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CEAL- 1053

SEMI-ANNUAL REPORT

For the Period

January 1 through June 30, 1970

Karl Strauch
Director

November 30, 1970

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
and HARVARD UNIVERSITY

CAMBRIDGE ELECTRON ACCELERATOR

CAMBRIDGE, MASSACHUSETTS 02138

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SEMI-ANNUAL REPORT

For the Period

CTRE, 01 JANUARY 1970
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.

Director

November 30, 1970

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CEAL-1053

TABLE OF CONTENTS

	<u>Page</u>
SUMMARY	1
Part I INTRODUCTION	3
A. Revision of Laboratory Program	3
B. Committees and Boards	7
Part II ACCELERATOR OPERATION	9
A. Statistics on Accelerator Use	9
B. Operation, Maintenance, and Minor Improvements	10
Part III EXPERIMENTS IN HIGH-ENERGY PHYSICS	25
A. Experiments in Analysis-of-Data Stage	25
B. Experiments in Data-Taking Stage	33
Part IV PROJECT BYPASS	37
A. Introduction	37
B. Bypass Trials	39
C. Multicycle Injection Studies	40
D. Single-Beam Instabilities	41
E. Simultaneous Storage of Electrons and Positrons	42
F. On-Line Detector (BOLD)	43
G. Optical Detector	46
H. Magnetic Detector	46
Part V OTHER ACTIVITIES IN HIGH-ENERGY PHYSICS	48
A. Theoretical Studies in Particle Physics	48
B. Design Studies of a Miniature Storage Ring for Production of Light of Very High Monochromaticity	48
C. Source of Polarized Electrons	48

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	<u>Page</u>
Part VI OTHER PROGRAMS	50
A. Safety	50
B. Training of Disadvantaged Persons	50
PART VII PUBLICATIONS RESULTING FROM WORK DONE AT THE CEA .	51
A. Publications on High-Energy Research Performed at CEA	51
B. Papers Presented at Conferences and Meetings	53
C. Theses on High-Energy Research Performed at CEA	54
D. CEAL Reports	55
E. CEAL-TM Reports	55

CEAL-1053
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SEMI-ANNUAL REPORT FOR THE PERIOD

January 1 - June 30, 1970

SUMMARY

Part I indicates the purpose of the contract: to operate and improve the 6-GeV Cambridge Electron Accelerator. The 30% reduction in funds for FY 71 and the consequent curtailments of experiments in progress and concentration of effort on the colliding beam project are discussed.

Part II, on accelerator operation for experimenters, shows that the total number of delivered prime-user hours and parasite-user hours in the first half of 1970 was 4502. The number of delivered prime-time hours was 2628 compared to 3018 originally scheduled; the delivery factor was 0.87.

Part III describes the 18 experiments that were underway.

Part IV summarized progress on the development of the colliding beam facility in which electron and positron beams,

each with an energy of 3.5 GeV, will collide with an available energy of 7.0 GeV in the center-of-mass system. By the end of June we had succeeded in accumulating (in the cycling mode) stored electron and positron beams with peak currents of 25 and 11 mA respectively. Changeover from cycling mode storage to dc storage was accomplished with an efficiency exceeding 90% at peak beam currents of 3 mA or less. Unacceptable losses still occurred at large beam intensities. (As of November 1970 this loss problem had been cured.) A dc-stored-beam 1/e lifetime of two hours was achieved. Electron beams were switched into the bypass successfully, with a 1/e lifetime of 45 minutes. Construction of the components of the core of the on-line detector was nearly completed and tests with 3-GeV positron beams from the accelerator showed the performance to be in accord with expectations. Progress was made on the design and construction of second-generation detectors.

Part V discusses theoretical studies, design studies of a miniature storage ring for producing light of very high monochromaticity, and development of equipment for producing a beam of polarized electrons.

Part VI deals with safety and training.

Part VII lists the major publications.

PART 1 - INTRODUCTION

This report summarizes work done under the Harvard-AEC Contract AT(30-1)-2076 during the six-month period from January 1 through June 30, 1970. The contract calls for the operation and maintenance of the CEA 6-billion-electron-volt synchrotron and for designing, procuring, installing and operating various essential facilities. At present our efforts are concentrated on constructing a colliding beam facility, described in Part IV.

A. Revision of Laboratory Program

On February 2, 1970, we were informed by Dr. P. W. McDaniel, Director of the AEC Research Division, that the Laboratory's FY 71 operations funds were to be reduced to \$2.4 M, compared to \$3.475 M in FY 70, and that "..... it is anticipated that this level of funding will permit the colliding beam program to be maintained but will probably force cessation of conventional electromagnetic experiments at CEA".

It was immediately apparent that reduction by about one third of the CEA 180-man staff by July 1, 1970, would be necessary, and that no longer would it be possible to pursue in parallel (1) the development of the colliding beam facility, and (2) the running of experiments with electron and photon beams.

After conferring with CEA staff members, users of the CEA, members of M.I.T. and Harvard physics departments and

administrations, the CEA Director met with the Scientific Subcommittee on February 6th to draw up specific recommendations. On February 9th the resulting recommendations were presented to the Executive Committee of the CEA, which unanimously approved (1) a reduction in personnel from 180 to 112, (2) the plan (to start June 1, 1970) of concentrating, for a while, all effort on the colliding beam project, and (3) a mechanism for deciding how to distribute the accelerator shifts available up to June 1 among the active experiments. Conventional experiments, to be phased out by that date, would be put into storage ready to be reactivated if this should prove desirable and possible. In addition, activities such as the theoretical work by the Theoretical Physics Group and the development of a source of polarized electrons were to be curtailed as rapidly as possible.

The decision to no longer pursue a laboratory program balanced between electron-photon-beam physics and colliding-beam physics was reached with great reluctance. However, the budget reduction forced a reduction in laboratory activity and made a choice inescapable. There was complete agreement that (1) the colliding beam program was the most exciting half of the laboratory program since it opens a new window into the problems of particle physics, (2) even at the reduced rate of funding, CEA will remain a great scientific asset to the local community and the U.S. and will continue to deserve the strong support of the physics community.

A special committee consisting of Prof. F. E. Low (MIT), Prof. J. C. Street (Harvard), Prof. D. Yennie (Cornell), and Prof. A. Silverman (Cornell) was assigned the task of recommending the distribution of accelerator time available up to June 1, 1970, among the active electron-photon-beam experiments. This group met on February 16 and recommended the following distribution of accelerator 8-hour shifts:

- 50 shifts to Pipkin et al for the experiment on electroproduction of pions,
- 34 shifts to Bar-Yam, Luckey, Osborne et al for the experiment on photoproduction of π^+ in the resonance region with polarized photons,
- 25 shifts to Russell and Tannenbaum for the experiment on photoproduction of neutral bosons in the mass range from 500 to 1800 MeV, with Deutsch and Rutherford making concurrent use of the beam for their experiment on recoil proton polarization in π^0 photoproduction.

In fact, thanks to special efforts made to increase the efficiency of accelerator operation during this period, the amount of useful accelerator time made available to experimenters was greater than had been expected. The actual distribution of accelerator time in March, April, and May was as follows.

Group	Delivered Machine Hours	
	Prime	Parasite
Pipkin et al	456.5	13.5
Bar Yam-Luckey-Osborne et al	183.0	664.0
Russell-Tannenbaum et al	382.0	167.0
Deutsch-Rutherford et al	9.5	406.0
Yuan et al	0	203.0
	1031.0	1453.5

The major experimental installations in the Experimental Hall are being maintained intact so as to permit further data taking on short notice. These include:

Area 4 equipment recently used by Deutsch-Rutherford et al (MIT-Tufts) in Experiment 114b: Recoil Proton Polarization in π^0 Photoproduction near $t = -0.30(\text{GeV}/c)^2$.

Area 5 equipment recently used by Russell-Tannenbaum et al (Harvard) in Experiment 107a: Boson Resonance Photoproduction.

Area 7 equipment recently used by Pipkin et al (Harvard) in Experiment 121a: Elastic π^+ Electroproduction near 0° and at Pion-Nucleon c.m. Energies above the Nucleon Resonances.

Area 10 equipment recently used by Bar-Yam et al (SMU) and Luckey-Osborne et al (MIT) in Experiment 109j: Asymmetry in Single Pion Photoproduction, by Polarized Photon, in the Resonance Region, and Experiment 117b: Photoproduction of Single Charged Pions by Polarized Photons of 3-GeV Energy.

B. Committees and Boards

The general policies of the Laboratory are determined by a joint MIT-Harvard "Executive Committee of the CEA". In 1969-70 this committee included the following:

from MIT: Dr. Malcolm G. Kispert
 *Prof. Francis E. Low
 *Prof. Louis S. Osborne
 *Prof. Victor F. Weisskopf
 Prof. Jerome B. Wiesner, Chairman

from Harvard: Dean John T. Dunlop
 *Prof. Francis M. Pipkin
 *Prof. J. Curry Street
 Mr. L. Gard Wiggins
 *Prof. Richard Wilson

The Cambridge Electron Program Advisory Committee (CEPAC) reviews the status of experiments in progress and examines proposals for future experiments. CEPAC serves in an advisory capacity to the Director. During the half-year in question, this committee included, in addition to the Director:

Prof. Samuel Berman, SLAC
Prof. Louis N. Hand, Cornell
Prof. Clemens A. Heusch, Cal. Tech.
Prof. Francis E. Low, MIT
Prof. Louis S. Osborne, MIT
Prof. Burton Richter, SLAC
Prof. Roy Weinstein, Northeastern
Prof. Richard Wilson, Harvard
Prof. Donald Yennie, Cornell
Dr. Gustav-Adolf Voss, CEA
Dr. James M. Paterson, CEA, Secretary

*denotes member of Scientific Subcommittee

The CEA Visiting Board reports to the presidents of MIT and Harvard. Its membership in 1970 was:

Dr. James B. Fisk, Chairman
President, Bell Telephone Laboratories

Prof. James W. Cronin
Dept. of Physics, Princeton University

Prof. Maurice Goldhaber
Director, Brookhaven National Laboratory

Prof. J. David Jackson,
Dept. of Physics, Univ. of Calif., Berkeley

Prof. Boyce D. McDaniel
Director, Lab. of Nuclear Science, Cornell

Prof. W. K. H. Panofsky
Director, Stanford Linear Accelerator Center

PART II - ACCELERATOR OPERATION

A. Statistics on Accelerator Use

During the period January 1 - June 30, 1970, the distribution of accelerator time and the efficiency were as shown in Table 1.

Table 1

Accelerator User Hours in First Half of 1970					
Month	Delivered Prime Time			Parasite Time	Total
	High Energy Physics	Accelerator Physics(a)	Total	1st & 2nd Parasites	(Prime & Parasite)
January	328	172	500	265	765
February	160	43	203	132	335
March	420	106	526	621	1147(b)
April	192	90	282	338	620
May	420	96	516	518	1034
June	7(c)	594(c)	601	0(c)	601
Total	1527	1101	2628	1874	4502

Notes: (a) Includes development of the colliding beam facility as well as general development of the accelerator.

(b) Highest user-hour figure for any month in the history of the accelerator.

(c) As explained elsewhere, all regular experimentation ceased at the end of May to permit concentration of efforts on the colliding beam project.

As the number of scheduled prime hours was 3018 and the number of delivered prime hours was 2628, the delivery factor was $2628/3018 = 87\%$.

The distribution of machine time delivered to high-energy physics prime and parasite users was as shown in Table 2.

Table 2

Machine Time (hours) Delivered to High-Energy Physics
Prime and Parasite Users

User	<u>Delivered Time (hours)</u>	
	Prime	Parasite
Pipkin et al Experiment 121a	669.5	39.0
Russell-Tannenbaum et al Experiment 107a	490.5	290.5
Bar-Yam -Luckey-Osborne et al Experiments 109j, 117a	349.0	748.5
Deutsch-Rutherford et al Experiment 114b	9.5	474.5
Yuan et al Experiment 120a	0	298.0

A scheduled shutdown of accelerator operation occurred January 26 - February 17 inclusive.

B. Operation, Maintenance, and Minor Improvements

The accelerator operated with increasing intensity and increasing reliability throughout the six-month period in question. In March the user-hour figure (1147 hours) was larger than in any previous month in the history of this accelerator, and in May the figure was again very large (1034). In these later months the intensity achieved routinely at near-maximum energy (5.5 GeV) was 15 mA, larger than in previous years.

Starting June 1, 1970, a new scheduling system went into effect:

0800 - 2400 Monday through Friday: a full operations crew was maintained.

0000 - 0800 Tuesday through Saturday: a skeleton crew kept key components of the accelerator warmed up so as to permit prompt resumption of operation at 0800. This crew also performed various maintenance and repair tasks.

0800 - 2400 Saturday: full maintenance, installation, and repair crew available for work. The accelerator was normally not working during this period.

0000 Sunday through

0800 Monday: accelerator off and laboratory closed

In the following pages we discuss the performance of each of the major components of the accelerator.

1. Linac

a. Operation

The linac performed well throughout most of the period. Temporary interruptions took place which were caused by failures of:

power supply for the gun trigger,
suppressor capacitors of the high-voltage power supply,
capacitors of the pulse-forming network,
electrical insulation in the linac gun and consequent
failure of the linac voltage control circuit; also
failure of a nylon stand-off insulator and several switches.

b. Improvements

We improved the controls for the linac gun and the controls for focusing and steering the linac beam. Also we improved the water cooling of the linac, the supports for the linac transport system, and the interlock system for the linac high-voltage supply. We received a spare choke for the linac power supply and improved the fast plate system of the linac gun. We improved the temperature regulation system of the buncher section of Waveguide #1 and planned a major improvement (to consist of an adjustable heat source to compensate for loss of normal heat-generation during linac-off time). We began construction of a linac-gun high-voltage power supply that will provide greater ease of control and a wider range of voltage and will reduce the present large load on the main high-voltage power supply.

We installed faster motors for actuating the phase shifters that serve the linac prebuncher, linac chopper, and Waveguides 2, 3, 4, 5. Also we installed a post accelerator chopper (PAC) which makes it possible for us to achieve precise control of the length of the train of bunches (sausage) injected into the ring; any desired length from ~ 20 to ~ 500 ns can be achieved.

2. The e^- and e^+ Injection System

a. Operation

Performance was generally good. Interruptions occurred because of failures of:

The power supply for the on-axis inflector of electrons; a spare power supply was put into use.

A coil of the upstream bending magnet of the electron transport system; repair was accomplished in 24 hours.

Cooling-water hose of the coaxial, 3000-ampere, dc supply for the bending magnets; discharge of water into the Circular Tunnel caused an air-to-vacuum leak in a high-voltage feed-through of a vacuum pump.

b. Improvements

In January we developed procedures for operating the upstream and downstream linacs in series and in correct phase relationship, with no converter intervening, so that electrons could be accelerated routinely to 240 MeV in the Linac Tunnel - twice the injection energy used heretofore. High injection energy is especially necessary when a positron beam has already been accumulated in the ring, because a relatively high value

of $B_{\min}$ of the synchrotron ring can then be established and losses of positrons at $B_{\min}$ become small.

In January, February and March we constructed and installed a versatile set of controls for positron production and injection and for quick (15 second) changeover from positron multicycle injection at 120 MeV to electron multicycle injection at 240 MeV. The new system permits full control from the Main Control Room. All controls are in duplicate, so that, for each type of injection (e^- or e^+) all of the adjustments of linacs proper, beam transport systems, and synchrotron ring itself can be optimized and left undisturbed.

In February and March we constructed a new inflector for use in positron multicycle injection. The new device, situated on the radially inner side of the orbit, provides a larger clear horizontal aperture than was provided by the earlier (outside) inflector and affords better control of fringing fields.

In June we installed an rf-type intensity monitor in the electron injection beampath. A similar monitor was installed earlier in the positron train. Such monitors provide clean signals despite the high levels of ambient electromagnetic noise.

By the end of June the construction of an improved power supply for exciting the 3000-ampere dc bending magnets of the electron and positron injection trains was well advanced.

3. Synchrotron Magnet Ring

a. Operation

Operation was almost without incident. The only exception was the failure (in May) of several insulators of the bus system carrying current to the magnets. We found that these insulators were not necessary and we are now operating routinely without them.

b. Improvements

We made a two-fold improvement in the voltage regulation of the dc supply to the ring of 48 magnets. As a result of this improvement and earlier improvements, the regulation is now better than 0.02%.

We built and installed an improved type of peaking strip that permits reliable triggering of the linac at magnet-ring excitations corresponding to energies as great as 260 MeV even when the magnet excitation is arranged so that the undershoot (below 260 MeV, e.g.) is small.

We removed from the Circular Tunnel many unused cables and we improved the routing of cables in active use.

We completed the development of a new method of radial survey of the ring of 48 magnets and found the method to take only one third as many man-hours of surveying as the previous method (five hours compared to fifteen hours). The new method avoids obstruction of lines-of-sight by the 120-ft-long bypass.

4. Rf System

a. Operation

The rf system performed well and we were able to achieve week-long, high-energy (5.5-GeV) runs at higher intensity (15-mA) than was possible in any previous year.

In March we found slight damage (from arcing) in the A4R1 HPA triode, and repair was made quickly. Later the tube socket was damaged and was repaired. Because this was our only operable triode we adopted the practice of holding the average power level down to 50 kW in order to minimize the chance of injuring the tube.

In February - and also in April - we installed and briefly tried out the X1R1 triode that was still the property of RCA and had performed poorly in an earlier test. In each of the present tests the tube again proved to be unsatisfactory and was returned to the manufacturer.

In January an rf-system driver tube failed after 2000 hours of use and was replaced by a spare.

b. Improvements

In April we incorporated an SCR voltage control unit in the rf power supply to permit continuous variation of voltage to the HPA triode and to increase the amount of rf power delivered to the accelerator ring.

c. Plans for New Rf System

In January we came to a decision as to the most practical way of doubling the average power capability of the rf system

and thus providing the capability of storing a 100-mA electron beam and a 100-mA positron beam with an energy as great as 3.5 GeV and a circumferential filling factor of 0.25. We decided on a scheme that will make use of Varian 55-kW Type 953-C klystrons - tubes that are reliable and readily available. Four such klystrons are to be used, and the four outputs will be combined by a special network that insures maintenance of the proper phase relationship.

In March we ordered four such klystrons from Varian Associates and at the same time placed an order with Visual Electronics Corp. for the four transmitters and the combining system.

In April we began preparations for the arrival of the new equipment. Partitions were removed from the Power Building first floor area where the new equipment is to be placed. Electrical and steam services were rerouted. By June 30 preparations were 60% complete.

5. Vacuum System

a. Operation

As in the previous half-year, the vacuum system performed well. Few leaks occurred. In April, during a routine bake-out of the vacuum ring, a crack and subsequent local implosion occurred in one segment of a ceramic vacuum chamber. The chamber was repaired and the bake-out procedure revised to reduce temperature gradients and thermal strains in the chambers.

In May an obstruction of the orbit at Straight Section 23 was discovered and was traced to small pieces of fiberglass that had entered the ring during the above-mentioned implosion; the obstruction was removed and the use of fiberglass straps as supports for vacuum chambers was discontinued. In May a leak occurred in Chamber 10, probably as a result of improper mounting of an iron-core correction coil there, and in June a leak developed at Straight Section 16.

In January we found that the exit spout of Vacuum Chamber 10 was misaligned, greatly reducing the aperture of the combination of synchrotron ring and bypass. On realigning the spout we found the aperture to be greatly increased and to correspond to the expected value.

b. Improvements

In January we installed eleven Varian high-vacuum pumps in place of the Drivac pumps that had been in use for eight years. Additional Varian pumps were installed in February, bringing the total number of such pumps to 34.

In June we installed an additional ring-segmenting, pneumatically actuated, high-vacuum valve in the synchrotron ring.

6. Beam Controls and Monitors

In January we constructed and installed an improved system of electrostatic plates for vertically displacing the electron beam relative to the positron beam in the synchrotron ring and in the two end portions of the bypass. See Fig. 1.

Fig. 1. High-potential testing of the electrostatic separation plates installed near the west end of the 120-ft bypass. The slender vertical cylinders above and below the beampipe are the connectors.

The new plates are of stainless steel and can stand potentials of 35 kV, compared to the earlier plates which were of aluminum and could stand potentials of only 20 kV. In April we constructed a powering system for the new plates; the power supply can be modulated so as to match the 60-cycle excitation of the synchrotron magnet ring.

We installed a system for optically monitoring the position and cross section of the orbiting electron beam by virtue of the synchrotron radiation emitted and we installed a corresponding system (with opposite direction) for monitoring the orbiting positron beam. The systems employ closed-circuit TV cameras the information from which is displayed in the Control Room. In all there are three pairs of systems, for monitoring the beams at three locations around the ring.

In February we installed a fluorescent screen (viewed by TV) adjacent to the external electron beam. When moved temporarily into the path of the beam (by remote control), the screen provides the Control Room operator with information permitting him to adjust beam aim reliably and quickly.

In March we installed additional coil-type monitors of beam intensity and transverse position.

Also in March we installed two Panofsky-type, ferrite-core, quadrupole magnets (Fig. 2) for controlling the separation between horizontal and vertical betatron-oscillation frequencies. In April three additional v-separation magnets were installed, making five in all. In June we improved the

Fig. 2. Panofsky-type, ferrite-core, quadrupole lens for adjusting the separation between horizontal and vertical betatron frequencies.

powering of these quadrupoles: we connected them in series with the coils of the 48 magnets of the synchrotron; thus the separation between v_h and v_v is automatically maintained throughout the magnet excitation cycle. Also we installed a pulser that supplies additional power to two of the quadrupoles later in the cycle when the beam is bumped toward the damping magnets; the pulser has the effect of maintaining the desired v -separation (and avoiding cross coupling) despite the tendency of the damping-magnet fields to alter the betatron frequencies.

In May the sextupole circuits of the pole face windings in Magnets 13 and 15 were made operational. They are used in studies of the effects of change in synchrotron chromaticity.

In June we removed the two damping magnets temporarily and machined their magnetic shields to provide a larger vertical aperture for beams bumped radially toward the damping magnets.

Also in June we assembled and tried out a beam-intensity sampling and display system. The new system shows, by CR oscilloscope trace in the Control Room, the individual intensities of one or more bunches of orbiting particles. The crucial part of the apparatus is a recurring trigger that is synchronized with the orbital frequency and, throughout several milliseconds, provides a precision of ~ 0.05 nsec. The trigger governs the timing of the instantaneous (~ 0.03 nsec) sampling of the signal from a loop-type current monitor in a

straight section of the synchrotron. The system can clearly resolve individual bunches which are 25 inches (~ 2 nsec) apart on centers. Interesting traces produced by this device are shown in Figs. 3 and 4.

In addition, we developed and installed a preliminary model of a special, rf-powered, quadrupole magnet for altering the accelerator v -values synchronously with the orbital frequency (1.3 MHz) to such an extent that successive bunches have v -values shifted by ~ 0.001 . We expected that, by thus assigning to each bunch a slightly different set of v -values, harmful crosstalk between bunches would be reduced. (This expectation was borne out, as explained in Part IV.) This (core-less) quadrupole magnet was mounted in Straight Section 5 and was powered, at 1.3 MHz, with enough current (20 amps, r.m.s.) to produce a Δv of ~ 0.001 from one bunch to the next when the beam energy was 220 MeV. (The device proved so promising that, recently, we have constructed a far superior device. It operates on the 24th harmonic of 1.3 MHz, to reduce power requirements and permit operation at a machine energy up to 3 GeV, and is supplied by a source that is modulated to correspond to the cycling machine energy.)

7. The Bypass Train

The bypass train had largely been completed in the previous half-year. In the present period several minor improvements were made; for example, we installed interlocked thermal switches to insure against serious damage in the event of failure of the cooling system.

FIG. 3. Distribution of intensities among 100 successive bunches of positrons during cycling mode of operation.

FIG. 4. Same set of bunches immediately after a.c. turn-off. Note that several individual bunches have drastically reduced intensity.

Construction of the specially-designed, 8-inch-diameter, thin-walled (60-mil stainless steel) interaction-region beam-pipe was completed.

8. Radiation Protection and Monitoring

The various area monitors and recorders of gamma radiation and neutron radiation continued to perform well.

Additional rotating red beacons were installed in Areas 5 and 7 of the Experimental Hall. The procedures for arranging special access to the Circular Tunnel to permit specially qualified engineers to make observations and adjustments close to a stored beam were simplified. A detailed report (CEAL-TM-186) on the rationale of the main personnel-exclusion interlock system was prepared and issued.

In May, with the suspension of most of the experimentation in the Experimental Hall and concentration of efforts on the colliding beam project, all shutters (except #5) between Target Area and Experimental Hall were moved to closed (fail-safe) position and then rendered inoperative. Shutter #5 was left operative so that components of colliding beam detectors could be tested in Area 5 with a multi-GeV beam.

Greatly increased attention was given to the measurement of radiation levels in or close to the nearby Hammond and Gorham Streets, to make sure that the levels were well below the permissible upper limit of 500 mrem per year. A review made in January (see CEAL-TM-187) showed that the average levels for 1969 were an order of magnitude below the permissible level.

In April we made detailed measurements of the neutron radiation field at the northern portion of the CEA north parking lot and on Hammond Street while a 15-mA, 5.5-GeV beam was being employed by the Russell-Tannenbaum Group. We found the dose-rate at the hottest spot (12 ft inside CEA property) to be 2 mrem/hr, and we found the dose rate at the side of Hammond Street nearest the adjacent houses (NE side, at ground level and also at 14-ft height) to be less than 3% of the hot-spot rate. Results are reported in CEAL-TM-189.

In May we made additional studies of neutron radiation fields in the north and east portions of the north parking lot near Hammond Street and Gorham Street. Among the principal results, reported in CEAL-TM-190, CEAL-TM-191, and CEAL-TM-192, are the following:

- a. The neutron radiation present above-ground in the east portion of the parking lot, above the downstream end of the linac, is produced by the 250-MeV linac itself, not by the orbiting multi-GeV beam.
- b. The neutron radiation in the north portion of the parking lot is produced by the orbiting multi-GeV beam, not from 250-MeV linac spill during injection.
- c. The neutron radiation in the north portion of the parking lot is attenuated by a factor of 2 by a one-foot-thick horizontal layer of water.
- d. When the neutron monitor is moved 10 feet farther north from the hot-spot 12 feet within CEA property near

Hammond Street, the neutron dose-rate measured decreases by an order of magnitude.

These measurements showed that during the period covered by this report all radiation levels in accessible areas of the laboratory and the outside were well below the permissible levels.

9. Miscellaneous Components

We completed the installation and adjustment of improved types of mechanically refrigerated liquid hydrogen targets. The newest and largest of these CEA-designed, remote-controlled assemblies, shown in Fig. 5, successfully completed 1000 hours of operation without serious failure.

We completed the design and construction of a computer-control system for controlling sets of experimental magnets, e.g. the magnets of the bypass train and the magnets used in typical experiments in the Experimental Hall.

We completed a year-long effort to upgrade the equipment for filtering, de-ionizing, and de-oxygenating the cooling water for the synchrotron magnet ring and for the experimental magnets. A 5-GPM system for treating city water employed as make-up water was completed and we completed also a 150-GPM system for filtering the water in the main 400-gallon loop.

Fig. 5. Four-liter mechanically cooled liquid hydrogen target assembly used by Russell, Tannenbaum et al in Area 5. The mylar target cup is inside the horizontal scattering chamber at the left. Above is the 6-liter-capacity condenser. By means of remotely operated cryovalves the operator can fill the target (or empty it) in two minutes. The Phillips Co. Stirling-cycle mechanical refrigerator is at the right

PART III - EXPERIMENTS IN HIGH-ENERGY PHYSICS

During the six-month period in question there were 18 experiments in high-energy physics in progress or in various stages of preparation or completion. These are described below.

A. Experiments in Analysis-of-Data Stage

Pipkin, Stanfield, et al (Harvard), Experiment 102f:

Continuation of Small Angle Scattering of Electrons by Carbon.

Seeking additional information on the form factor of the carbon nucleus, the investigators employed an external electron beam of 1.5 to 4.0 GeV electrons, a carbon target, and a single-arm spectrometer that detected and analyzed the scattered electrons. Data taking was completed in February 1968. A detailed account of the work was presented in the August 1969 thesis by K. C. Stanfield, "Quasi-Elastic Electron Scattering and Pion Electroproduction off C^{12} from 1.0 to 5.0 BeV". Also, a brief account was presented at the April 1970 meeting of the Am. Phys. Society in Washington, D.C. The draft of an account for the Phys. Rev. is nearly complete.

Brenner, Walker, et al (Harvard), Experiment 103h: Study of Small-Angle Compton Scattering of Photons, at 2° to 6° lab, from protons. The group used tagged photons (of known energy, from 2.0 to 4.6 GeV) and measured 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. In the second half of 1968 the investigators obtained and analyzed a large amount of data; they also improved the operation of the spark chambers so that the tracks would be more nearly distortion-free and improved the accuracy of their analysis techniques. Much additional data was taken in the first half of 1969. By the end of June 1970 the analysis of results was nearly complete.

Wilson et al (Harvard), Experiment 105f: Backward Angle e-p and e-d Scattering, as part of the determination of the electric and magnetic form factors of the neutron and an effort to obtain a better understanding of the structure of the deuteron. Electrons of 0.45 to 2 GeV energy that were quasi-elastically scattered at 90° lab from a liquid hydrogen or liquid deuterium target were measured by means of a quadrupole spectrometer, scintillation counters, a lead-lucite shower counter, and a freon Cerenkov counter -- connected on-line to the Harvard Physics Department PDP-1 computer. Late in 1968 the investigators took a large amount of data and determined the ratio σ_n/σ_p with an accuracy of a few percent at six q^2 values between 7 and 45 f^{-2} . In May 1969 the investigators confirmed the calibration of the main beam monitor used, and in July and August much additional data was taken. Analysis of results is nearly complete; results are to be presented in two theses (K. Hanson thesis on e-d scattering, and L. Price thesis on e-p scattering).

Luckey et al (M.I.T.), Experiment 109h: Photoproduction of π^0 from Neutrons. In an effort to understand the mechanism of photoproduction of π^0 from nucleons in the t -value range from -0.2 to -2.0 $(\text{GeV}/c)^2$, the investigators directed a beam of 4-GeV unpolarized photons at a liquid deuterium target and detected the π^0 particle by means of two lead-glass Cerenkov counters that responded to the two resulting photons, and detected the recoil neutron by means of a special neutron counter consisting of a 12 x 12 x 15 inch scintillator block viewed by 20 photomultiplier tubes. The equipment was set up late in 1968 and tested in February 1969. Data taking occurred in March through June, and subsequent months were devoted to analysis of results -- presented at the September 1969 Daresbury Symposium. Preparation of a detailed report is nearly complete.

Luckey, Bar-Yam, et al (M.I.T. and S.M.U.), Experiment 109i: Photoproduction of π^+ from Polarized Photons. This experiment complemented Experiment 117a (by Bar-Yam et al) on photoproduction of π^- from polarized photons. Again 6-GeV electrons in the synchrotron orbit struck a diamond and produced bremsstrahlung having a linearly polarized spike at 3 GeV. The target was of liquid hydrogen, rather than deuterium. The π^+ was detected by the Moby Dick magnetic spectrometer, augmented by a gas-filled threshold Cerenkov counter to discriminate against protons. The neutron was detected by a large (12 x 12 x 15 inch) scintillator counter assembly viewed by 20 photomultiplier tubes. The investigation covered the t -value range from -0.2 to $-1.2(\text{GeV}/c)^2$,

and found that, throughout this range, the asymmetry $(d\sigma_{\perp} - d\sigma_{\parallel})/(d\sigma_{\perp} + d\sigma_{\parallel})$ is positive, implying dominance of natural parity exchange. Comparison with $d\sigma_{\perp}(\gamma_{\perp}p \rightarrow \pi^{+}n)$ and $d\sigma_{\perp}(\gamma_{\perp}n \rightarrow \pi^{-}p)$ results from a previous experiment indicates strong interference between the isoscalar and isovector photon amplitudes for photons polarized perpendicular to the production plane. Results were summarized at a talk at the September 1969 Daresbury Symposium, and the drafting of an account for Phys. Rev. Letters was nearly completed by 6/30/70.

Deutsch et al (M.I.T.), Experiment 111d: Proton Compton Effect at 2 to 4.5 GeV and $t = -0.16 \text{ (GeV/c)}^2$. The investigators studied γ, p scattering with photon energies as high as 4.5 GeV, scattering angles as small as 30° c.m. and t -values as small as -0.16 (GeV/c)^2 . Energy of the recoil proton was determined by means of range measurements with spark chambers. Data taking was completed in November 1969. Analysis of the data indicated that for an average photon energy of 3.5 GeV the differential cross section extrapolates at $t = 0$ to the value expected from total cross section and optical theory, and the slope is approximately 5 (GeV/c)^{-2} . A brief account is to be presented at the Kiev, USSR, High-Energy Physics Conference on August 26, 1970, and a more complete report of the work is in preparation. Further details are contained in a thesis of June 1970 by D. F. Jacobs of M.I.T.

Frisch et al (M.I.T.), Experiment 112a: Study of Photo-production of a $2 \pi^0$ Resonance (f^0 particle) with tagged photons.

The investigators used tagged photons from the internal beam-tagging facility in Magnet 12; photon energy was known to within 2%. A search for f^0 and other meson resonances was undertaken with a $0.1 X_0$ polyethylene target. The direction of the recoil proton was 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 found the locations of the resulting showers by means of a spark chamber containing thick iron plates that had an aggregate thickness of $7.3 X_0$. By the end of June 1969 the investigators had analyzed 50,000 photographs and obtained four events of the type $\gamma + p \rightarrow 2\pi^0 + p$. They found that, within a dipion mass range from 850 to 1400 MeV and at forward angles up to 60° c.m., the upper limit on production cross section was $0.9 \mu\text{b}$. Results were summarized in a June 1969 thesis "Upper Limit on the Cross Section for Photoproduction of Neutral Pion Pairs Having an Invariant Mass Near 1 BeV", by S. R. Smith of M.I.T. In the latter half of 1969 the photographs were analyzed for three pion (π^-, π^0, π^+) events and a thesis presenting the results is expected to be completed by November 1970. In June 1970 a manuscript of a summarizing article was sent to Nuclear Instruments and Methods.

Kendall, Friedman, et al (M.I.T.), Experiment 113b: Study of Inelastic e,d Scattering with the purpose of exploring the electro-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. The investigators used an external beam of 1 to 4 GeV electrons and a liquid deuterium target. The scattered electron was detected by a quadrupole spectrometer that included wire chambers and scintillation counter hodoscopes. In 1969 the investigators completed the analysis of results and used the results in an investigation of the validity of one of the leading theories as to electro-disintegration of the deuteron. Detailed accounts of the results have been presented in two theses: A June 1970 thesis "Studies of Quasi-Elastic Electron-Deuteron Scattering" by J. Elias of M.I.T., and a June 1970 thesis "Effects of Final State Interactions near Threshold of Inelastic Electron-Deuteron Scattering" by M. Sogard of M.I.T. An account for publication in Phys. Rev. is in preparation.

Milburn et al (Tufts), Experiment 114a Part I: Measurement of the Polarization of the Proton Recoiling in $\gamma + p \rightarrow p + \pi^0$ Events in which the pion is ejected at 65° c.m. and the photon energy varies from 1.2 to 1.8 GeV. The investigators employed (a) a small spark chamber and lead glass Cerenkov counters for detecting photons from the decay of π^0 , (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. The experimental work was done in the fall of 1968 and the analysis of results is nearly complete. To date it appears that the polarization, if any, is small.

Brief reports on the project were presented at the 1969 winter meeting of the Am. Phys. Society and the September 1969 Daresbury Symposium. A portion of the results has been incorporated in a thesis by N. Tanaka of Tufts and another portion is to be covered in a thesis now in preparation.

Bar-Yam et al (S.M.U.), Experiment 117a: Study of Photo-production of Single π^- on Deuterium by Polarized Photons.

A beam of photons with a linearly-polarized 3-GeV spike was produced by a diamond situated in the synchrotron orbit. The beam struck a liquid deuterium target and the π^- particles photoproduced singly were detected by a magnetic spectrometer in coincidence with the recoil proton. A photon subtraction method was used to determine the energy of the incoming photon and to substantially eliminate the incoherent production as well as the multi-pion production. The investigators then determined the photoproduction asymmetry, defined as the ratio $(\sigma_{\perp} - \sigma_{\parallel})/(\sigma_{\perp} + \sigma_{\parallel})$, where $\sigma_{\perp}$, for example, is the differential cross section when the electric vector of the incident photon is perpendicular to the plane of production. The asymmetry was measured between 0.15 and 2.0 (GeV/c)² and was found to be positive at $-t$ values below 0.3 (GeV/c)², dipping to negative values between 0.4 and 0.6 (GeV/c)² and rising again to positive values above 0.7 (GeV/c)². Results were summarized in several talks and in Phys. Rev. Letters 24, 1078 (1970).

Weinstein et al (Northeastern), Experiment 118d: Study of Photoproduction of Muon Pairs at High Mass, with the purpose of observing the decay $\phi^0 \rightarrow \mu^+ + \mu^-$ and thus providing an accurate test of vector dominance and of e, μ universality. Electrons of 5-GeV energy struck a thin lead converter (situated in the target area) and produced bremsstrahlung photons with energies up to 5 GeV. These struck a carbon target and the resulting ϕ^0 particles immediately decayed into μ^+ and μ^- . The two-arm spectrograph included 5-ft-thick stacks of iron plates and a 200-counter hodoscope; the equipment permitted determination of the muon ranges and directions. Data-taking runs were made early in 1969 and analysis of results was completed by the fall of that year. Results were summarized in a talk given at the 1969 Daresbury Symposium and in an article in Phys. Rev. Letters of 13 July 1970. A detailed account was presented in a thesis by Ken Min Moy of Northeastern, and an article for publication is in preparation.

Weinstein et al (Northeastern), Experiment 118i: Search for Heavy Vector Mesons. Employing a high-intensity 6-GeV external electron beam incident on a $0.2 X_0$ lead converter, the experimenters concentrated the resulting bremsstrahlung beam on a carbon target. Muon pairs corresponding to invariant mass between 0.9 and 1.9 GeV were detected by means of a two-arm spectrometer each arm of which covered an angular range from 10° to 21° lab from the beam axis. Each arm carried iron plates with an aggregate thickness of six feet, with intervening

arrays of scintillators. Data taking occurred in March and April, and by the fall of 1969 the analysis of results was nearly complete. Results were summarized in talks given at the Daresbury Symposium and at the Boulder, Colorado meeting of the Am. Phys. Society. A manuscript to be submitted to Phys. Rev. Letters is nearly complete.

Fulmer, Dell, et al (ORNL and CEA), Experiment 119a: Study of Electro-Induced and Photo-Induced Spallation. Iron sheets were exposed to 1.5-GeV electrons and shipped by air to Oak Ridge for prompt analysis. Results were published in Phys. Rev. 188, 1752 (1969), issued in April 1970.

B. Experiments in Data-Taking Stage

Russell, Tannenbaum et al (Harvard), Experiment 107a: Boson Resonance Photoproduction. The goal was to survey the spectrum of neutral bosons (in the boson mass range from 500 to 1800 MeV) in the reaction $\gamma + p \rightarrow p + \text{boson}$. The investigators hoped to determine the energy dependence and angular dependence of production of known bosons (e.g. the ρ^0 , ω^0 particles) and perhaps new ones also. They employed a tagged photon beam and a liquid hydrogen target. Protons recoiling at 20° to 60° lab were detected by two sets of wire spark chambers (8 in all) and an intervening magnet 'Enry 'Iggins. Kaons and pions were detected by an array of four 5-ft-square wire spark chambers situated directly downstream from the target. The data were interfaced by a CEA SDS-92 computer to the Harvard IBM 360/65 computer. In May the group made a long

data-taking run covering the boson mass range from 1200 to 1800 MeV, complementing a 500 to 1200 MeV run made earlier. Data taking is now complete and the analysis of results is underway.

Deutsch, Rutherford, et al (M.I.T. and Tufts), Experiment 114b: Recoil Proton Polarization in π^0 Photoproduction ($\gamma + p \rightarrow p + \pi^0$) near $t = -0.30 \text{ (GeV/c)}^2$. Employing a bremsstrahlung photon beam on a liquid hydrogen target, the investigators measured the direction and energy of the resulting π^0 by means of an arm containing a lead converter, a scintillation counter hodoscope, and a lead glass hodoscope. The direction, energy, and polarization of the scattered proton were measured by means of a sequence of wire spark chambers with intervening carbon plates. In May 1970 the investigators took much data which is now being analyzed. The relationship of proton spin asymmetry to four-momentum-transfer squared in the neighborhood of $t = -0.3 \text{ (GeV/c)}^2$ is to be compared with the relationships predicted by various competing theories.

Bar-Yam et al (S.M.U.) and Luckey, Osborne, et al (M.I.T.), Experiment 109j: Asymmetry in Single Pion Photoproduction, by Polarized Photon, in the Resonance Region. The method was similar to that used in Experiment 117b, described on a later page. Data taking occurred in February through May 1970. Analysis of results is underway.

Bar-Yam et al (S.M.U.), Experiment 117b: Extension of Measurements of Photoproduction of Single π^- on Deuterium by Polarized Photons. A beam of photons with a linearly polarized

3-GeV spike was produced by a diamond situated in the synchrotron orbit. The beam struck a liquid deuterium target and the π^- particles photoproduced singly were detected by a magnetic spectrometer in coincidence with the recoil proton. Data taking, at t-value of -2.4 (GeV/c)^2 , occurred in January through May 1970. A photon subtraction method was used to determine the energy of the incoming photon and to substantially eliminate the incoherent production as well as the multi-pion production. The investigators then computed the asymmetry of photoproduction, where asymmetry is defined as the ratio $(\sigma_{\perp} - \sigma_{\parallel})/(\sigma_{\perp} + \sigma_{\parallel})$, where $\sigma_{\perp}$, for example, is the differential cross section when the electric vector of the incident photon is perpendicular to the plane of production. Analysis of results is underway.

Yuan et al (BNL), Experiment 120a: Energy Dependence of Transition Radiation. In March the investigators completed measurements of the angular distribution, spectral energy distribution, and absolute amount of transition radiation produced in a stack of foils by a multi-GeV beam of positrons. They now have the basic data needed for optimizing the design of a device for measuring the energy of high-gamma charged particles produced by the NAL proton synchrotron or naturally present in cosmic radiation. Results are summarized in several articles listed in Part VII.

Pipkin et al (Harvard) Experiment 121a: Elastic π^+ Electro-production near 0° and at pion-nucleon c.m. energies above the nucleon resonances. The investigators used the new Beam 7

spectrometer, each arm of which supports an 8-inch half-quadrupole magnet, a 6-ft analyzing magnet mounted on edge so as to deflect particles in a vertical plane, a 12-inch half-quadrupole magnet, and an elevated tail structure containing scintillation counters, wire spark chambers, a threshold gas Cerenkov counter, and shower counters. The 30-inch cylindrical spectrometer magnet Orpheus was mounted at the pivot point. The external 5.5-GeV electron beam struck a 1/2-liter liquid hydrogen target just upstream from this cylindrical magnet. Much data was taken in October 1969 - March 1970, and in a supplementary run in May 1970. The investigators extended the range of measurements to higher Q^2 : they took data at the point $Q^2 = 1.2 \text{ (GeV/c)}^2$, $W = 2.15 \text{ GeV}$. Analysis of the data is underway.

The Bypass On-Line Detector Group employed 22 hours of parasite time in tests of spark chambers, shower counters, and other components of the on-line detector. Results are discussed in Part IV.

PART IV - PROJECT BYPASS

A. Introduction

As explained in Part II, since June 1, 1970, all work at the CEA has been concentrated on Project Bypass, the goal of which is to develop a facility for

- (1) Producing approximately head-on collisions of electrons and positrons with energies up to 3.5 GeV in each beam, and
- (2) Investigating the results of such collisions by means of large-solid-angle detection systems.

The plan is to fill the orbit of the existing synchrotron with counter-traveling, high-intensity electron and positron beams by means of multicycle injection. Positrons and electrons are injected by means of two 130-MeV linacs arranged in tandem in the (nearly radial) Linac Tunnel. When positrons are to be injected, the upstream linac produces accelerated (~ 130 -MeV) electrons which strike a tungsten converter from which gamma radiation and electron-positron pairs emerge; positrons of ~ 10 MeV energy are collected and guided into the downstream linac whence they emerge with an energy of 130 MeV; they are then deflected to the right so as to enter the circular orbit in clockwise sense. When electrons are to be injected, the converter is removed (in a few seconds, by remote control), the phase of the second linac is shifted suitably, and the two linacs are operated in series to accelerate electrons to 260 MeV; these are deflected to the left and are inflected into the orbit in counterclockwise sense.

When the beam intensities have been built up sufficiently (the design intensity is 100-mA peak with a 30% circumferential filling factor) synchrotron operation is converted to dc mode and the particle energies are increased to the desired value. The stored beams are then switched into a 120-ft-long detour or bypass. See Fig. 6. In most of the ring and bypass, the two beams are kept vertically separated by means of electrostatic fields so as to minimize beam-beam interactions; but they are guided so as to collide at the interaction region, at the center of the bypass. Focusing magnets reduce the beam cross section here to ~ 0.01 -mm high by 0.3-mm wide and accordingly the interaction rate (number of collisions per second) will be relatively high; the design luminosity is expected to be $1.5 \times 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$.

The interaction region will be surrounded by a detector array that will include spark chambers, absorbers (converters, or radiators) and scintillation counters. Initially a non-magnetic "bypass on-line detector" (BOLD) will be used. The spark chambers are of wire type, digitized; all signals from spark chambers and scintillation counters are read out and analyzed by an IBM 360/65 computer. An optical detector is under development also. A magnetic detector is also under development; it will provide a more detailed analysis of complex events.

By the end of 1969 the upstream linac (electron linac) had been in use for 1½ years and was performing well. The downstream linac (positron linac) had passed the acceptance test on

Fig. 6. Relationship of the bypass to the synchrotron ring of 48 magnets. The terminations of the bypass, and likewise the septum magnets used in switching, are at straight sections 10 and 19.

August 14, 1969, and by the end of 1969 had delivered a 0.5-mA positron beam of which 0.1 mA had a momentum spread with a total range of 2% at 124 MeV. We had gained much experience in multi-cycle injection and in converting from cycling-mode storage to dc storage of electrons (by "ac turn-off"). The vacuum in the ring had been improved to the 10^{-7} to 10^{-8} torr range and we achieved, for a 2.6-GeV constant-energy electron beam, a $1/e$ lifetime of two hours. We had succeeded in switching 1-mA electron beams into the bypass and obtaining, for this beam, a $1/e$ lifetime of 20 minutes. In December 1969 we found that the horizontal aperture available to such a beam was much smaller than expected -- because of misalignment of an exit spout at the west end of the bypass.

B. Bypass Trials

Early in January 1970 we realigned the faulty exit spout at the west end of the bypass and thereby doubled the horizontal aperture available to a beam circulating through ring and bypass. We then succeeded in switching a 2-mA-peak, 2-GeV electron beam into the bypass with switching losses of 20 to 40%; and we obtained a $1/e$ lifetime of 45 minutes, compared to a 100-minute lifetime when the beam circulated in the ring only.

No further bypass trials were made in the six-month period in question. Instead, efforts were concentrated on positron multicycle injection and accumulation and on studies of single beam and beam-beam instabilities.

C. Multicycle Injection Studies

Studies of positron multicycle injection and accumulation were started in January, and gradual improvements in injection efficiency and intensity of accumulated current were made in the subsequent months. See Fig. 7. We found that the efficiency of (off-axis) injection was limited mainly by machine horizontal aperture; the aperture was smaller than expected (1.5 inch as compared to the expected value of 2.0 inch) and accordingly we found that the optimum value of peak energy in multicycle injection mode was smaller than we had expected (2.1 GeV as compared to the expected value of 2.7 to 3.0 GeV), because the lower-energy beam has suffered less widening from the process of quantized emission of synchrotron radiation. By the end of June we had succeeded in accumulating a 4-mA-average, 11-mA-peak positron beam with a $1/e$ build-up time constant of 20 seconds.

Many improvements in machine components were responsible for the increased efficiency of positron injection. The most important improvement was a new off-axis positron inflector designed for operation on the radially inner side of the orbit; a smaller deflection then sufficed, fringing fields were confined more effectively, and consequently the effective horizontal aperture was larger.

Efficiency of electron multicycle injection (at 200 to 240 MeV) was increased also, and by the end of June we succeeded in accumulating cycling-mode currents of 25-mA peak.

FIG. 7. POSITRON BEAM STORED IN SYNCHROTRON RING, JAN. 19, 1970. ENERGY: 2 GEV. PEAK CURRENT: 1 MA. THIS SYNCHROTRON-RADIATION PHOTOGRAPH, TAKEN USING CLOSED-CIRCUIT TV, SHOWS THE BEAM CROSS-SECTION AT THE CENTER OF AN OPEN MAGNET. SPACING OF LINES OF REFERENCE GRID CORRESPONDS TO 1.4 MM. WIDTH OF BEAM CROSS-SECTION HERE IS ~ 2 MM. HEIGHT, NOT FULLY RESOLVED, IS LESS THAN .5 MM.

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Fig. 8. Intensity distribution among the 80 bunches in an orbiting, 2-mA-peak sausage of positrons. Leading end of sausage is at left. Horizontal scale: 20 ns per cm.

are weakened or are entirely eliminated; in such case the intensity pattern within the sausage has a characteristic structure such as is exemplified in Fig. 9

Reasoning that giving different bunches in the synchrotron ring slightly different betatron frequencies would reduce bunch-bunch interactions and permit an increase in the ceiling on current that can be accumulated in multicycle injection, we improvised a quadrupole lens powered in synchronism with the 1.3-MHz orbital frequency and obtained evidence that a properly designed, more powerful rf quadrupole would be very helpful.

We found also that beam losses during the transition from ac cycling mode to dc storage mode are due to the same kind of instabilities - which (with the machine conditions then prevailing) appeared to limit the dc-stored positron beam current to 1 mA average, 3 mA peak.

E. Simultaneous Storage of Electrons and Positrons

In mid-April, after making several improvements in the linacs, we achieved the first cycling-mode and subsequent dc-mode storage of electrons and positrons simultaneously. See Fig. 10. (The principal improvement in the linacs was the installation of a duplicate set of controls so that the change-over from positron injection to electron injection could be accomplished in 15 seconds, from the Main Control Room, without disturbing any of the adjustments that have been optimized for the two kinds of particles individually.)

Fig. 9. Intensity pattern in a 10-mA-peak sausage.
Scale: 20ns per cm. Leading end of sausage is at left.

Fig. 10. First simultaneous storage of electrons and positrons in the CEA synchrotron ring, April 11, 1970. The three TV views show the e^- and e^+ beam cross sections in three different portions of the ring. Each view is provided by a TV camera that is mounted adjacent to a straight section and receives (via two oppositely facing mirrors situated within the vacuum system) visual-range synchrotron radiation traveling counterclockwise from e^- and clockwise from e^+ . A given camera shows two differently shaped cross sections because the two pertinent beam segments are in magnets of different type: open and closed. The separation of the two resulting spots is artificial and arbitrary, being a consequence of deliberately adjusting the mirror tilts so as to show the two spots separately. The two beams were actually coincident on this occasion because the electrostatic-plate beam-separation system was then not powered. Beam energy: 2 GeV. Intensity: ~ 1 mA.

We found that when the e^-e^+ beam-separation plates are not powered, the lifetime of the few-mA-peak stored positron beam is little affected by the electron beam provided that the electron beam current is less than ~ 5 mA peak; but when larger electron currents are accumulated, the lifetime of the positron beam is greatly reduced. Exploration of the effect of powering the separation plates was being started at the end of June.

F. On-Line Detector (BOLD)

At the end of the six-month period in question, construction of the bypass on-line detector (BOLD) for analyzing results of e^-e^+ collisions was nearing completion. (This detector is being developed jointly by the CEA and a Harvard group.) Designed to detect photons, electrons, muons, and pions, the detector consists of a 4-ft-cube core and an exterior array as shown in Fig. 11.

The detector core consists of four similar quadrants grouped close to the interaction-region beampipe. Each quadrant contains six digitized wire spark chambers interspersed with five scintillators and five radiators (absorbers with thicknesses of 1.25, 1.25, 1.25, 1.25, and 1.50 radiation lengths) as shown in Fig. 12. See also the Fig. 13 photograph. Each spark chamber contains four planes of wires, i.e., a pair at $(0^\circ \text{ and } 75^\circ)$ and a pair at $(0^\circ \text{ and } 105^\circ)$ that provide unambiguous specification of the positions of as many as four simultaneous tracks. The active area of a spark chamber ranges from 7" x 13" for a chamber close to the interaction point to 24" x 38" for a chamber at a distance of 16" from the interaction point.

Fig. 11. Vertical section through bypass (and adjacent portion of synchrotron ring) at the bypass midpoint.

Fig. 12. Cross section of north quadrant of detector core, showing the six wire spark chambers (w), five scintillation counters (Sc), and five radiators (R). The e^- and e^+ beams are at the center of the beampipe.

Fig. 13. General view of the interaction region of the bypass and two flanking quadrants of the bypass on-line detector, on July 31, 1970. At the center of the photograph is the thin-walled, 8-inch-diameter vacuum pipe in which the countertraveling e^- and e^+ beams will collide. A collision-product particle traveling to left or right encounters three spark chambers, a scintillator, and then a mixed sequence of lead radiators, spark chambers, and scintillators. At top and bottom of the photograph, portions of the quadrupole triplet focusing magnets may be seen.

Supplementary scintillators are mounted above and below the core (see Fig. 11) to permit distinguishing (by time-of-flight data) downward-traveling cosmic-ray particles from particles traveling outward from the interaction region. On either side of the core there is a hadron converter consisting of ten 1" x 72" x 72" iron plates interspersed with additional wire chambers each of which has an active area of 58" x 65"; the hadron converters make it possible to distinguish hadrons from muons.

All of the information from the spark chambers and scintillators is recorded by the Harvard IBM 360/65 computer interfaced by an SDS-92 computer.

In the six-month period in question, construction of all wire spark chambers, scintillators, radiators, etc., of the core was completed, two quadrants of the core were assembled, principal tests on one quadrant were completed, and plans were made for installing the first two quadrants in their intended positions beside the bypass interaction region. See Fig. 13.

Assemblies of components of the cores were tested successfully with the Area 5 beam of 3-GeV positrons. In one test series a stack of five spark chambers with intervening lead radiators was placed in the 3-GeV beam and the number of sparks produced in each event was counted; a similar run was made without the lead radiators. Comparison of results showed that the efficiency of the composite stack in distinguishing shower-producing particles (exemplified by the positron) from non-

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on-line detector will be ready for preliminary data analysis
Present aspects are that, by the end of 1971, the bypass
interaction region was completed. See Fig. 1.
Construction of an 8-12-GeV proton beamline to analyze the
the beam-pulse and core was started.
The construction of the hadron beamline is scheduled to include
the detector. See Fig. 2.
The detector is made of a series of silicon strip detectors
of the on-line computer program and other programs are used
to record the data on the beam-pulse and core.
The detector is made of a series of silicon strip detectors
of the on-line computer program and other programs are used
to record the data on the beam-pulse and core.

Fig. 14. On-line computer-generated display of the trajectory of a cosmic-ray muon that happened to pass (at $\phi \cong 20^\circ$) through the interaction point of the bypass and through the radially inner and radially outer quadrants of the detector core. The supplementary fiducials comprise a large "X" showing the limits of effective coverage of the two quadrants ($\sim 66^\circ$ in ϕ for each). The colliding beams are normal to the plane of the photograph.

G. Optical Detector

We continued work on an optical detector to serve as back-up for the on-line detector. This device, a joint undertaking by the CEA and an M.I.T. group, was to employ a main array of scintillation counters, optical spark chambers (with 3-degree stereo-photographic recording) that include lead shower generators - and iron absorbers for hadron identification. Also there was to be a large overhead hemispherical dome (radius of curvature: 5 ft) of solid scintillators for vetoing cosmic-ray muons by time-of-flight relative to small scintillators surrounding the bypass interaction region.

In the six-month period in question construction of two of the spark chamber quadrants was completed and many of the basic tests were made. Assembly of the mechanical framework to hold the spark chambers was started. The large field lens was received and installed and strip mirrors for the stereo optical system were ordered. Design of the integrated-circuit trigger electronics was completed and construction started.

(In October, work on this detector was halted to allow concentrating our efforts on BOLD and the magnetic detector.)

H. Magnetic Detector

Work was continued (by the CEA and an M.I.T. group) on the design and construction of a magnetic detector the purpose of which is to measure the momentum of the particles coming out of the interaction region. This will permit:

Testing of time-like photon term in e^+e^- scattering by identifying e^+ and e^- particles,

Better identification of hadrons and possible new particles;

Increased knowledge of baryon and boson channels resulting from e^+e^- annihilation.

The heart of the magnetic detector is a core consisting of counters and spark chambers mounted within a rectangular solenoidal coil having inside height, width, and length of 64, 98, and 60 inches respectively. The main (60-inch) axis is coincident with the e^- and e^+ beams. When powered at 2 MW the coil will provide a 5-kilogauss field. Outside the coil there are to be four arrays of iron plates and spark chambers; at each end of the coil there is to be an iron end-cap and a 20-inch-diameter solenoidal correction coil.

The large coil was received and preparations for testing it with 2000-ampere current were begun.

Various tests of optical spark chambers suitable for this detector were carried out.

PART V - OTHER ACTIVITIES IN HIGH-ENERGY PHYSICS

A. Theoretical Studies in Particle Physics

The staff theoretical physicists continued the analysis of the photo-excitation of nucleon resonances, investigated the difference between muon and neutrino induced production of the intermediate vector boson and started calculations on hard photon corrections to colliding beam experiments.

Four papers resulted from these studies. Part VII lists these papers.

B. Design Studies of a Miniature Storage Ring for Production of Light of Very High Monochromaticity

In the previous half-year, we completed the general systems design of a miniature, 8-inch-diameter, electron storage ring (proposed in CEAL-1032 of 9/19/66 by K. W. Robinson) for producing uniformly spaced, highly monochromatic lines of synchrotron radiation of accurately known frequency (the frequency can be measured to an accuracy of greater than one part in 10^{12}). Such light could be used in determining the speed of light with greater accuracy than is possible today. In the present half-year we began considerations of engineering details of design and construction, and means for achieving alignments accurate to ~ 0.0001 inch.

C. Source of Polarized Electrons

Progress made included:

Start of testing and adjusting the Mott-type polarization detection system,

Successful first efforts to bring the spin exchange chamber and associated equipment to potentials of 50 to 80 kV (to permit 50-to-80-KeV acceleration and measurement of degree of polarization).

As part of the necessary reduction in the laboratory program, efforts were started to transfer this polarized-electron-source project to another laboratory. These efforts were successful and Dr. Krisciokaitis took the prototype source (on loan) to DESY in the fall of 1970.

PART VI - OTHER PROGRAMS

A. Safety

In the half-year in question there were no lost-time accidents.

Much effort was devoted to planning for automatic fire detection and fire extinguishing systems for the Main Control Room and certain other areas containing compact, flammable, valuable equipment.

No CEA film-badge user's films showed a dose as great as 50% of the maximum permissible dose.

B. Training of Disadvantaged Persons

We continued our participation in training programs, sponsored by the Cambridge School Department, TEST, and the Harvard Minority Recruitment Program, to introduce disadvantaged young persons to a variety of technical jobs. Ten persons participated in the training program at CEA.

PART VII - PUBLICATIONS RESULTING FROM WORK DONE AT CEA

A. Publications on High Energy Research Performed at CEA

"Photoproduction of Muon Pairs: $\rho^0 \rightarrow \mu^+ + \mu^-$, (e, μ) Universality, and (ρ,ω) Phase", P. L. Rothwell, R. C. Chase, D. R. Earles, M. Gettner, G. Glass, G. Lutz, E. von Goeler, R. Weinstein, Phys. Rev. Letters 23, 1521 (1969).

"Production of Single Negative Pions from Deuterium with Polarized Photons", Z. Bar-Yam, J. de Pagter, J. Dowd, and W. Kern, Phys. Rev. Letters 24, 1078 (1970).

"Phenomenological Model for the Electromagnetic Structure of the Proton", G. B. West, Phys. Rev. Letters 24, 1206 (1970).

"A Measurement of Electroproduction of Muon Pairs", D. R. Earles, R. C. Chase, W. L. Faissler, M. W. Gettner, G. Glass, G. Lutz, R. G. Parsons, P. L. Rothwell, K. M. Moy, H. von Briesen, E. von Goeler, R. Weinstein, Phys. Rev. Letters 25, 129 (1970).

"Energy Dependence of X-Ray Transition Radiation from Ultra-Relativistic Charged Particles", L. C. L. Yuan, C. L. Wang, H. Uto, and S. Prunster, Phys. Letters 31B, 603 (1970).

"Yields of Radionuclides Produced in Thick Targets Bombarded with 3.0 GeV Electrons", C. B. Fulmer, I. R. Williams, K. S. Toth, and G. F. Dell, Phys. Rev. 188, 1752 (1969).

"Gauge Invariance and the Born Approximation in Pion Electroproduction", F. A. Berends and G. B. West, Phys. Rev. 188, 2538 (1969).

"Production of Single W Mesons in Electron-Positron Colliding Beams and in Electron or Muon Scattering Experiments", F. A. Berends and G. B. West, Phys. Rev. D 1, 122 (1970).

"Search for Violation of Time-Reversal Invariance in Inelastic e-p Scattering", J. A. Appel, J. R. Chen, J. Sanderson, G. Gladding, M. Goitein, K. Hanson, D. C. Imrie, T. Kirk, R. Madaras, R. V. Pound, L. Price, Richard Wilson, C. Zajde, Phys. Rev. D 1, 1285 (1970).

"Relative Phase Angles in Leptonic Decay of Photoproduced Vector Mesons", G. K. Greenhut, R. Weinstein, R. G. Parsons, Phys. Rev. D 1, 1308 (1970).

"Elastic Electron-Proton Scattering Cross Sections Measured by a Coincidence Technique", M. Goitein, R. J. Budnitz, L. Carroll, J. R. Chen, J. R. Dunning, Jr., K. Hanson, D. C. Imrie, C. Mistretta, and Richard Wilson, Phys. Rev. D 1, 2449 (1970).

"Forward Charged-Pion Electroproduction from Fixed-Momentum-Transfer Dispersion Relations", F. A. Berends, Phys. Rev. D 1, 2590 (1970).

"Methods of Crystal Alignment for the Production of Coherent Bremsstrahlung", D. Luckey and R. F. Schwitters, Nuclear Instruments and Methods 81, 164 (1970).

"Theoretical Consideration of a Spin-Polarized Electron Source Based on Elastic Electron-Hydrogen Spin-Exchange Collisions",

R. J. Krisciokaitis and Wu-Yang Tsai, Nuclear Instruments and Methods 83, 45 (1970).

"Alternating Gradient Electron Synchrotron", W. A. Shurcliff, article in 1970 Encyclopaedia Britannica, Vol. 1, p. 63.

B. Papers Presented at Conferences and Meetings

1. Presented at the American Physical Society Meeting in Washington, D.C., April 27-30, 1970

"Yields of Radionuclides in Thin Iron Targets Bombarded with 40-MeV to 16-GeV Electrons", C. B. Fulmer, K. S. Toth, I. R. Williams, G. F. Dell, paper AG 10.

" π^+ Photoproduction on Hydrogen with Polarized Photons", Z. Bar-Yam, J. de Pagter, J. Dowd, W. Kern, L. S. Osborne, P. D. Luckey, paper GK 2.

"Quasi-elastic Electron Scattering and Pion Electroproduction off C-12", K. C. Stanfield, C. R. Canizares, W. L. Faissler, F. M. Pipkin, paper GK 5.

"Inelastic Photoproduction of π^0 Mesons at 2 - 4.6 GeV and at Small Angles", R. Wearn, S.-L. Wu, paper GK 7.

"Scattering Experiments with Polarized Electrons and Polarized Targets at High Energy", R. J. Krisciokaitis, paper GK 11.

"Compton Scattering at High Energy and Small Momentum Transfer", A. E. Brenner, D. Petersen, J. H. Scharenguivel, J. K. Walker, R. Wearn, S.-L. Wu, paper GK 15.

"Proton Compton Effect at Small Momentum Transfer", D. F. Jacobs, Martin Deutsch, paper HK 6.

"Energy Dependence of X-Ray Transition Radiation Emitted from Ultrarelativistic Charged Particles", L. C. L. Yuan, C. L. Wang, H. Uto, S. Prunster, paper HK 15.

2. Presented at Scintillation and Semiconductor Counter Symposium in Washington, D.C., March 11, 1970

"Transition Radiation and Its Application to the Detection of Super-High-Energy Particles", L. C. L. Yuan, invited paper.

C. Theses on High Energy Research Performed at CEA

"Experiments with Electron-Positron Colliding Beams", thesis of April 1970 by A. Litke of Harvard.

"Studies of Quasi-Elastic e-d Scattering", thesis of June 1970 by J. Elias of M.I.T.

"Proton-Compton Scattering at Momentum Transfers near $t = -0.2 \text{ (GeV/c)}^2$ ", thesis of June 1970 by D. F. Jacobs of M.I.T.

"Proton Compton Scattering at High Energies near the Forward Direction", thesis of June 1970 by S.-L. Wu of Harvard.

"Effects of Final State Interactions near Threshold on Inelastic e-d Scattering", thesis of June 1970 by M. Sogard of M.I.T.

D. CEAL Reports

CEAL-1051 "Semi-Annual Report for the Period July 1 through December 31, 1969", K. Strauch and W. A. Shurcliff, April 10, 1970.

E. CEAL-TM Reports

CEAL-TM-186 "Rationale of the CEA Radiation-Safety Interlocked Personnel-Exclusion System as of December 1, 1969", W. A. Shurcliff, January 26, 1970.

CEAL-TM-187 "Radiation Safety Results for the Period October 1, 1968, through September 30, 1969", W. A. Shurcliff, January 29, 1970.

CEAL-TM-188 "Measurement of Neutron Radiation, at Museum Street, as a Function of Height above Street", B. J. Maddox and G. F. Dell, February 9, 1970.

CEAL-TM-189 "Neutron Dose Rates in Vertical Plane Perpendicular to Hammond Street during High-Intensity Run by Russell and Tannenbaum", G. F. Dell, May 8, 1970.

CEAL-TM-190 "Extent to which a Horizontal One-Foot Layer of Water Attenuates Neutron Radiation Emerging above Ground near the North Portion of the CEA Circular Tunnel during a Run for the Russell-Tannenbaum Group", G. F. Dell and W. A. Shurcliff, June 19, 1970.

CEAL-TM-191 "Demonstration that the Neutron Radiation Emerging above Ground in the CEA North Parking Lot during a High-Intensity Run with Long Spill is Produced by the High-Energy Beam and not by Linac Spill", G. F. Dell and W. A. Shurcliff, June 26, 1970.

CEAL-TM-192 "Effectiveness of a Two-Foot-High Wall in Blocking Radiation Emerging above Ground in the CEA North Parking Lot and Traveling toward Houses on North Side of Hammond Street during a Russell-Tannenbaum Run", G. F. Dell and W. A. Shurcliff, June 22, 1970.

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