area, required for installation of the magnets and beampipes comprising the northeast portion of the bypass.

Construction of the magnetic switching system for guiding the orbiting 3 GeV beams into, or out of, the bypass is about 70% complete. Two systems are required: one near each end of the bypass. Each consists of two elements: (1) a fast-acting ultraflector providing a small (∿ 5 mr) deflection but capable of being turned on in 100 ns, i.e., about 1/7 the time it takes a particle to make one turn around the orbit, and (2) a septum magnet which does not have to be turned on or off quickly, hence can be designed to provide a much larger deflection (about 35 mr). The ultraflector is turned on in the small interval (about 0.3 μs) in which no particles are passing by; and when the particles later come by they are deflected here just enough so that they engage the septum, situated about 45 ft. away. The septum then produces the large deflection required by the geometry of the bypass. The components of the ultraflectors and septums are on hand and assembly is about

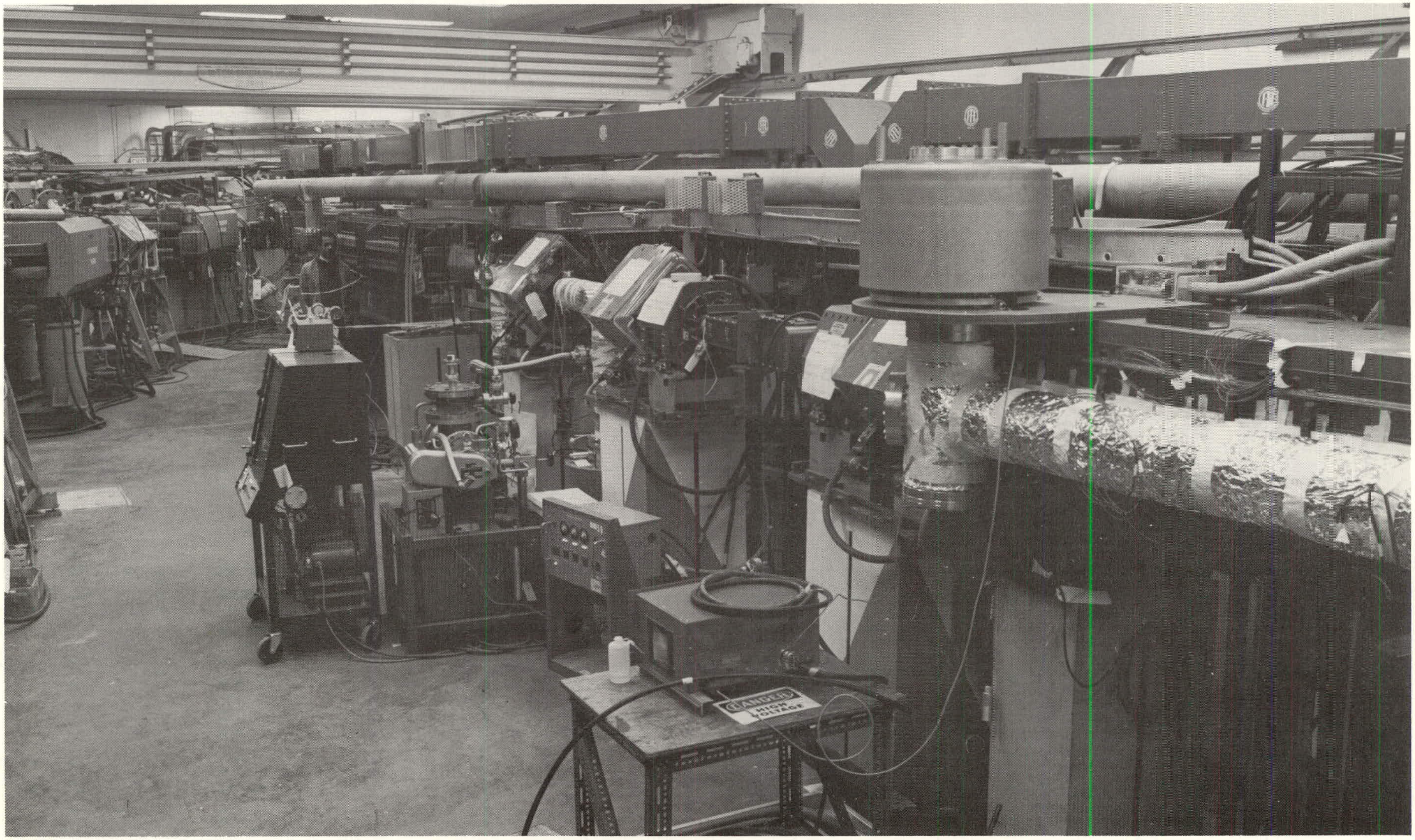


FIGURE 5 General view of west half of the CEA bypass, in the Target Area, as of January 31, 1968. Near the center of the photograph are several quadropole and sextupole magnets of the bypass. At the right a bending magnet may be seen, partly obscured by the jacketed and foil-wrapped plenum. The midpoint of the bypass (the interaction station) is not shown, but it is just off to the right. The technician is standing beside the west end of the bypass, where it joins the synchrotron ring. The equipment shown at the extreme left has nothing to do with the bypass, but serves the external electron beam runs.

50% complete. The construction of the special power supplies is essentially complete. Such a supply consists of two parts, one providing the fast (100 ns) rise and the other providing a steady holding current that remains constant to within 0.1%.

The main components of the bypass proper are (1) six bending magnets, to define the curved portions of the particle trajectories, (2) twelve quadrupole magnets to provide the necessary focusing and low beta, (3) four sextupole magnets to correct the trajectories of off-momentum particles, (4) six special stainless steel tanks to serve as beam pipes and provide the necessary pneumatic conductance along the trains of bending magnets, (5) six General Electric Co. titanium-ion high-vacuum pumps, (6) beam monitors of various types. By December 31, 1967, nearly all of these components had been received, assembled, tested, and made ready for installation in January 1968. Special methods of aligning the equipment were worked out, and, as a preliminary preparation, the heights of the 48 magnets were resurveyed. Concrete support blocks for the main components of the bypass were in place, and the installation of the necessary cable trays, cabling, water cooling, etc., was started.

In November, using the New Linac, we successfully accomplished off-axis multi-cycle injection. We were then able to accumulate an electron current about ten times that which resulted when we used single-cycle injection. We believe that this was the first successful multi-cycle injection into any strong-focusing accelerator

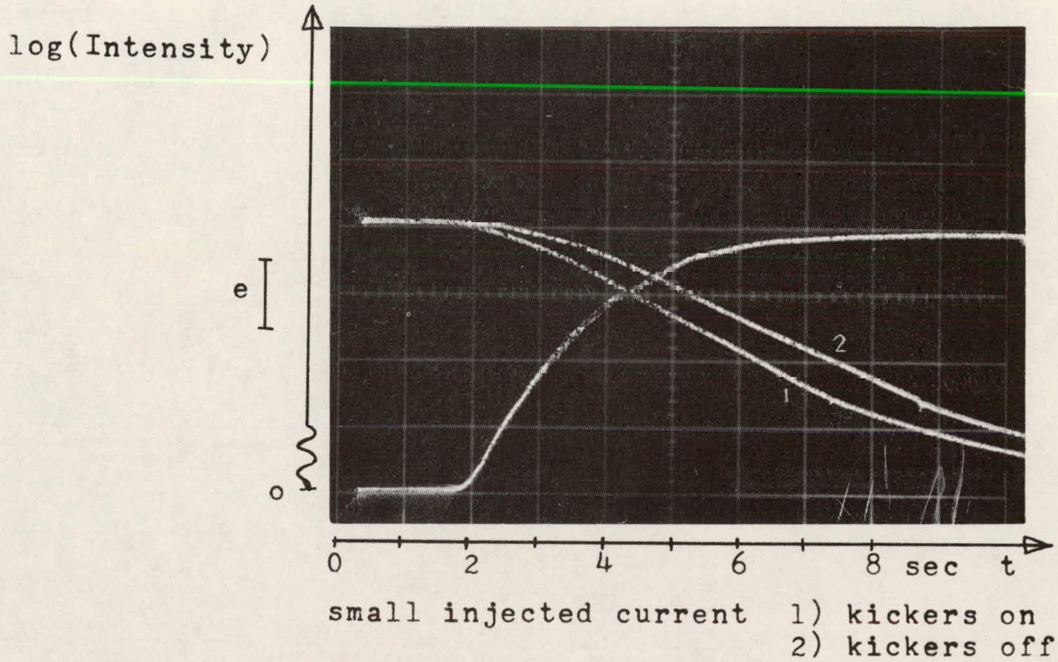


FIGURE 6

Multicycle injection with improved control, Dec. 21, 1967. The rising curve indicates a build-up factor of 180, and a time constant of build-up of 3 seconds. The falling curves show the decay after injection has been stopped permanently, with two different conditions of ejection kicker-magnet operation. The decay curves' deviations from linearity are probably due to non-linearity in the current monitor used.

anywhere. On December 21 we made further multi-cycle injection tests; and, using better controls, we achieved a build-up factor of 180 and a time-constant of build-up of the order of 3 seconds.

Thus, in general, Project Bypass is coming well, and on schedule. No notable unforeseen difficulties have yet been encountered. If the positron source arrives on schedule, we could be ready for starting colliding beam experiments late in 1969 or early in 1970.

PART VI - SAFETY

During the six-month period in question there were no lost-time accidents at CEA. A number of meetings of the Safety Committee were held. Fire protection sytems were installed in the New Linac Tunnel and in the New Linac Control Area. The ventillation system for the Vacuum Shop, where toxic epoxy vapors might constitute a hazard to health, was greatly improved. Safety tests on liquid hydrogen targets were carried out, (see Part IV) and likewise tests on fire alarm and flammable gas detection systems. Several training sessions on safety were held.

Radiation levels in outdoor and indoor work areas were held well below the permissible levels, and personal film badges showed that all doses to persons were well within permissible limits.

Inspection tours were made by safety engineers from the US AEC, the Commonwealth of Massachusetts, and from Harvard and M.I.T.

PART VII

SIXTH INTERNATIONAL CONFERENCE ON HIGH-ENERGY ACCELERATORS

The Sixth International Conference on High-Energy Accelerators was held at Cambridge, Massachusetts, September 11 - 15, 1967, with the CEA serving as host. Dr. M. S. Livingston was Conference Chairman, and Dr. W. A. Shurcliff was Conference Secretary. R. A. Mack was Editor of the Conference Proceedings. The Conference was sponsored and supported by the Atomic Energy Commission.

Invitations, arranged with advice from the International Union of Pure and Applied Physics, were sent out in January 1967. By the end of May about 140 manuscripts of papers had been received, and by mid-June a compact five-day program had been formulated. In July a program pamphlet was mailed to all invitees. In August an abstract volume was prepared, and plans for lecture halls, session chairmen, public address systems, registration facilities, etc., were completed. We succeeded in obtaining the services of Russian-English and English-Russian interpreters who had familiarity not only with the languages in question but with the subject of high-energy physics. A revised program pamphlet was prepared and distributed on September 11.

On September 11 the 300 invitees arrived and registered, and the Conference began. A total of 94 papers were presented orally, and another 50 were presented for publication only. During many of the sessions, talks were given in two halls simultaneously. Two special discussion sessions were held--on boosters and on limitations on intensity in high-energy accelerators. Ample periods for relaxed and informal discussion were provided. There was a reception, and several private dinners were arranged. A half-day excursion to the Crane's Beach area of Ipswich, Mass. was especially enjoyable.

The consensus was that the Conference was an unusually pleasant and valuable one.

A notable feature of the Conference was a paper by Veksler, and 16 co-authors (and actually presented by Kolomenskii) on "Collective Linear Acceleration of Ions", this being the first available paper presenting specific information on this most interesting new method of accelerating protons to multi-GeV energies. The method is now attracting attention in many laboratories here (especially at Lawrence Radiation Laboratory) and abroad.

The editing of the Conference Proceedings was completed quickly, and by December 31 the printing was nearly complete.

PART VIII - PUBLICATIONS RESULTING FROM WORK DONE AT THE CEA

A. Publications on High-Energy Research Performed at CEA

Photoproduction of Single-Charged Pions from Deuterium and Hydrogen, Z. Bar-Yam, J. de Pagter, M. M. Hoenig, W. Kern, D. Luckey, L. S. Osborne, Phys, Rev. Ltrs. 19, 40 (July 3, 1967).

Search for S = + 1 Baryon States in Photoproduction, J. Tyson, J. S. Greenberg, V. W. Hughes, D. C. Lu, R. C. Minehart, S. Mori, J. E. Rothberg, Phys. Rev. Ltrs. 19, 255 (July 31, 1967).

Search for Leptonic Quarks, J. Foss, D. Garelick, S. Homma, W. Lobar, L. S. Osborne, J. Uglum, Phys. Ltrs. 25B, 166 (August 7, 1967).

Quasi-Elastic Electron-Deuteron Scattering at Forward Angles, R. Budnitz, J. Appel, L. Carroll, J. Chen, J. R. Dunning, Jr., M. Goitein, K. Hanson, D. Imrie, C. Mistretta, J. K. Walker, R. Wilson, Phys. Rev. Ltrs. 19, 809 (Oct. 2, 1967).

Experimental Test of Electron-Scattering Sum Rules for Carbon, W. L. Faissler, F. M. Pipkin, K. C. Stanfield, Phys. Rev. Ltrs. 19, 1202 (November 13, 1967).

Photoproduction of π^+ Mesons at 3.4 and 6.5 BeV, P. M. Joseph, N. Hicks, L. Litt, F. M. Pipkin, J. J. Russell, Phys. Rev. Ltrs. 19, 1206 (November 13, 1967).

Apparatus for Measuring Photoproduction Reactions in the GeV Range with On-Line Data Analysis Facilities, Z. Bar-Yam, V. Elings, D. Garelick, P. Lewis, W. Lobar, P. D. Luckey, L. Osborne, S. Tazzari, J. Uglum, R. Fessel, Nuclear Instruments and Methods 56, 1, (November 1967).

Evidence for Photofission of Iron, C. B. Fulmer, I. R. Williams, T. H. Handley, G. F. Dell, L. N. Blumberg, Phys. Rev. Ltrs. 19, 522 (August 28, 1967).

Photoproduction of Antineutrons and Antiprotons for Photon Energy Between 4.0 and 5.7 BeV , D. Earles, M. Gettner, G. Glass, Y. Laohavanich, E. von Goeler, R. Weinstein, D. Garelick, Phys. Rev. Ltrs. 19, 922, (October 16, 1967).

Observation of Photoproduced Neutral K Mesons, J. F. Schivell, E. Engels, Jr., A. Entis, Phys. Rev. Ltrs. 19, 1349 (December 4, 1967).

Photoproduction of K^+ Mesons at 3.4 and 5.0 GeV, P. M. Joseph, N. Hicks, L. Litt, F. M. Pipkin, J. J. Russell, Phys. Ltrs. 26B, 41 (December 11, 1967).

Production of the N* (1238) Necleon Isobar by Photons of Energy up to 6 BeV, Cambridge Bubble Chamber Group, Phys. Rev. 163, 1510 (November 1967).

Fission Product Yields from 1.5 and 3.0 GeV Electrons on Uranium, I. R. William, C. B. Fulmer, G. F. Dell, M. J. Engebretson, Phys. Ltrs. 26B, 140 (January 8, 1968).

Ratio of Λ and Σ° Photoproduction Cross Sections; High-Mass Hyperon Resonances, J. S. Greenberg, V. W. Hughes, D. C. Lu, R. C. Minehart, S. Mori, J. E. Rothberg, J. Tyson, Phys. Rev. Ltrs. 20, 221 (January 29, 1968).

B. Theses on High-Energy Research performed at CEA

Quasi-Elastic Electron-Deuteron Scattering, Thesis by R. J. Budnitz of Harvard, July 1967.

Wide-Angle Electron-Positron Pair Production, Thesis by K. J. Cohen of MIT, August 1967.

Total Cross-Section for Photoproduction of Electron-Positron Pairs, Thesis by T. M. Knasel of Harvard University, December 1967.

Photoproduced and Electroproduced Muon Pairs, Thesis by P. Rothwell of Northeastern University, June 1967.

Associated Production of Charged K Mesons and Hyperons, Thesis by J. Tyson of Yale, 1967.

C. Papers Given at September 1967 SLAC Electron Photon Conference, re High-Energy Research Performed at CEA

Invited Papers

Experiments on Inelastic Electron Scattering, L. Hand

Photoproduction of Strange Particles, K. Strauch

Diffraction Production, F. M. Pipkin

Experimental Quantum Electrodynamics, R. Weinstein

Spectrometers and Their Specifications, R. Wilson

Contributed Papers

Photoproduction of K^+ Mesons at 3.4 and 5.0 BeV, P. Joseph, N. Hicks, L. Litt, F. Pipkin, J. Russell.

Experimental Test of Electron Scattering Sum Rules for Carbon, W. Faissler, F. Pipkin, K. Stanfield.

The Incoherent Scattering Function, the Total Pair Production, Cross Section, and the Pair Production Length for Helium, T. M. Knasel.

Production of the N**(1238) Nucleon Isobar by Photons of Energy up to 6 BeV, Cambridge Buble Chamber Group - Weizman Inst.

Angular Distributions for Single Pion Electroproduction, Mistretta, Appel, Budnitz, Carroll, Chen, Dunning, Goitein, Hanson, Imrie, Litke, R. Wilson.

Proton Compton Effect at 60° CM for $0.57 < h < 1.85$ GeV, Deutsch, Loh, Marini, Patel, Stiening, Tsipis.

Quasi-Elastic Electron-Deuteron Scattering at Forward Angles, Budnitz, Appel, Carroll, Chen, Dunning, Goitein, Hanson, Imrie, Mistretta, Walker, and R. Wilson.

Photoproduction of Antineutrons and Antiprotons for Photon Energy Between 4 and 5.7 BeV, Earles, Gettner, Glass, Laohavanich, Von Goeler, Weinstein, Garelick.

Photoproduction of Muon Pairs, Weinstein et al.

Photoproduction of Kaons on Hydrogen: Evidence for New S = + 1 and S = - 1, Baryon States, J. S. Greenberg, V. W. Hughes, D. C. Lu, R. C. Minehart, S. Mori, J. E. Rothberg, J. Tyson.

D. Papers Given at 6'th International Conference on High-Energy Accelerators, September 11 - 15, 1967, at Cambridge, Mass.

Colliding Beam Project at the CEA, A. Hofmann, R. Little, H. Mieras, J. M. Paterson, G. A. Voss, H. Winick.

Design of the CEA Colliding Beam Bypass, H. Mieras, G.A. Voss.

Design and Performance of the Damping System for Beam Storage in the CEA, A. Hofmann, R. Little, J. M. Paterson, K. W. Robinson, G. A. Voss, H. Winick.

Radiation Effects in Multicycle Injection, K. W. Robinson.

RF Beam Dynamics in the CEA Storage Experiment, J. Dekleva, G. L. Nicholls.

Beam Switching System for the CEA Bypass, H. J. Greenberger, L. A. Law, J. M. Paterson.

Multi-Purpose Monitor for the Beam in an Electron Synchrotron, B. Anderson, S. M. Matin.

E. Other Papers on High-Energy Research Performed at CEA

Photoproduction of Hyperon Resonances with Strangeness +1 and -1, V. W. Hughes et al, at September, 1967, Heidelberg Conference.

F. CEA Reports, Type "CEAL".

Semi-Annual Report for the Period July 1 - December 31, 1966. Report CEAL-1036, M. S. Livingston, July 14, 1967.

RF Beam Dynamics in the CEA Storage Experiment. Report CEAL-1037, J. Dekleva, G. L. Nicholls, August 17, 1967.

Semi-Annual Report for the Period January 1 - June 30, 1967. Report CEAL-1038, K. Strauch, December 15, 1967.

Proceedings of the Sixth International Conference on High-Energy Accelerators, 1967. Report CEAL-2000, R. A. Mack, Editor. December 1967.

G. CEA Reports, Type "CEAL-TM"

Depolarization of Electrons. Report CEAL-TM-171, K. W. Robinson, December 11, 1967.

Detector of Polarized Electrons. Report CEAL-TM-172, J. Dekleva, August 27, 1967.

Bending Magnet Measurements: Orpheus and Grenada. Report CEAL-TM-173, L. Litt, August 25, 1967.

* * * * * * * * * *