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SEMI-ANNUAL REPORT

For the Period

JANUARY 1 through JUNE 30, 1969

K. Strauch, Director

W. A. Shurcliff

July 29, 1969

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
and HARVARD UNIVERSITY

CAMBRIDGE ELECTRON ACCELERATOR

CAMBRIDGE, MASSACHUSETTS 02138

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Contract AT(30-1)-2076 between
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J. A. Schrieffer

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TABLE OF CONTENTS

	<u>Page</u>
SUMMARY	1
Part I INTRODUCTION	3
Part II ACCELERATOR OPERATION	5
A. Statistics on Accelerator Use	5
B. Operation, Maintenance, and Minor Improve- ments	6
C. RF System	12
Part III EXPERIMENTS IN HIGH-ENERGY PHYSICS	15
A. Experiments in Which Analysis of Data was in Progress during the Period in Question	15
B. Experiments Involving Use of Machine Time in the Period in Question	20
C. Experiments in Which the Data-Taking is Scheduled to Start in the Second Half of 1969	25
Part IV PROJECT BYPASS	27
A. Introduction	27
B. Injection - Positron Linac	28
C. Beam Storage	30
D. Bypass Studies	32
E. On-Line Detector	34
F. Optical Detector	36
G. Magnetic Detector	36
Part V OTHER ACTIVITIES AND NEW PROJECTS	37
A. Theoretical Studies	37
B. Experimental Magnets	37
C. Magnet Control System	37
D. Computer System	38
E. Cooling Water System for Experimental Magnets	38
F. Cryogenics	39
G. Radiation Monitoring	39
H. Source of Polarized Electrons	40

	<u>Page</u>
Part VI SAFETY	41
Part VII PUBLICATIONS RESULTING FROM WORK DONE AT THE CEA ...	42
A. Publications on High-Energy Research Per- formed at CEA	42
B. Papers Presented at American Physical So- ciety Meetings	42
C. Papers Presented at the 3rd National Particle Accelerator Conference	43
D. Other Papers and Preprints	44
E. Theses	45
F. CEAL Reports	46
G. CEAL-TM Reports	46

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CAMBRIDGE ELECTRON ACCELERATOR

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K. Strauch
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SEMI-ANNUAL REPORT FOR THE PERIOD

January 1 - June 30, 1969

SUMMARY

Part I indicates the purpose of the contract, which is concerned with the operation of the 6-GeV Cambridge Electron Accelerator, and lists the main guiding committees.

Part II, on accelerator operation, shows that the total number of delivered prime-user hours and parasite-user hours was 3630. The number of delivered prime-time hours was 2498 compared to 1546 in the previous six-month period; this is an increase of 62%. In March we achieved the highest-intensity (10 to 20 mA) long-term (8-day) 6-GeV run to date.

Part III describes the 20 experiments underway or in preparation.

Part IV summarizes progress on the colliding beam facility (Project Bypass). For the first time we switched a constant-energy electron beam from the ring into the bypass, and in June

we achieved a $1/e$ time constant of 25 seconds for such a beam. Our understanding of beam cross sections, v values, chromaticity, momentum vector, and beta function is improving, and we are confident that longer time constants will soon be possible.

The 130-MeV positron linac has been received, and by June 30, installation of parts was nearly complete. The injection runs, also, were nearly ready.

The on-line detector is progressing well. Many of the principal components are being built, and most of the other equipment required is on order. Satisfactory progress was made on the optical detector and magnetic detector also.

Part V summarizes the work done on various new projects.

Part VI deals with safety, and Part VII lists the major publications.

PART I - 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, 1969. 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.

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

from M.I.T.	Prof. Carl F. Floe
	*Prof. Francis E. Low
	*Prof. Louis S. Osborne
	*Prof. Victor F. Weisskopf
	Prof. Jerome B. Wiesner, Chairman
from Harvard	Dean Franklin L. Ford
	*Prof. Francis M. Pipkin
	*Prof. J. Curry Street
	Mr. L. Gard Wiggins
	*Prof. Richard Wilson

The Scientific Subcommittee met on April 24. It reviewed and approved the Laboratory's proposed budget for Fiscal Year 1970.

The "Cambridge Electron Program Advisory Committee" (CEPAC) reviewed the status of experiments in progress and examined proposals for future experiments. During the half-year

*denotes member of Scientific Subcommittee

in question this committee included (in addition to the Director):

Dr. Samuel Berman, SLAC
Prof. Louis. N. Hand, Cornell
Prof. Louis S. Osborne, M.I.T.
Dr. Burton Richter, SLAC
Prof. Julian Schwinger, Harvard
Prof. Steven Weinberg, M.I.T.
Prof. Roy Weinstein, Northeastern
Prof. Richard Wilson, Harvard
Prof. Donald Yennie, Cornell
Dr. Gustav-Adolf Voss, CEA
Dr. James M. Paterson, CEA, secretary

The committee met on February 14th.

The "CEA Scheduling Committee" determined the day-to-day priorities in assignment of eight-hour shifts of accelerator time to the experimenter groups. In the half-year in question the committee included:

Dr. Wolfhard Kern, S.M.U.
Dr. John J. Russell, Harvard
Dr. Herman Winick, CEA
Dr. William A. Shurcliff, CEA, secretary

PART II - ACCELERATOR OPERATION

A. Statistics on Accelerator Use

The following tables provide statistical information on overall efficiency, distribution of accelerator prime and secondary time, and causes of unscheduled downtime.

TABLE 1

EFFICIENCY OF SCHEDULED OPERATION

	<u>Hours</u>	<u>Percent</u>
Delivered Prime Time	2497.5	80.6
Unscheduled Downtime	602.0	19.4
	3099.5	100.

TABLE 2

USE OF DELIVERED PRIME TIME

	<u>Hours</u>	<u>Percent</u>
High Energy Physics	1946.0	77.9
Accelerator Physics	551.5	22.1
	2497.5	100.

TABLE 3

USE OF PRIME AND SECONDARY TIME IN HIGH-ENERGY-PHYSICS

<u>User</u>	<u>Exp't No.</u>	<u>No. of Prime Hours Scheduled</u>	<u>Delivery Delivered</u>	<u>Eff. (%)</u>	<u>Delivered Sec'd Hrs</u>
Pipkin et al	102h	79.5	77.5	98	394.0
Brenner et al	103h	387.5	283.0	73	148.0
Wilson et al	105f	47.5	34.0	72	0
Russell et al	107a	0	0	--	207.5
Luckey et al	109h	622.5	512.0	82	81.0
Deutsch et al	111d	120.0	94.0	78	55.0
Milburn et al	115a	12.0	12.0	100	77.5
Bar-Yam et al	117a Ph. I	198.5	191.5	96	25.0
Luckey, Bar-Yam et al	109i	364.0	269.5	74	16.0
Bar-Yam et al	117a Ph. II				
Weinstein et al	118d	449.0	320.5	71	0
Weinstein et al	118i	194.5	139.0	71	0
Dell et al	119a	15.5	13.0	84	14.0
Yuan et al	120a	0	0	--	73.0
Univ. of Chicago	--	0	0	--	11.0
Air Force CRL	--	0	0	--	8.0
Frisch Opt. Detector	--	0	0	--	23.0
		2490.5	1946.0	78.0	1133.0
				weighted average	

TABLE 4

USE IN ACCELERATOR PHYSICS

<u>Scheduled Hours</u>	<u>Delivered Hours</u>	<u>Eff. (%)</u>
609	552	91

Note: Total delivered prime and secondary time for high energy physics and accelerator physics: 3630.5

TABLE 5

ANALYSIS OF UNSCHEDULED DOWNTIME

<u>Cause</u>	<u>Hours</u>	<u>Percent</u>
Rf System	162.5	27.0
Linac	129.5	21.5
Tune-up	74.0	12.3
Emergent Electron Beam	49.0	8.1
Vacuum System	42.5	7.1
Magnet System and Magnet Powering	37.0	6.1
Ejection Magnet	29.0	4.8
Miscellaneous	78.5	13.1
	602.0	100

B. Operation, Maintenance, and Minor Improvements

Three-Week Operations Schedule. The three-week operations schedule, inaugurated on December 2, 1968, with the purpose of

- (1) increasing the available accelerator running time from 14 to 17 shifts per week,
- (2) increasing the scheduled block of running time from 28 (in two weeks) to 51 (in three weeks) and
- (3) permitting maintenance work to be done on weekdays,

has proved to be very successful. Longer runs for experimenters have significantly increased the efficiency of utilization of accelerator time. In a typical period of 21 days (63 shifts) 40 shifts were devoted to high-energy physics, 11 to bypass tests, and 12 to maintenance.

In the six-month period in question the total number of delivered prime-time hours was 2498, compared to 1546 in the previous half-year -- an increase of 62%.

In March, after making various improvements in the 130-MeV linac and in the accelerator proper, we achieved the highest intensity (10 to 20 mA), long-term (8-day), 6-GeV run to date.

Shutdown for Accelerator Repair, etc. The accelerator was shut down for scheduled repairs and improvements from December 18, 1968, through January 6, 1969.

Re-activation of Original (30-MeV) Linac. Starting on April 28 we injected from the original Arco 30-MeV linac in the Spur Tunnel, to permit installation of a 130-MeV positron linac in the same near-radial tunnel housing the 130-MeV Varian linac that has been in use for a year. The positron linac is discussed in Section IV-B.

Reconditioning of the 30-MeV linac was begun in February. A new gun was installed and adjusted. The standard ceramic vacuum chamber in Magnet 48 was replaced by an epoxy Y-type chamber, and the beam-run hardware for connecting the linac to this chamber was installed. The inflector was installed in Straight Section 1.

We arranged an operator refresher-training program in the use of this old linac. In April we were unable to capture and accelerate in the synchrotron a current exceeding 3 mA, and in May, after correcting a defect in the inflector, we

achieved a captured current of 7 mA. Further increase in captured current was made in June, by installing a new cathode button.

In June the inflector was damaged by arc-over, and was repaired.

Improvement of the 130-MeV Electron Linac. Prior to shutting down the Varian 130-MeV electron linac to permit installing the positron linac in the same tunnel, we made several improvements in the 130-MeV electron linac. After two transients-suppressing capacitors in the high-voltage supply failed, causing 24 diodes to fail, we installed capacitors having more conservative rating. By readjusting the position of the upstream bending magnet of the transport system, we increased the current captured in the synchrotron orbit by 25 to 50%. We installed a new phase shifter in the power supply, to reduce tuning time.

We tried out successfully an electrostatic system for fast-chopping the linac beam between gun and accelerating waveguide, and producing a pulse of any desired length from 0.1 μ s to several μ s. The system will be used routinely in multicycle injection and filling of a small portion (0.2 to 0.4) of the circumference of the ring in colliding beam studies, and has the merits of reducing the loading and power requirement of the linac waveguides, reducing radiation damage, and minimizing residual radioactivity in the downstream portion of the linac tunnel.

We installed a calibration cable through all four of the linac intensity-monitor toroids and equalized the responsivities of these monitors.

We relocated a portion of the linac rf supply system to make room for the console of the positron linac, discussed in Section IV-B.

Ring of 48 Magnets. We improved the system for regulating the power supplied to the 48 magnets in order to achieve greater stability during multicycle injection. During such operation of the accelerator, reversal of current direction cannot be permitted, and consequently the time-rate of increase of field strength (dB/dt) near injection was too small for reliable operation of the existing excitation-control sensors. In June we improved the magnet current regulation further, to provide uniformity of 0.1% at 1 GeV and 0.05% above 2 GeV.

We revised the pole-face-winding installation so that such windings are present only on one open magnet and four closed magnets. This quantity of windings provides adequate control, without occupying unnecessarily large amounts of space in the magnet gaps. In addition we have developed a new type of winding, employing a compact ferrite quadrupole, that would be located in a straight section, rather than in a magnet gap, thus releasing additional space in the magnet gap.

We completed the assembly of a spare core-block (complete with end packets and cooling tubes) for the 60-ton inductor of the magnet power supply.

Vacuum System. Many improvements in the vacuum system were made during the six-month period in question. Additional ceramic vacuum chambers were installed; at present 47 of the 48 chambers are ceramic. The sole exception is an epoxy chamber of special injection type required temporarily while the old 30-MeV linac is in use. In the last six months, four of the ceramic vacuum chambers developed small leaks (at the stainless steel flanges between ceramic segments) and were removed for repair.

Believing that such leaks at the flanges are a result of excessive stress and vibration, we have taken steps to further reduce stress and vibration. To reduce longitudinal stress we have replaced the old, circular-cross-section bellows (between vacuum chamber and straight sections) with bellows of elliptical shape, which have a cross-sectional area matching that of the vacuum chamber, so that no noteworthy longitudinal stresses develop when the system is pumped down or let up to atmospheric pressure. As of June 30, 94 of the 96 bellows were elliptical. The two remaining circular bellows are scheduled to be replaced in July.

By June 30 there were 39 ionization gages operative in the ring, and nearly all of the rf cavities, straight-section tanks, and high-vacuum pumps had been equipped for high-temperature bake-out and for operation at pressures down to 10^{-8} torr. During a 3-GeV, 3-mA run, we achieved an average pressure around the ring of 3×10^{-8} torr, and during a 2-GeV beam-storage trial (see Section IV-C) we achieved a 1/e decay

time of 2300 seconds. The lifetime of the stored beam provides the most accurate measure of average ring pressure!

Miscellaneous Components. We modified our beam-intensity leveling device, to increase the precision of leveling. Also we developed a modified design of rf-loop-type monitor of beam intensity and transverse position; the new design fits within a straight section and is compatible with use of elliptical bellows. We installed in Straight Section 5 a device for measuring the height of the beam cross section.

An improved type of beam-bump coil was developed. Employing four turns of pierced copper, the new coil is especially compact and may be used in pulsed mode, in normal operation of the accelerator, or in dc mode appropriate to storage of e^- and e^+ beams. Beam-Bump-34-Star, used to deflect the circulating beam toward the damping magnets, was modified in such a way (involving pulsing six, rather than four, magnets) that the amplitude of residual displacement of the beam in portions of the ring that are far from Straight Section 34, was reduced by a factor of five.

We improved the ejection magnet used in slow extraction of the electron beam.

We installed remotely controlled equipment for automatically and accurately moving bypass septum magnets and ultra-flectors radially into predetermined operating positions in the ring.

We developed and installed an improved type of octupole magnet for selectively altering the frequency of horizontal

betatron oscillation of particles having large oscillation amplitudes. The new design, shown in Fig. 1 can be powered so as to be effective throughout much of the acceleration and deceleration cycle during multicycle injection in order to produce high-intensity stored e^- and e^+ beams.

C. RF System

Although the rf high-power amplifier, employing an RCA 4612 triode, performed reliably in the half-year in question, alternatives to the existing system were being studied extensively. The serial U-1 triode was used throughout, except during brief tests of other tubes, and is still in use now (July 9). It has operated for 6000 hours. Slight repair was required at 4000 hours when a ceramic-to-metal seal was damaged by arcing. To prolong the life of this tube we lowered the ambient temperature by installing a new heat exchanger for the screen room in which the tube is housed, removed the filament supply from this room, and made other improvements. As a precaution, we are holding the average power level of the tube below 80 kW.

In February several hundred diodes of the 500-kW rf power supply failed and were replaced. To reduce the likelihood of further such failure, we installed vacuum interrupters and surge suppressors; also, we now employ a larger number of diodes.

To make the high-power amplifier operate as a class B amplifier irrespective of power level chosen, we installed a non-linear grid-cathode bias resistor.

Fig. 1: Octupole magnet for selectively altering the frequency of horizontal betatron oscillations of electrons that have large amplitude of oscillation (newly injected electrons, mainly). The magnet consists of four turns of pierced copper, i.e., 8 segments in all. The four inner segments carry current in one direction, and the four outer segments carry current in the opposite direction.

We installed an interlock system that turns off the rf power whenever the current drawn by any high-vacuum pump serving an rf cavity exceeds a specified value (i.e., whenever the pressure there becomes excessive). Thus dangers of arcing and resulting breakage of rf-cavity ceramic windows are reduced.

Several rf-cavity ceramic windows cracked, presumably as a result of arcing within the cavity. We planned improved bake-out procedures and have ordered equipment that will permit setting up an effective test facility for subjecting windows to high levels of rf power.

We installed electrical heaters for rf-cavity temperature-control water to make it possible to maintain adequate control even during temporary failure of the steam supply normally used.

Throughout the half-year in question we were very much concerned that we had no spare 4612 triode. The new tube (serial X-1) ordered in October 1968 was received, installed, and tested, but soon developed an air leak while still being operated at half power. After it had been repaired by RCA it was tested at the CEA again and a water leak developed. Further repair was made, but the tube failed again in trial use on 6/30/69.

In March we placed an order with RCA for the repair of our old serial A-4 tube that failed in October 1968 when an input seal became overheated and developed a leak. Repair is scheduled to be completed by August.

Meanwhile we have given much consideration to alternative kinds of rf supply, such as must be adopted in order to:

- (1) increase our rf capability (see previous semi-annual report CEAL-1047)
- (2) ease our triode supply problems.

Because we are the only user of the 4612 triode, delays in procuring additional units, or having present units repaired, are becoming excessively long. In June, two of our engineers (G. Nicholls and R. Mack) went to Europe to visit the NINA, DESY, and CSF laboratories to investigate the performance and availability of other kinds of high-power triodes and also of klystrons.

PART III - EXPERIMENTS IN HIGH-ENERGY PHYSICS

During the six-month period in question there were 20 experiments in high-energy physics in progress or in various stages of preparation or completion. These are described below.

A. Experiments in which Analysis of Data Was in Progress during the Period in Question

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. Analysis of results continued through the first half of 1969, and a full report is expected by August.

Pipkin, Hicks, et al (Harvard), Experiment 102g: Search for the R Meson. A two-spectrometer system capable of detecting the decay products (the π^+ and π^-) of the R^0 was used in March 1968 to search the mass range 1500 to 1800 MeV. No evidence was found for the photoproduction of R^0 mesons with a differential cross section $d\sigma/(dt dM)$ exceeding $1 \mu\text{b per } [(\text{GeV})^3 \text{ nucleon}]$. A summary of the principal results was presented at the August-September 1968 Vienna Conference on High Energy Physics: "Photoproduction Search for Dipion Resonances

in the Mass Range from 1400 to 1800 MeV". A detailed account of the work was written during the first half of 1969 and is now nearly ready for publication.

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. Electrons of 0.45 to 2 GeV energy that were quasielastically 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. During November and December 1968, the investigators took a large amount of data -- some of it at machine energy lower than ever used before at CEA (0.45 GeV) -- 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, using eight shifts of machine time, the investigators confirmed the calibration of the main beam monitor used, namely the CEA 9-inch Faraday Cup #2. The investigators are in process of analyzing the present data on quasielastic scattering in conjunction with similar data taken previously at 20° lab, with the hope of deriving more accurate values of neutron and proton form factors and obtaining a better understanding of the structure of the deuteron.

Frisch et al (M.I.T.), Experiment 112a: Study of Photoproduction 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 $0.9 \mu\text{b}$.

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. Preliminary analysis of the data taken in mid-1968 shows that the results will be sufficiently accurate to permit critical evaluation of various proposed models. The investigators expect to complete the analysis by September 1969.

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 was completed early in 1969. No significant polarization of the proton was observed. A report on the conclusions is now in preparation.

Milburn et al (Tufts and CEA), Experiment 115a: Study of Production of Polarized Photons with the aid of a laser. The investigators continued development of the method of producing polarized high energy photon beams demonstrated on a pilot scale in 1964 and 1965. Using a ruby laser pulsed once a second and producing about 15 joules per pulse, they directed a very intense beam of polarized 2 eV photons head-on at the 6-GeV electrons in orbit in the synchrotron; the photons recoiled with energies as great as 850 MeV and were presumed to retain their original polarization. Most of the measurements were made late in 1968. In January 1969 the investigators determined the spectral energy distribution of the recoiling

photons and used the system to explore the cross section of the orbiting electron beam. Principal results are summarized in report CEAL-1046 "Laser-Induced Polarized Photon Beam at the CEA", issued January 30, 1969. As indicated in this report, the investigators obtained 1000 back-scattered photons (with energies up to 850 MeV) per pulse, which is ample for bubble-chamber applications. Also, they found the method to provide an accurate, non-destructive means of exploring the cross section of an orbiting beam of charged particles.

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. From data taken in mid-1968 the investigators found that, at t -values of -0.6 and -1.2 (GeV/c)^2 , the asymmetry of photoproduction was 0.08 ± 0.2 and 0.2 ± 0.3 respectively. (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.) In December 1968 and January 1969, the investigators took much additional data

at a wider range of t -values, from -0.4 to -2.4 $(\text{GeV}/c)^2$. The results indicate that the asymmetry is positive at $-t = 0.4$ $(\text{GeV}/c)^2$, goes through zero at $-t = 0.6$, becomes positive again between $-t = 1.2$ and 1.8 , and then drops to negative values between $-t = 1.8$ and 2.4 . A summary of the results was presented at the April 1969 meeting of the Am. Phys. Society in Washington, D.C., and a full report is in preparation.

B. Experiments Involving Use of Machine Time in the Period in Question

Pipkin et al (Harvard), Experiment 102h: Beam 7 Spectrometer Testing. The spectrometer, shown in Fig. 2, consists of two arms which can be swung horizontally with the aid of pneumatic lifting pads. Each arm 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 on which scintillation counters, wire spark chambers, differential gas Cerenkov counter, and shower counters are mounted. The 30-inch cylindrical spectrometer magnet Orpheus is mounted at the pivot point. The majority of the equipment was installed in the last half of 1968. In the first half of 1969 the investigators timed trigger counters, reduced background, and determined the angular acceptance and momentum resolution.

Brenner, Walker, et al (Harvard), Experiment 103h: Study of Small-Angle Compton Scattering of Photons, at 2° to 6° lab,

Fig. 2: General View of the Area 7 spectrometer in October 1968 when assembly was approximately 70% complete. The two large gas-filled Cerenkov counters, with hemispherical ends, are visible at right and left. The equipment in the foreground is part of an independent experiment, on (e,d) inelastic scattering.

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 February and March 1969. Analysis of results is underway.

Russell, Tannenbaum, et al (Harvard), Experiment 107a: Boson Resonance Photoproduction. The goal is 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 hope 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 employ a tagged photon beam and a liquid hydrogen target. Protons recoiling at 20° to 60° lab are detected by two sets of wire spark chambers (8 in all) and an intervening magnet 'Enry 'Iggins. Decay products of the bosons produced are detected by six wire spark chambers situated downstream from the target. The data are interfaced by a CEA SDS-92 computer to the Harvard IBM-360/65 computer. The equipment was assembled in April 1969 and in the following months the investigators measured the

performance of spark chambers and made a trial data-taking run in order to record, on magtape, data for use in testing and improving the computer program for analyzing data.

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 (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 - June. Analysis of results is underway.

Luckey, Bar-Yam, et al (M.I.T. and S.M.U.), Experiment 109i: Photoproduction of π^+ from Polarized Photons. This experiment complements Experiment 117a (by Bar-Yam et al) on photoproduction of π^- from polarized photons. Again 6-GeV electrons in the synchrotron orbit strike a diamond and produce bremsstrahlung having a linearly polarized spike at 3 GeV. The target is of liquid hydrogen, rather than deuterium. The π^+ is detected by the Moby Dick spectrometer, augmented by a gas-filled threshold Cerenkov counter to discriminate against protons. The neutron is detected by a large (12 x 12 x 15 inch) scintillator block viewed by 20 photomultiplier tubes. The investigation

will cover the t -value range from -0.2 to -2.5 $(\text{GeV}/c)^2$. In May 1969 the Cerenkov counter was assembled and pressure-tested. Data taking started in June.

Deutsch et al (M.I.T.), Experiment 111d: Proton Compton Effect at 2 GeV and $t = -0.16$ $(\text{GeV}/c)^2$. In 1967 the investigators studied γ, p scattering at 65° c.m. with photon energies from 0.8 to 2.5 GeV and with t -values of -0.35 to 1.15 $(\text{GeV}/c)^2$. In the present experiment measurements are being made at angles as small as 30° c.m., t -values as small as -0.16 $(\text{GeV}/c)^2$, and photon energies possibly as high as 4 GeV. Energy of the recoil proton is determined by means of range measurements with spark chambers rather than by use of a magnetic spectrometer. In May 1969 a rough examination of the data taken in April was made, with the promising results that the signal-to-noise ratio was of the order of 7 to 1 and the rate of accumulation of useful events was about $25/\text{hr}$. Additional runs were made in June.

Bar-Yam et al (S.M.U.), Experiment 117a Phase II: Supplementary Measurements of Photoproduction of Single π^- on Deuterium by Polarized Photons. This experiment is an extension of Experiment 117a discussed in Part III-A. In June the experimenters made supplementary measurements at $t = -0.3$ $(\text{GeV}/c)^2$.

Weinstein et al (Northeastern University), 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 occurred in February, and by June 30 the analysis of results was nearly complete.

Weinstein et al (Northeastern Univ.), 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 June 30 the analysis of results was nearly complete.

Fulmer, Dell, et al (ORNL and CEA), Experiment 119a: Study of Electro-Induced and Photo-Induced Spallation. Iron sheets were exposed to 40, 80, 120, 130, and 500 MeV electrons and were shipped by air to Oak Ridge for prompt analysis.

Yuan et al (BNL), Experiment 120a: Energy Dependence of Transition Radiation. In 17 parasite shifts the investigators measured the energy dependence of transition radiation from a

stack of several hundred aluminum foils mounted perpendicular to a positron beam in Area 5. They expect that such radiation will provide a uniquely effective method of determining (at NAL; for example) the speed of highly relativistic protons or other charged hadrons for which $\gamma \geq 10^2$.

The Air Force Cambridge Research Laboratory used one shift of parasite time to make a range-vs-energy calibration of nuclear track plate emulsions placed in a tagged positron beam.

University of Chicago physicists used this same positron beam to calibrate a cosmic-ray telescope that included scintillators and gas filled Cerenkov counters.

The Optical Detector Group used 23 hours of parasite time for tests of spark chamber performance.

C. Experiments in which the Data Taking is Scheduled to Start in the Second Half of 1969

Pipkin et al (Harvard), Experiment 121a: Elastic π^+ Electroproduction near 0° and at pion-nucleon c.m. energy above the nucleon resonances. With the purpose of testing Regge-pole models and other models of hadron photoproduction, the investigators propose to take the photon off the mass shell and study the narrow peak of elastic π^+ production at small momentum transfer and with energy high enough to be above the nucleon resonances and in the region where the structure of forward production is no longer changing with energy. The investigators will use a liquid hydrogen target and the Beam 7 spectrometer. The two arms are similar, and each bends the particles in a vertical

plane. Wire spark chambers provide information as to trajectories, and Cerenkov counters, time-of-flight sensors, and shower counters provide particle identification. Measurements are to be made at two photon masses: -0.14 (GeV)^2 and -0.30 (GeV)^2 .

PART IV - PROJECT BYPASS

A. Introduction

The principal development project at the CEA is Project Bypass, the goal of which is to develop a facility for producing head-on collisions of electrons and positrons with energies up to 3.5 GeV in each beam.

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. When the beam intensities have been built-up sufficiently (design intensity is 100 mA) synchrotron operation is converted to dc mode (storage mode) and the particles remain in orbit with constant energy with a predicted lifetime of the order of one hour. The stored beams are promptly switched into a special 120-ft. detour or bypass and thence back into the synchrotron. Throughout the synchrotron proper and a major portion of the bypass, the counter-traveling beams are kept vertically separated by means of electrostatic fields; but the beams are guided so as to collide head-on at the interaction region, at the center of the bypass. Focusing magnets make the beam cross section very small here (about 0.3×0.01 mm) and accordingly the interaction rate (number of collisions per second) will be relatively high. The computer nominal luminosity to be expected is 1.5×10^{31} cm⁻² sec⁻¹.

The interaction region will be nearly surrounded by a detector that will include arrays of spark chambers, absorbers (converters), and scintillation counters. Three kinds of detector are under development. Initially, an on-line, magnetic-field-free detector will be used; the spark chambers will be of wire-type, digitized; all signals from spark chambers and scintillation counters will be read out and analyzed by an IBM 360/65 computer. Later, a magnetic detector will be used and will provide a more detailed analysis of complex events. An optical detector is under development also.

B. Injection - Positron Linac

Positrons and electrons are to be injected by means of two 130-MeV linacs arranged in tandem in the (nearly radial) Linac Tunnel. See Fig. 3. When positrons are to be injected, the upstream linac produces accelerated electrons which strike a converter from which gamma radiation and electron-positron pairs emerge; positrons having of the order of 10 MeV energy are collected and guided into the downstream linac, from which 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), the phase of the second linac is shifted suitably, and the two linacs operate in series to accelerate electrons to 260 MeV; these are deflected to the left and are inflected into the orbit in counterclockwise sense. Figure 4 shows the off-axis inflector used.

FIG. 3 LINACS & TRANSPORT SYSTEMS

2-3-69

Fig. 4: The off-axis inflector of electrons. Mounted in Straight Section 29.

The upstream (electron) linac is the one that has already been used for normal operation of the accelerator. Its performance has been improved steadily, as indicated in Part II.

The positron linac was ordered to provide CEA with a positron beam. The first use of this beam will be in the colliding beam facility.

Varian Associates delivered the two modulators and control console of the downstream (positron) linac in January, the two waveguides in February, and the phase shifters, vacuum pumps and klystrons in March. On April 7 a senior engineer from Varian arrived at CEA to take charge of the assembly and testing. By the end of May nearly all components were in place in the linac tunnel, most of the plumbing was complete, the modulators had been tried out successfully, and the two RCA 8568 klystrons had been operated for several days at full (20 MW) power level into a dummy load. On June 30, just after both waveguides had been conditioned and powered to 20 MW peak with 1 μ sec pulse length, a leak developed in the upstream accelerating waveguide. Preparations for repair are underway.

Most of the components of the transport systems for positron and electron beams are in place. The special straight-section tanks required at Straight Sections 26 and 28, and likewise the final bending magnets to be used there, were installed in May.

The shielding between linac tunnel and circular tunnel was improved, and the radiation-protection interlock system was modified to permit trial operation of upstream and downstream

linacs without need for clearing personnel from the circular tunnel.

C. Beam Storage

Thanks to the steady improvement of the synchrotron vacuum system, we have been able to achieve in the ring an air-equivalent average pressure of 3×10^{-8} torr. Beam-decay time in multicycle injection mode was about 40 sec. when the peak energy during the cycle was 2.75 GeV, and was 160 sec. with the slightly smaller peak energy of 2.5 GeV. These lifetimes seem to be comfortably large compared to the 16-sec. lifetime that is estimated to be necessary for positron filling. However, the time constant of filling during multicycle injection appears to be much shorter, because of the instabilities that develop as the accumulated current increases. A filling time-constant of 27 sec. was observed when only 1 μ A peak of beam was injected in each cycle. The resulting accumulated peak current was 2 mA. Increasing the injected current per cycle decreased the filling time; the increase in total accumulated current was far less than the increase in injected current. Injecting a current of 5 mA peak per cycle resulted in a peak accumulated current of 50 mA, with a 1/6 sec. time constant of filling.

We made tests to determine whether the radial instabilities which limit the amount of current that can be accumulated by multicycle injection could be reduced by means of an octupole lens. We found that the saturation current achieved in multicycle

injection was only slightly larger (a maximum of 30% larger) when octupole fields were employed. The powering of octupole lenses must be programmed so that their strengths match the particle energy during multicycle injection. In those first tests of the effectiveness of octupole lenses only a crude match was achieved.

Multicycle injection tests stopped in March as scheduled when the 130-MeV electron linac was shut down to allow installation of the positron linac. (Synchrotron operation was continued with use of the 30-MeV injector.) Multicycle filling of a synchrotron is critically dependent on injection energy and cannot be accomplished at the low injection energy provided by the 30-MeV injector. Multicycle tests will resume in the fall of 1969.

All of the multicycle injection tests were made with 130-MeV electrons and therefore may not be representative of positron multicycle injection tests, to be made late in 1969. Electron injection, too, will be very different: electrons will be injected at an energy of about 250 MeV, provided by the two linacs operating in series.

The improvements made in the vacuum system resulted in a beam decay time of 45 min. for small currents of 2 GeV electrons stored in a dc-powered synchrotron. Such a beam was actually maintained for a 2.7 hour period, terminated by accidental turn-off of rf power. Because the synchrotron vacuum system was frequently opened up for installation of new components, little

time was available for bakeout; we expect that, ultimately (with adequate time made available for bakeout) even longer decay time will be achieved. We found that larger electron currents (30 mA peak) resulted in shorter decay times (23 minutes) presumably because of photo-desorption of gas from chamber walls by synchrotron radiation.

With stored beams exceeding 20 mA peak, radial beam instabilities occasionally occurred, especially when ion clearing in the ceramic chambers was used. In some instances such an instability resulted in sudden loss of a large fraction of the beam intensity. Increasing the threshold at which these instabilities occur will be one of the main tasks in the future.

D. Bypass Studies

In our first attempts (reported previously) to switch the synchrotron electron beam into the bypass, the switching was done during cycling-mode operation of the synchrotron; the beam was ejected from the ring into the bypass just at, or slightly preceding, the instant of maximum energy.

Bypass tests made late in 1968 revealed large coherent synchrotron oscillations, indicating that the length of the bypass train was about $3/4$ inch too great. In January 1969 we shortened the bypass train by moving the central portion of the train 0.6 inch toward the ring. Subsequent tests showed that this adjustment was successful, and greatly reduced the amplitude of synchrotron oscillations.

In February 1969 we tried for the first time switching a beam of constant energy electrons (i.e. in the dc mode) into the bypass.

In the first half of 1969 we made studies of the chromaticity of the system comprising ring plus bypass, i.e., the change in betatron frequency with particle momentum. The chromaticity was found to be about twice as large as expected. We found that, with the help of sextupole magnets, we could eliminate most of the chromaticity of the system.

Efforts were made to measure the width of the beam cross section (in the bypass and in the synchrotron proper) as described by the beta-function at representative locations, and to measure the momentum vector at those places. Comparing these measurements with results from computer programs allowed us to improve the input into the computer program and get a better understanding of the optical properties of the bypass.

Measurements were made to determine empirically the available horizontal and vertical beam apertures in the synchrotron and the bypass, and to optimize the apertures. These studies resulted in a better understanding of the properties of the bypass and a gradual increase in the lifetime of electron beams switched into the bypass. At the end of June we achieved a lifetime of 25 sec. From the best match of the observed beam sizes in certain locations in the bypass and the synchrotron with the output of the computer program which calculates those quantities, we infer that in those tests, the beam size at the

interaction point was smaller than the beam size in the synchrotron by a factor of .119 in the horizontal plane and .153 in the vertical plane. These results correspond to values of the amplitude function (beta-function) of 4" in the horizontal plane and 6.75" in the vertical plane. We have been preparing to make a more direct type of measurement of beam size at the interaction point: the beam cross section will be scanned by a 10^{-4} -cm-diameter quartz wire, which will be moved through the beam in a few msec. The time distribution of the resulting x-ray radiation will be a measure of the spatial distributions of electrons in the beam cross section. With the above-mentioned values of beta functions, the beam cross section at the interaction point is expected to be .001 cm high and .03 mm wide.

E. On-Line Detector

Construction of the on-line detector for analyzing results of e^-e^+ collisions continued. The detector core consists of four similar quadrants, each containing many wire spark chambers interspersed with scintillators and absorbers, arranged symmetrically around the interaction beam-line. (See Fig. 3 of CEAL-1047, the previous semi-annual report.) The active area of the wire spark chambers varies 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. On either side of the core there is a "hadron converter" consisting of twelve 1"-thick iron plates interspersed with additional wire chambers each of which has an

active area of 58" x 65". All of the information from the chambers will be recorded by the SDS-92 and IBM-360/65 computer system.

A total of 62 spark chamber gaps are contained in the core. Production of wire chambers, accomplished using a wire winding machine designed and built here, was started in April. Assembly of the core chambers is scheduled to be complete by January 1970. The single-spark efficiency of the prototype chambers was found to be $\geq 99\%$, and an individual chamber can support many sparks in a single event. Multi-spark-efficiency tests of more sophisticated type are planned.

The chambers are pulsed by English Electric CX1157 thyratrons. The prototype pulsers were found to operate successfully, and production of the system as a whole, which employs 20 thyratrons, was started.

The mechanical support system for the core was designed, a prototype was built and tested, and a complete system was ordered.

Tests were made on time-of-flight scintillators to be used for vetoing cosmic ray muons. A rejection rate of 98% was achieved, with only 1% rejection of real $\mu^+\mu^-$ events expected.

All of the scintillators, light guides, and phototubes were ordered. Also, we ordered the fast electronics for event triggering, cosmic ray vetoing, and luminosity monitoring.

The task of writing and debugging the basic on-line program for the 360/65 was largely completed. Emphasis is now being placed on the on-line programs for the SDS-92, which accepts

information from the detector core and transfers it to the IBM computer. We developed an off-line display program that permits an experimenter to examine an event-reconstruction.

F. Optical Detector

We completed the design of an optical detector, which will employ scintillation counters, optical spark chambers with stereo-photographic recording, and lead and aluminum absorbers. This device serves as a back-up for the on-line detector, particularly for the confirmation of unexpected or complex events.

One quadrant of spark chamber was constructed and tested successfully. The decision was made to use integrated-circuit electronics for the fast triggering of spark chambers because of the flexibility and economy provided.

We explored a scheme for vetoing cosmic rays by measuring the time-of-flight between a matrix of solid scintillators comprising a hemispherical shell (of 5-ft radius) above the detector proper and a small scintillator close to the interaction station.

G. Magnetic Detector

Progress continued on the design of the reduced scope magnetic detector, which will employ scintillation counters and optical spark chambers mounted inside and outside a large rectangular solenoidal coil the axis of which is parallel to the beam.

The design of the conventional solenoidal coil was completed, and we placed an order for such a coil with Westinghouse. Also, we completed the design of the iron plates to flank the coil, and a set of such plates was ordered.

PART V - OTHER ACTIVITIES AND NEW PROJECTS

A. Theoretical Studies

In the period in question the CEA staff theoretical physicists made studies which included:

Hard pion calculations,

Speculations on tensor and scalar meson dominance,

Uniqueness of Veneziano representation,

Dispersion treatment and the problem of gauge invariance in pion electroproduction,

Production of single W mesons in e^+e^- colliding beams.

Three papers resulting from these investigations are listed in Part VII-D.

Also, these physicists conducted an informal course in high-energy theoretical physics for experimenters at CEA.

B. Experimental Magnets

We received two additional 18-kilogauss analyzing magnets for later use on an improved Beam 7 spectrometer. One magnet, for analyzing high-momentum electrons, has a gap 5 x 22 x 84 inches; it was built by Valley Machine Co. The other magnet, for low-momentum analysis of protons, has a tapered gap 12 x 24/36 x 36 inches; it was built by Westinghouse. Both are being assembled in the CEA experimental hall.

C. Magnet Control System

We continued the development of a computer program that would facilitate monitoring and controlling the powering of

trains of experimental magnets. Such a program would lead to saving of operator time and accelerator time, and would increase the accuracy of control. By the end of June the development had progressed to the point that one of our four SDS-92 computers could control one power supply and one simulated magnet load, and could respond to teletypewritten commands to turn on, turn off, adjust within any specified tolerance, and record values of current.

D. Computer Systems

During the half-year in question the efficiency and reliability of our computer interface equipment for permitting experimenters to employ the Harvard IBM-360/65 computer on-line increased considerably. In May the equipment performed perfectly throughout 36 hours of continuous use. On June 30, for the first time, two groups of experimenters employed the 360/65 on-line simultaneously.

E. Cooling Water System for Experimental Magnets

Early in 1969 we initiated extensive improvements in the water cooling system serving the experimental magnets. Improvement in quality of the water was needed in order to reduce the tendency of the water conductors and fittings of magnet coils to become coated or clogged with deposits of copper and iron compounds and organic materials, with resulting loss of electrical resistance of the water passages between coils and grounded manifolds, and risk of permanent damage from overheating.

Plans were made for improving the equipment supplying 10 gallons per minute of make-up water (from city supply) by installing special filter cartridges to remove suspended material, activated carbon to remove organic material, and resins to remove (by ion exchange) dissolved metallic ions. Also, preparations were made for improving the 160-gpm of recirculating cooling water by installing a resin bed for removing metallic ions and a sodium sulfite bed for removing dissolved oxygen. The pipes of the distribution system are to be cleaned also. By June 30 this general program was well advanced: planning was essentially complete, 95% of the components have been received, and installation is to start in July.

F. Cryogenics

We completed construction of a first model of a liquid-hydrogen target control system (including mechanical refrigerator) that is designed to be operated by the experimenters themselves. In subsequent months we built two additional coolers, also employing mechanical refrigerators. Three such coolers have now been used routinely by experimenters, and a fourth unit is nearly ready for use.

G. Radiation Monitoring

We obtained a more sensitive, portable, sphere-type device for measuring and recording neutron dose in rems, and steadily improved our other monitoring equipment. In May we made a detailed study of radiation levels in areas adjacent to the

Experimental Hall when there is an external electron beam striking a thick, unshielded target in that Hall; results were reported in CEAL-TM-181. We prepared a comprehensive report CEAL-TM-179 on the radiation safety program at the CEA.

H. Source of Polarized Electrons

Progress was made in the program to develop a source of polarized electrons. We hope that, with such a source, we could inject polarized electrons into the synchrotron ring and accelerate them, without serious loss of polarization, to an energy of several GeV. The vacuum assembly was tested successfully and electrical supplies, a cooling system, and safety interlocks were completed. The magnetic bottle was operated and electrons were successfully trapped in it. Preliminary tests were made on the source of polarized hydrogen atoms (which, by spin exchange with electrons in the bottle, will polarize the electrons). Much of the equipment to be used in measuring the degree of polarization of the electrons has been procured.

PART VI - SAFETY

During the first half of 1969 there was one lost-time injury, resulting in loss of 39 man-days.

No CEA employee or experimenter received, in the period in question, a radiation dose as large as one third of the six-month permissible dose. The three largest 6-month doses were 760, 680, 645 mrem.

Seventeen members of the Operations Division were given a brief course in first aid.

PART VII - PUBLICATIONS RESULTING FROM WORK DONE AT THE CEA

A. Publications on High-Energy Research Performed at CEA

"Form Factors of Elementary Particles", Richard Wilson, Physics Today, 22, 47 (Jan. 1969), a survey article.

"Search for the Electroproduction of the N'(1470) Resonance from Deuterium", J. L. Alberi, J. A. Appel, R. J. Budnitz, J. Chen, J. R. Dunning, Jr., M. Goitein, K. Hanson, D. C. Imrie, C. A. Mistretta, and Richard Wilson, Phys. Rev. 176, 1631 (1968).

"Measurement of Elastic Electron-Deuteron Scattering at High Momentum Transfers", J. E. Elias, J. I. Friedman, G. C. Hartmann, H. W. Kendall, P. N. Kirk, M. R. Sogard, L. P. Van Speybroeck, and J. K. dePagter, Phys. Rev. 177, 2075 (Jan. 1969).

"Secondary Emission Yield by Extreme Relativistic Particles", G. F. Dell and M. Fotino, Phys. Rev. Letters 29B, 324 (May 1969).

B. Papers Presented at American Physical Society Meetings

1. New York Meeting, February 1969

"Recoil Proton Polarization in Neutral Pion Photoproduction by 1200 to 1800 MeV Photons", N. Tanaka, M. Castro, R. H. Milburn, J. P. Rutherford, W. B. Richards, B. F. Stearns, M. Deutsch, K. Tsipis, P. Patel.

"Further Search for $S = +1$ Baryon States in Photoproduction",
S. Mori, J. S. Greenberg, V. W. Hughes, D. C. Lu, J. E. Roth-
berg, P. A. Thompson.

2. Washington Meeting, April 1969

"Backward Angle e-p Elastic Scattering", L. E. Price, J. R.
Dunning, Jr., M. Goitein, K. Hanson, R. Wilson, Paper BJ5.

"Ratios of Electromagnetic Form Factors G_{M_N}/G_{M_P} ", K. M. Hanson,
J. R. Dunning, Jr., M. Goitein, L. E. Price, R. Wilson, Paper BJ6.

"Photoproduction of Single Negative Pions from Deuterium with
Polarized Photons of 3.0 GeV at $-t$ between 0.4 and 2.4 $(\text{GeV}/c)^2$ ",
Z. Bar-Yam, J. dePagter, J. Dowd, W. Kern, Paper CJ11.

"Photoproduction of Muon Pairs at High Invariant Mass", C. Tank,
W. L. Faissler, D. R. Earles, M. W. Gettner, G. Lutz, H. von
Briesen, E. von Goeler, R. Weinstein, Paper CJ12.

"Electrodisintegration of Al, Fe, and Ta", C. B. Fulmer, K. S.
Toth, I. R. Williams, G. F. Dell, Paper HG-13.

C. Papers Presented at the 3rd National Particle Accelerator
Conference, Washington, March 1969

"Low Conductivity Cooling Water System", G. Homsy, W. J. Jones,
Paper F42.

"A Precision Goniometer for Use in Accelerators", E. A. Thebado,
Paper F41.

"Improvements in Liquid Hydrogen Target Techniques", M. O. Hoenig, Paper F34.

"A Laser-Induced Compton Back-Scattered Photon Beam at the Cambridge Electron Accelerator", J. R. Sauer, R. H. Milburn, C. K. Sinclair, M. Fotino, Paper I25.

"The Design of Beam Inflector Magnets for Ultra-High Vacuum Operation", R. D. Hay, Paper G24.

"Post Accelerator Beam Pulse Length Chopper", R. J. Averill, T. L. Collins, Paper B33.

"Detectors for CEA RF Monitors", B. Anderson, Paper H34.

"A Gradient Ferrite-Pulsed Inflector for 130-MeV Electrons", T. Dickinson, Paper G23.

"The Ultraflexor Current Switch", L. Law, J. M. Paterson, Paper G25.

"Flat Topping the CEA Alternating Gradient Magnetic Field", R. J. Averill, Paper G10.

D. Other Papers and Preprints

"Hard Pion Results from the Algebra of Fields", S. G. Brown, G. B. West, Phys. Rev. 180, 1613 (April 25, 1969).

"Experimental Data from a Closed Loop Supercritical Helium Heat Transfer System between 4.2° and 8° K", R. D. Hay, presented at the Cryogenic Engineering Conference, Los Angeles, June 1969.

"Gauge Invariance and the Born Approximation in Pion Electroproduction", F. A. Berends, G. B. West, submitted to Phys. Rev.

"Coincidence Measurements of Single-Pion Electroproduction near the $\Delta(1236)$ Resonance", C. Mistretta, J. A. Appel, R. J. Budnitz, L. Carroll, J. Chen, J. R. Dunning, Jr., M. Goitein, K. Hanson, D. C. Imrie, R. Wilson, submitted to Phys. Rev.

"Construction of Veneziano-Like Formulae from Superconvergence", G. B. West, submitted to Phys. Letters.

"Search for $S = +1$ Baryon States in Photoproduction", S. Mori, J. S. Greenberg, V. W. Hughes, D. C. Lu, R. C. Minehart, J. E. Rothberg, P. A. Thompson, J. Tyson, submitted to Phys. Rev.

"Photoproduction Search for Dipion Resonances in the Mass Range from 1360 to 1780 MeV", N. Hicks, A. Eisner, G. Feldman, L. Litt, W. Lockeretz, F. M. Pipkin, J. K. Randolph, and K. C. Stanfield, submitted to Phys. Letters.

E. Theses on High-Energy Research Performed at CEA

"Test of Time Reversal Invariance in Inelastic Electron Scattering from a Polarized Proton Target", thesis by J. A. Appel, Harvard, December 1968; received at CEA in March 1969.

"Asymmetric Electron Pair Production", thesis by J. K. Randolph, Harvard, April 1969.

"Photoproduction of Electron-Positron Pairs at 2.3 and 5.6 GeV", thesis by J. Tenenbaum, Harvard, January 1969.

"Large Angle π^+ Photoproduction at Photon Energies between 1 and 3 GeV", thesis by G. Cooperstein, M.I.T., 1968; received at CEA in 1969.

" π^0 Photoproduction with Plane Polarized 3-GeV Photons", thesis by D. Bellenger, M.I.T., November 1968; received at CEA in 1969.

"Photoproduction of η^0 Mesons at 4 GeV", thesis by S. Deutsch, M.I.T., 1968; received at CEA in 1969.

F. CEAL Reports

CEAL-1047 "Semi-Annual Report for the Period July 1 through December 31, 1968", K. Strauch, February 12, 1969.

CEAL-1048 "Operation of the Cambridge Electron Accelerator for Fiscal Years 1969, 1970, and 1971; AEC Contract AT(30-1)-2076 and AEC Contract AT(30-1)-3025", K. Strauch, May 1, 1969.

G. CEAL-TM Reports

CEAL-TM-179 "Radiation Safety Program at the CEA: A Comprehensive Account as of December 31, 1968", W. A. Shurcliff, January 20, 1969.

CEAL-TM-180 "Interlock System for Radiation Protection", G. R. Gonzalez, May 14, 1969.

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