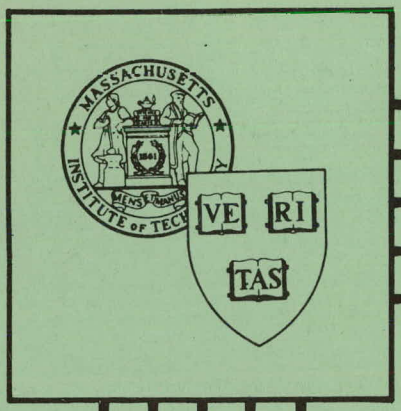

CEAL-1023

SEMI-ANNUAL REPORT
for the period

January 1 through June 30, 1965

A.E.C. Contract AT(30-1)-2076

M. Stanley Livingston
Director

September 22, 1965

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
and HARVARD UNIVERSITY

CAMBRIDGE ELECTRON ACCELERATOR

CAMBRIDGE 38, MASSACHUSETTS

DISCLAIMER

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

SUMMARY

Part I indicates the purpose of the contract, which is concerned with the operation of the 6-Gev Cambridge Electron Accelerator. Part II indicates the general nature of each of the 34 experiments that were in progress or in preparation during the six-month period in question. Part III lists some of the improvements made in the accelerator and the associated facilities. Part IV deals with the routine operation of the accelerator, and indicates that beam intensity was increased to levels never before achieved and the total number of user-hours was greater than in any previous six-month period. Part V discusses other matters, including the storage ring proposals submitted in May 1965, the fire that occurred on May 6 in a portion of the linac power supply, and the serious explosion that occurred on July 5 in the Experimental Hall.

PART I. INTRODUCTION

This report summarizes the work done under the Harvard-AEC Contract AT(30-1)-2076 during the six-month period January 1 through June 30, 1965. 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

pertinent to the experiments performed.

General policies of the Laboratory were determined by a joint M.I.T.-Harvard "Executive Committee of the CEA". On June 30 this Committee included the following:

from M.I.T.:	Dr. Carl F. Floe
	Dr. Bernard T. Feld
	Dr. Francis E. Low
	Dr. Louis S. Osborne
	Dr. Charles H. Townes (Chairman)
from Harvard:	Dr. Franklin L. Ford
	Dr. Norman F. Ramsey
	Dr. J. Curry Street
	Dr. L. Gard Wiggins
	Dr. Richard Wilson

Scheduling of research experiments was the responsibility of the Director of CEA assisted by a "Scheduling Committee for the CEA". During the period in question the Committee members were Dr. Henry Kendall of M.I.T. and Dr. K. Strauch of Harvard.

PART II. THE EXPERIMENTS

During the six-months period in question there were 34 experiments in progress or in various stages of preparation or completion. They are described briefly below, arranged alphabetically by name of a principal investigator.

1. Photoproduction of π^+ and K^+ at Large Angles, and Study of Angular Distributions and Spins (R. A. Alvarez et al)

Physicists from M.I.T. have been preparing to study

the photoproduction of positive pions and kaons by means of a 1 to 3 Gev photon beam. They use a large deflecting magnet, spark chambers, and other detectors. They expect that data-taking runs will be underway within six months.

2. Photoproduction of Pions from Deuterium (Bar-Yam et al)

Physicists from Southeastern Massachusetts Technological Institute have been preparing to study the photoproduction of pions from deuterium. They will use a liquid deuterium target, much of the Moby Dick spectrometer equipment, and two special hodoscopes. They expect that data-taking runs will be underway within six months.

3. Experiment Involving the 12-Inch-Diameter Liquid Hydrogen Bubble Chamber (Cambridge Bubble Chamber Group)

During the first six months of 1965 the Cambridge Bubble Chamber Group continued the analysis of the 120,000 photographs taken at the CEA last year with the 12-inch liquid hydrogen bubble chamber.

Recent publications:

"N^*_{33} and ρ^0 production by high energy photons", Phys. Rev. Letters 13, 640, Nov. 1964.

"Gamma ray proton interactions between 0.5 and 4.8 Bev", Phys. Rev. Letters 13, 636, Nov. 1964.

"Three-pion production in a 5 Bev bremsstrahlung beam", Bull. Am. Phys. Soc. II, 9.

"Pion pair production in a 5 Bev bremsstrahlung beam", Bull. Am. Phys. Soc. II, 9.

"Photonucleon interactions in a 5 Bev bremsstrahlung beam", Bull. Am. Phys. Soc. II, 9.

"Multiple pion and strange particle production in gamma ray proton interactions between 0.5 and 4.8 Bev", Dubna Conf. on High Energy Physics, August 1964.

4. Experiment Involving the 40-Inch-Diameter Liquid Hydrogen Bubble Chamber (Cambridge Bubble Chamber Group)

The assembly and testing of this bubble chamber, designed for use in conjunction with the CEA 300-ton magnet COLOSSUS, continued. By Jan. 1, 1965, the task of assembling and testing the large helium refrigerator to be used in conjunction with the bubble chamber had been completed and in April 1965 the CEA staff finished installing power cables and control cables. By mid-June the Cambridge Bubble Chamber Group had completed several preliminary leak-testing operations, and by the end of June the chamber was being filled with liquid hydrogen for the first time. (The explosion that occurred in the CEA Experimental Hall on July 5 is mentioned in a later section.)

5. Proton Compton Effect (Deutsch et al)

Physicists from M.I.T. are continuing the study of (gamma, proton) scattering, undertaken earlier at CEA, by extending the measurements to photons of 2.5 Gev energy and to center-of-mass angles of 90° and 120°. The detection equipment will include spark chambers and

Cerenkov counters, and the data will be analyzed with the aid of the SPASS computer. Runs are expected to start within about 6 months.

6. Photoproduction of N^* Particles (Deutsch et al)

M.I.T. physicists have been preparing to study the photoproduction of $N^*(1238)$ resonance particles by means of photons of energy exceeding 1 Gev. Much of the equipment used will be the same as that mentioned in the previous paragraph. Runs are expected to start within about 6 months.

7. Photon Energy Determination (Fessel et al)

CEA physicists have designed and assembled a pair spectrometer by means of which the spectral energy distribution of a given beam of multi-Gev photons can be determined with high accuracy. The individual photon strikes a thin foil just upstream from the spectrometer magnet, and the energies of the resulting electron and positron are measured with the aid of large banks of scintillation counters and Cerenkov counters. The equipment is to be used also in measurements of the attenuation (of photons of given energy) that results when a sheet of attenuator of given atomic number is interposed in the photon beam.

8. Production of Quasi-Monochromatic, Linearly Polarized Photon Beam with the Aid of a Crystal (Fessel et al)

CEA physicists have been making preparations for orienting a diamond in a 1 to 4 Gev bremsstrahlung beam in such a way as to achieve a beam which, after collimation, will be quasi-monochromatic and will have a degree of linear polarization of 40 to 80%. The above-mentioned pair spectrometer will be used in the analysis of the beam.

9. Determination of the Geometry of a Multi-Gev Shower (Fotino et al)

CEA physicists plan to determine the geometry of electron-induced and photon-induced showers. Arrays of small rectangles of cobalt glass, and perhaps spark chambers also, are to be employed.

10. Internal Beam Tagging Facility (Frisch et al)

M.I.T. physicists have been investigating the feasibility of producing a beam of tagged multi-Gev photons originating directly within the synchrotron. A fine wire target is to be mounted directly in the equilibrium orbit of the multi-Gev electrons (at the center of Magnet 12) and the energies of individual spent electrons are to be determined with the aid of the analyzing field of this magnet and a bank of 30 detectors situated nearby. The tagged photons will

enter the Experimental Hall and strike a target there, and the resulting events will be analyzed with the aid of a spark chamber.

11. Positron Scattering Experiment (Hand et al)

This experiment, performed by Harvard physicists, is nearly complete. The results (on the scattering of positrons by protons) are being analyzed and a report is being prepared.

12. Electroproduction of K_2^o (Hand et al)

Physicists from Harvard have been preparing to study the electroproduction of K_2^o, which is the longer-lived species of neutral kaon. To study the flux of such particles, the investigators convert the particles to the shorter-lived species by means of a tungsten converter and then detect the resulting pions by means of a spark chamber.

13. Large-Angle Photoproduction of Lepton Pairs (Hughes et al)

Physicists from Yale University have been investigating the large-angle photoproduction of electron pairs and muon pairs. The experiment is nearly complete and an article on the results is to be published soon. Some of the results were presented in a talk given at the June 1965 High Energy Physics Conference at Hamburg, Germany.

14. Photoproduction of Charged Pions and Charged Kaons (Hughes et al)

Physicists from Yale University measured the cross sections for photoproduction of single (charged) pions and single (charged) kaons. Preliminary results were reported in two talks given at the January 1965 meeting of the Am. Phys. Soc. in New York and two talks given at the June 1965 High Energy Physics Conference at Hamburg, Germany. Also a preliminary account has been presented in Phys. Rev. Letters.

15. Photoproduction of Kaons and Y^* Resonances (Hughes et al)

Physicists from Yale have been preparing to measure (with greater accuracy than was possible previously) the production of positive kaons by a 3 to 6 Gev photon beam incident on a liquid hydrogen target, with the purpose of finding the cross section for the production (with the kaons) of Y^* resonances as a function of energy. By 6/30/65 the equipment had been set up in the Beam 4 area, some preliminary runs had been made, and the group was ready for routine data-taking runs.

16. Elastic Scattering of Electrons by Deuterons (Kendall et al)

This group of M.I.T. physicists made use of a liquid deuterium target situated directly in Straight Section 14

of the synchrotron ring and employed a spectrometer arm, situated in the Target Area, that included a quadrupole focusing magnet, three banks of scintillation counters, and 20 Cerenkov counters. The group succeeded in studying the rare events in which a high-energy electron strikes a deuterium target and is scattered elastically by a deuteron, rather than by a single nucleon. A thesis describing a portion of this work was published in June 1965; the analysis of the rest of the work is continuing and the results will be published.

17. Search for an "e-prime" Particle (Kendall et al)

Physicists from M.I.T. conducted a search for a new lepton, called the e', the existence of which was suggested by Dr. F. E. Low of M.I.T. They sought a peak in the energy spectrum of protons that recoil inelastically from electron scattering. The outcome was negative. A report is in preparation.

18. Inelastic Scattering of Electrons by Deuterons (Kendall et al)

Physicists from M.I.T. have been preparing to investigate the inelastic scattering of electrons by deuterons, i.e., the electro-disintegration of the deuteron near threshold. They plan to use an external electron beam, a liquid deuterium target, and several arrays of

scintillation counters and Cerenkov counters.

19. Elastic Scattering of Electrons by Alpha Particles (Kendall et al)

Physicists from M.I.T. have been preparing to measure the elastic scattering of electrons by alpha particles, with the purpose of probing the short-range structure of this tightly bound particle and establishing upper limits on the magnitudes of the anomalous terms pertinent to the interaction of the electron and the (spin zero) alpha particle. They plan to use an external electron beam and also various arrays of scintillation counters and Cerenkov counters. The target will consist of liquid helium.

20. Coherent π^0 Photoproduction from the Deuteron (Kendall et al)

Physicists from M.I.T. have been preparing to investigate coherent π^0 photoproduction from the deuteron. They will direct an external electron beam at a converter and cause the resulting photon beam to strike a liquid deuterium target. They will detect the recoiling deuteron in coincidence with the shower generated by a photon from the π^0 decay. The results are expected to shed light on the relative phases of the production amplitudes from the neutron and the proton.

21. Photoproduction of π^0 and η^0 Mesons at Forward Angles (Luckey et al)

M.I.T. physicists have been preparing to investigate the photoproduction of π^0 and η^0 mesons at forward angles, to obtain information that will complement the results that have been obtained with the Moby Dick equipment. Many shower detectors will be used, and are already on hand. The group hopes to start taking data in about 6 months.

22. Production of Polarized Photons with the Aid of a Laser (Milburn et al)

Physicists from Tufts University and CEA set up a red-light (2 ev) laser in the Target Area and, by means of a mirror, directed the beam head-on at the 6-Gev electrons orbiting within the accelerator ring. As expected, some interactions occurred and some photons that had energies of the order of ½ Gev (and presumably had the same polarization as that of the initial 2-ev photons) were detected. The investigators conclude that if a more powerful laser (emitting polarized light) were employed and were fired at greater repetition rate, a useful beam of 0.3 to 0.8 Gev polarized photons would result. Preliminary tests on a 1000 times-more-powerful laser are now underway.

23. Spark Chamber Analysis of Photoproduced Polarized Protons (Milburn et al)

Physicists from Tufts University have been preparing to use a spark chamber that contains spaced plates of aluminum and graphite to (a) detect recoil protons produced during the photoproduction of pions in a liquid hydrogen target and (b) determine the degree of polarization of these protons. Preliminary tests, conducted in the Beam 10 area, were completed, and the group is now preparing the equipment to be used in full-scale runs.

24. Comparison of Rates of Photoproduction of Kaons and Pions (Osborne et al)

MIT physicists are midway along in the determination of the relative rates of photoproduction of positive kaons and positive pions, with the purpose of determining whether current theory (which implies that the rates are comparable) is correct. The Moby Dick spectrometer, used in previous experiments, is being used -- with the addition of a powerful vertical deflecting magnet and a long elevatable tail that contains arrays of scintillation counters. By June 30'th many runs had been made. The results obtained to date are in accord with the theory.

25. Exploration of Commonest Gamma-plus-Proton Reactions At Many Angles (Osborne et al)

MIT physicists have been preparing to explore, at many angles, the commonest reactions that occur when photons strike protons, i.e., the reaction in which a proton and a neutral pion are produced and the reaction in which a neutron and a positive pion are produced. The Moby Dick spectrometer is to be used, and also a smaller arm Remora. Many runs have been made and the results are being analyzed.

26. Small Angle Scattering of Electrons by Carbon (Pipkin et al)

This group of Harvard physicists have been preparing to obtain, from small angle scattering of electrons by carbon nuclei, supplementary information on the form factor of the carbon nucleus. Such information is needed by the physicists who are analyzing the data obtained in a wide-angle-electron-pair-production experiment performed at CEA some months ago. The experimenters will use one of the CEA's external electron beams and a single-arm spectrometer that analyzes and detects the electrons that are scattered by the carbon target. Actual runs should start within a few months.

27. Photoproduction of Charged Kaons (Pipkin et al)

Physicists from Harvard have been preparing to determine the number of charged kaons that are emitted from a target of liquid hydrogen or carbon as a function of energy and angle, with the purpose of discovering the dominant characteristics of the photoproduction of kaons. Many runs have been made, and others are to be made within the next few months.

28. Peripheral Photoproduction of Bosons with the Aid of Tagged Photons Produced by an External Electron Beam (Strauch et al)

During the six-month period concerned, physicists from Harvard were preparing to study the peripheral photoproduction of π, η, ρ, ω, and f mesons (especially the ρ meson) with the aid of an external electron beam, a converter, tagged photons, a liquid hydrogen target, and a wide-gap spark chamber used in conjunction with a 230-ton wide-angle magnet. (Recently, this group has revised its plans in order to give priority to the study of wide-angle electron pairs, a study that might succeed in confirming the results of Pipkin et al as to possible breakdown of quantum electrodynamics at high momentum transfer.)

29. Total Cross Section for Real Photon Striking Nucleon (Walker et al)

Physicists from Harvard have been preparing to measure the total cross section that applies when high-energy monochromatic photons strike protons or neutrons. Monochromatic photons, of energy as great as 5.5 Gev, produced with the aid of tagging equipment, are directed at a 12-ft-long body of liquid hydrogen or liquid deuterium. The number of photons passing straight through this body is determined.

30. Electroproduction of Wide-Angle Muon Pairs (Weinstein et al)

Physicists from Northeastern University have been preparing to investigate the electroproduction of wide-angle muon pairs, with a view to studying the time-like form factor of the (e, μ) scattering. The equipment cannot be set up until an external electron beam becomes available to this group, i.e., until some time in 1966.

31. Photoproduction of Baryon-Antibaryon Pairs (Weinstein et al)

Physicists from Northeastern University have been making preparations for using a 4 to 6 Gev photon beam in measurements of the cross section of the reaction: $\gamma + p \rightarrow \bar{n} + d$. Results should shed light on the photon,

neutron, antineutron vertex. The group will use the Moby Dick spectrometer and also various Cerenkov counters, dE/dx counters, and equipment for determining time of flight. Some preliminary runs (in which baryon-antibaryon pairs were produced and were detected with a 250-to-1 rejection ratio against pions and protons) have been completed, and additional runs will be made after the equipment has been altered so as to increase the rejection ratio.

32. Precise Elastic (e,p) Scattering at Very High Momentum Transfer (Wilson et al)

Physicists from Harvard have been making a precise study of elastic (e,p) scattering at very high momentum transfer, with the purpose of obtaining additional information as to the magnetic form factor of the proton. They use an external electron beam, a liquid hydrogen target, and a large spectrometer arm capable of detecting and momentum-analyzing recoil protons that travel in directions very close to the direction of the incident electrons. A second arm, which includes a quadrupole magnet and various scintillation counters and shower counters, detects the scattered electrons. Results are analyzed by an on-line PDP-1 computer. By June 30 a number of preliminary runs had been made.

33. Precise Quasi-Elastic (e,d) Scattering by Means of a Coincidence Method (Wilson et al)

Physicists from Harvard have been preparing to make a precise determination of the cross section of the reaction: e + d → e + p + n with the purpose of determining the two electromagnetic form factors of the neutron in the four-momentum-transfer range from 10 to 100 f^{-2}. The investigators employ an external electron beam and a liquid deuterium target. The scattered electron is detected with a spectrometer that includes a threshold gas Cerenkov counter and a lead-scintillator-sandwich shower counter. The proton is detected by means of a counter telescope that includes three counters of circular cross-section and a 144-square checkerboard of scintillators. Again the PDP-1 computer is used on-line. Data taking is expected to start early in 1966.

34. Inelastic (e,p) Scattering, and Excitation of Nuclear Resonances (Wilson et al)

Harvard physicists are preparing to study inelastic (e,p) scattering with a view of obtaining information as to the second nucleon resonance, which has appeared to exhibit anomalies, and as to the form factor of the pion. Much of the equipment to be used is the same as that used in the above-mentioned experiments by Wilson et al. Runs are expected to start in the spring of 1966.

The accelerator was used also in the calibration of a quantameter brought to the CEA by members of the DESY laboratory at Hamburg, Germany, and the calibration of cosmic ray equipment brought to CEA by representatives of the Enrico Fermi Institute of Nuclear Studies, University of Chicago. Also it was used in the development of equipment for switching and guiding external electron beams.

PART III EQUIPMENT AND FACILITIES

A large number of improvements and additions to equipment and facilities were made during the current half-year period.

Many improvements were made in the accelerator proper. An additional core block for the 60-ton inductor of the magnet power supply was obtained. Many additional vacuum chambers of solid-side-wall type were received; these included ten chambers of simple type and six of spout-type. Coils for correcting vertical distortions of the equilibrium orbit at low field strength were mounted in the ring and put to use. A clipping system for flat-topping the high-voltage pulses to the linac modulator was developed and installed. Also a pulsed magnet for producing horizontal blow-up of the beam -- and thus prolonging the duration of the beam supplied to experimenters -- was developed.

Current monitors of new type were built and tried out successfully. Rotatable target holders were installed in additional straight sections in the ring; five straight sections are now equipped with such devices. A re-survey of the heights of the 48 magnets was made; the results showed that the stability of the earth and of the magnet supports is excellent, and readjustment of the magnet heights is required only at intervals of several years.

During the winter and spring shutdowns (Dec. 21 - Jan. 6 and also April 12 - May 2) the shielding walls in the Experimental Hall were rearranged to accommodate new experiments. New beam-catcher huts, access gates, cable runs, and protective devices were provided.

Many new facilities were made available to experimenters. A second external electron beam run was set up and put to use. Several additional magnets for use in experiments were obtained and a number of additional power supplies were purchased. The large helium-operated refrigerator for servicing the 40-inch-diameter liquid-hydrogen bubble chamber was tested and then put into routine operation. The large equipment for producing liquid helium was completed and tried out successfully. Large numbers of power cable and control cables were installed, including cables capable of supplying the bubble chamber magnet COLOSSUS with 4000 amperes.

Available quantameters were calibrated more accurately, and other beam monitors were improved.

Additional equipment (capacitors) for increasing the power factor of the CEA plant was installed and put into use; the power factor was increased from about 0.69 to 0.99 under conditions of 4 MW load, and a saving of approximately $30,000 was achieved in the period in question.

New quarters were provided for the Electronics Laboratory and for the Purchasing Dept., and the Conference Room was enlarged. The Second Floor Counting Room, which has the same shape and area as the original Counting Room (above the Target Area) was completed and put into use.

In June we placed an order with Varian Associates for a new linac, which will provide higher energy, higher current, and greater reliability. It is designed to supply a 288 ma current at 80 Mev within a 1% energy bin and with 4×10^{-4} centimeter-radian emittance over a 2.0 microsecond pulse length at 60 pulses per second. The cost will be $864,000 and the delivery period is 18 months.

PART IV ACCELERATOR OPERATION

During the six-month period in question the accelerator was operated with greater reliability and at higher intensity than ever before. Also, it provided greater spill times and smaller energy spreads. Flexibility of

use increased, and it was not uncommon for three experimenter groups to be using the accelerator simultaneously.

The number of user-hours, estimated at 3000 hours, was greater than in any previous six-month period.

On Jan. 31, during a run at an energy of 5 Gev, we achieved the greatest beam intensity obtained to date, namely 17.5 milliamperes, corresponding to 5×10^{12} electrons/sec. This figure is close to the original design goal of 6×10^{12}. The increase in intensity resulted from better control of orbit distortions and use of a linac fast chopper that permits only one electron bunch in six (the bunch having optimum phase) to reach the synchrotron proper.

PART V OTHER MATTERS

In April, CEA staff members working with Harvard and M.I.T. scientists prepared revised proposals for an electron-positron storage ring at CEA. Two separate proposals were submitted to the AEC:

"New Proposal for a 3-Gev Storage Ring at the CEA"

"Proposal for a 1.5 Gev Storage Ring at the CEA".

In March CEA physicists completed the second stage of a study bearing on the effect of synchrotron radiation on the gas pressure present in a high-vacuum synchrotron ring or storage ring; the results were presented in Report CEAL-1017.

A fire broke out in the Linac Spur Tunnel at 4:30 a.m. on May 6, and the synchrotron was not able to operate for five weeks. The fire is discussed in detail in the monthly report for May, 1965. In carrying out the necessary repair and reconstruction work, centered on Cubicle #4 of the linac power supply, we introduced several modifications intended to reduce the chance that such a fire could occur again.

In the early morning of Monday, July 5, an explosion and fire occurred in the CEA Experimental Hall. One person was killed, several were badly injured, and it has been estimated that the damage to building and equipment is of the order of $1 million. Investigations of the cause of the explosion and of the ensuing fire are continuing. Since the explosion occurred just after the period covered by the present semi-annual report, no further details will be presented here.

LEGAL NOTICE

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