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SEMI-ANNUAL REPORT

for the period

July 1 through December 31, 1966

AEC Contract AT(30-1)-2076

M. Stanley Livingston

Director

July 14, 1967

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
and HARVARD UNIVERSITY

CAMBRIDGE ELECTRON ACCELERATOR

CAMBRIDGE 38, MASSACHUSETTS

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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.

CAMBRIDGE ELECTRON ACCELERATOR

COST PRICES

HARVARD UNIVERSITY
42 OXFORD STREET
CAMBRIDGE 38, MASS.

H.C. \$ 3.00; MN 65

CEAL-1036
M. Stanley Livingston
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SUMMARY

Part I indicates the purpose of the contract, which is concerned with the operation of the 6-GeV Cambridge Electron Accelerator. Part II states the general nature of each of the 38 experiments that were in progress or in preparation during the six-month period in question. Part III lists the principal improvements made in the accelerator and the associated facilities. Part IV deals with the routine operation of the accelerator, and indicates that the half-year in question was far more productive, in terms of user-hours, than any previous half-year period. Part V deals with safety, and indicates that there were no lost-time accidents. Part VI summarizes the plan for using the present ring as a beam storage and colliding beam facility; also it describes new tests and demonstrations of beam storage, including the storing of 3 GeV electrons for 20 minutes, a new world's record. This project continues to appear highly promising. Part VII deals with preparations for the sixth International Conference on High Energy Accelerators, to be held in Cambridge on September 11-15, 1967.

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PART I. INTRODUCTION

This report summarizes the work done under the Harvard-AEC Contract AT(30-1)-2076 during the six-month period from July 1 through December 31, 1966. 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.

General policies of the Laboratory were determined by a joint M.I.T.-Harvard "Executive Committee of the CEA". During the latter part of 1966 this Committee included the following:

from M.I.T.: Dr. Carl F. Floe
Prof. Jerome I. Friedman
Prof. Francis E. Low
Prof. Victor F. Weisskopf
Dr. Jerome B. Wiesner

from Harvard: Dean Franklin L. Ford
Prof. Sheldon L. Glashow
Prof. Francis M. Pipkin
Prof. Karl Strauch
Mr. L. Gard Wiggins

Scientific policies were established by a Scientific Committee which included representatives of M.I.T., Harvard, and other institutions. During the latter part of 1966 this Committee included:

from M.I.T.: Prof. Jerome I. Friedman
Prof. Francis E. Low
Prof. Victor F. Weisskopf

from Harvard: Prof. Sheldon L. Glashow
Prof. Francis M. Pipkin
Prof. Karl Strauch

from the CEA: Dr. Thomas L. Collins
Mr. Robert E. Cummings, sec'y
Dr. M. Stanley Livingston
Dr. Gustaf-Adolph Voss

others: Dr. Robert K. Adair (Yale, BNL)
Prof. Richard H. Milburn (Tufts)

Scheduling of research experiments on a day-to-day basis was the responsibility of the Director of the CEA assisted by a "Scheduling Committee for the CEA". During the half-year in question this Committee included the following:

from M.I.T.: Dr. David P. Luckey

from Harvard: Dr. Alfred E. Brenner

from CEA: Dr. Gustaf-Adolph Voss
Dr. William A. Shurcliff, sec'y

PART II. THE EXPERIMENTS

During the six-month period in question (July 1 - December 31, 1966), there were 38 experiments in progress or in various stages of preparation or completion. These are described briefly below, arranged alphabetically by name of a principal investigator.

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

Physicists from MIT nearly completed their preparations for studying the photoproduction of positive pions and kaons by means of a 1 to 3 GeV photon beam that strikes a liquid hydrogen target. They employed a large deflecting magnet, several precision, wide-gap spark chambers, and other detectors. Trial operation began in December.

2. Single Pion Photoproduction on Deuterium (Bar Yam et al).

Physicists from Southeastern Massachusetts Technological Institute and from MIT performed an experiment on single pion photoproduction on deuterium, using the Moby Dick magnetic spectrometer for the detection of the charged pion and, in the case of negative pion production, used a set of scintillation counter hodoscopes

for the detection of the recoil proton. Data taking began in midsummer 1966 and was completed by December. The investigators found an interesting asymmetry in production of π^+ and π^- , and reported this at the January 1967 meeting of the American Physical Society and also in the July 3, 1967, issue of Physical Review Letters.

3. Photoproduction of Charged Pions on Hydrogen and Deuterium, Using Polarized Photon Beam (Bar Yam et al). Physicists from Southeastern Massachusetts Technological Institute and from MIT were preparing an experiment on single pion photoproduction on hydrogen and deuterium at 6 GeV and also, using a polarized photon beam, at 3 GeV. The angular dependence of the differential cross section is to be measured. Data-taking is to start late in 1967.

4. Proton Compton Effect (Deutsch et al). Physicists from MIT completed preparations for continuing the study of gamma, proton scattering, undertaken earlier at CEA. The detection equipment included a magnetic spectrometer, spark chambers, and shower counter. Data are analyzed with the aid of the SPASS computer program. Data-taking runs started in October and November, and continued into the first few months of 1967.

5. Determination of the Polarization of Lambda Particles
Jointly Photoproduced with Kaons (Deutsch et al).

Physicists from MIT continued preparations for directing a beam of photons (of energy 1.4 GeV or greater) at a liquid hydrogen target and studying the polarization of the lambda particle found in the photoproduction of the (lambda, kaon) final state. The equipment includes a magnetic spectrometer, four spark chambers, and scintillation counters for time-of-flight determination. By the end of 1966 feasibility studies were underway.

6. Photoproduction of K^0 (Engels et al).

Physicists from Harvard and elsewhere essentially completed preparations for measuring the cross section of photoproduction of the neutral kaon. The equipment includes a target (e.g. aluminum), spark chambers, scintillation counters, and Cerenkov counters (but no magnet). K_1^0 particles are regenerated from K_2^0 particles in a block of tungsten or copper, and pions resulting from the decay of the K_1^0 are detected. By 12/31/66 the experimenters were nearly ready to start taking data.

7. Photon Energy Determination (Fessel et al).

CEA physicists completed construction of a pair spectrometer for use in measuring -- rapidly and accurately --

the spectral energy distribution of a multi-GeV bremsstrahlung beam, and then proceeded to put the equipment to practical use in analyzing photon beams. The individual photon strikes a thin foil just upstream from a pair spectrometer magnet, and the energies of the resulting electron and positron are determined with the aid of two banks of scintillation counters and two banks of glass Cerenkov counters. In trials carried out in October, the investigators found that a detailed spectral energy distribution curve could be obtained in 30 minutes.

8. Production of Quasi-Monochromatic, Linearly Polarized Photon Beam with the Aid of a Crystal (Fessel et al). CEA physicists completed installation of equipment for producing a bremsstrahlung beam which, after collimation, is quasi-monochromatic and has a high degree of linear polarization. The heart of the equipment is a small diamond crystal that is inserted in the beam of orbiting electrons by means of an in-vacuum goniometer, which permits fine control of the exact orientation of the crystal. The equipment was operated successfully in October, but certain background problems remained.

9. Search for e' Particle (Friedman, Kendall, et al).

MIT physicists were engaged in analyzing results on a brief search (in 1965) for the hypothetical e' particle. The result was negative, as their forthcoming report will indicate.

10. Elastic Scattering of Electrons by Deuterons
(Friedman, Kendall, et al).

MIT physicists were engaged in analyzing the results on the elastic scattering of electrons by deuterons. The experimental work was performed in 1965.

11. Inelastic Scattering of Electrons by Deuterons
(Friedman, Kendall, et al).

MIT physicists were making preparations for studying the inelastic scattering of electrons by deuterons, to supplement the elastic scattering work mentioned in the previous paragraph. The new experiment constitutes an exploration of the electro-disintegration of the deuteron near threshold and an exploration of the short-range structure of the (n,p) interaction at low energy in the (n,p) center-of-mass system. The recoiling proton will be detected by a quadrupole spectrometer that includes wire chambers and scintillation-counter detectors. Data-taking is expected to begin in mid-1967.

12. Elastic Scattering of Electrons by Alpha Particles
(Friedman, Kendall, et al).

MIT physicists continued preparations for the study of scattering of electrons by alpha particles, with the purpose of determining the short-range structure (form factor) of the alpha-particle -- a spin zero particle. They will use an external electron beam and a liquid helium target. The recoiling protons will be detected by scintillation counters, and the scattered electron will be detected by a quadrupole spectrometer that includes wire chambers and scintillation counter detectors. Data-taking is expected to begin in mid-1967.

13. Internal Beam Tagging Facility (Frisch et al).

MIT physicists, assisted by CEA engineers, continued preparations for producing a stream of tagged, multi-GeV photons by causing the internal electron beam of the CEA to strike an exceedingly fine wire situated within the vacuum chamber of Magnet 12. The energy of the individual, spent electron is to be determined with the aid of the magnetic field of this magnet (used as an analyzing magnet) and a bank of 20 detectors situated near the downstream end of that magnet. The tagged photons, with energy known to within about 2%, will enter the Experimental Hall and

strike a target there, and the resulting events will be analyzed with the aid of a spark chamber. By December 31, most of the components were ready, and runs were to start in April 1967.

14. Study of Wide-Angle Electron Pairs and Muon Pairs with the Aid of an Internal Beam Tagging Facility and a Large Spark Chamber (Frisch et al).

Physicists from MIT and Northeastern University continued preparations for employing the internal beam-tagging facility (discussed in the previous paragraph) in the study of the photoproduction, by means of photons of accurately known energy, of electron pairs and muon pairs. They planned to analyze each pair with the aid of a large spark chamber situated within the field of a large magnet; shower counters and range counters were to be used also. In November this group abandoned this experiment in favor of other, more promising, experiments.

15. Photo-Induced Evaporation of Nucleons from Uranium Nuclei (Fulmer, Handley, and Dell).

Physicists from Oak Ridge National Laboratory and the CEA are studying the evaporation of nucleons from nuclei of uranium and ten other elements (in the form of foils) by means of multi-GeV electrons and photons. Photo-induced fission of the iron nucleus was studied also.

Many exposures were made at the CEA in the six-month period in question.

16. Search for Leptonic Quarks (Garelick et al).

Physicists from MIT made a quick search for leptonic quarks that might originate in a large block of carbon struck by multi-GeV photons. Thick attenuators of iron and lead were used. The detectors consisted of scintillation counters. No particles clearly identifiable as quarks were found, and the experimenters concluded that, if quarks exist at all, they have a rest mass greater than 900 MeV.

17. Electroproduction of Wide-Angle Muon Pairs (Gettner et al).

Physicists from Northeastern University completed preparations for studying wide-angle muon pair production by means of multi-GeV electrons, with a view to exploring the time-like form factor of the (e,μ) scattering process and providing an additional test of the validity of quantum electrodynamics. In November and December the group made some preliminary runs, and was engaged in efforts to reduce the level of background counts. Routine data-taking runs were expected to start early in 1967.

18. Photoproduction of Kaons and Σ^* Resonances (Hughes et al).

Physicists from Yale University enjoyed long and fruitful data-taking runs in their effort to measure, with greater precision than had been achieved previously, the production of positive kaons by a 3 to 6 GeV photon beam incident on a liquid hydrogen target. The general goal was to find the cross section for the production (with the kaons) of Σ^* resonances as a function of energy. They used several large analyzing magnets and a variety of detectors. Preliminary analysis of the data revealed the presence of two or three new resonances -- hyperons of strangeness -1.

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

Physicists from MIT prepared an experiment on the photoproduction of π^0 and η^0 that will supplement the investigations made by them in 1964 and 1965. Specifically, they will study production at forward angles. Being unable to measure protons that are scattered almost straight backward, they will concentrate on measuring the directions and energies of the photons resulting from the decay of the neutral particles in question. They will use a liquid hydrogen target and two large arrays of glass Cerenkov-type shower detectors.

20. Photoproduction of Polarized Photons with the Aid of a Laser (Milburn et al).

Physicists from Tufts University continued preparations for exploiting the method of producing polarized high-energy photon beams demonstrated on a pilot scale in 1964 and 1965. The method entails directing a very intense beam of polarized photons head-on at the electrons in orbit in the synchrotron; the photons recoil with energies as great as 800 MeV and retain their original polarization. A very powerful ruby laser has been obtained; it provides 10 joules per pulse and may be pulsed once a second. Special Cerenkov counters of lead glass were prepared and tested.

21. Study of Bremsstrahlung Beam from Residual Gas in a Straight Section of the Synchrotron (Milburn et al).

Physicists from Tufts University and CEA have been studying the intensity and width of the bremsstrahlung beam originating at a straight section of the synchrotron as a result of collisions between orbiting electrons and residual gas molecules. The dependence on machine energy, gas pressure, etc., is being determined. Results are of interest to groups concerned with detection systems for the colliding beam studies soon to be undertaken at CEA.

22. Spark Chamber Analysis of the Polarized Proton Recoiling from Photoproduction of π^0 (Milburn et al).

Physicists from Tufts University and MIT nearly completed the preparation of equipment for the analysis of the polarized proton that recoils when a π^0 particle is photo-

produced on liquid hydrogen. Some of the equipment is the same as that used recently by Deutsch et al in the proton Compton-effect experiment; it includes a small spark chamber and lead glass Cerenkov counters for detecting the photons from the decay of the π^0 . A large spark chamber containing 60 plates of graphite is to be used to detect the recoil proton. Runs started early in 1967.

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

MIT physicists completed supplementary runs (pertinent to main runs made in 1965) relating to photoproduction of positively charged kaons and pions. A detailed report of results was published late in 1966.

24. Exploration of Some Simple (γ +P) Reactions at Many Angles (Osborne et al).

MIT physicists completed studies of some of the simpler reactions that occur when photons of 2 to 3 GeV energy strike liquid hydrogen. They used a two-arm spectrometer: one arm (Moby Dick) measured recoil protons, and the other (Remora) analyzed the decay products of the neutral pions. Various supplementary runs were finished in August 1966, and a detailed report was then prepared.

25. Study of Large-Angle Electron-Positron Pairs Produced in a Carbon Target (Osborne et al).

Physicists from MIT used the Moby Dick spectrometer and also a set of gamma-ray hodoscopes in a search for possible

breakdown of quantum electrodynamics when electron-positron pairs are produced by high-energy photons that strike a carbon target. The experimental work was completed in August 1966, and the results were then analyzed.

26. Exploratory Survey of Neutral Pion Photoproduction (Osborne et al).

MIT physicists made a brief exploration of the broad features of π^0 photoproduction under a variety of conditions. Emphasis was given to the highest energy range achievable at the CEA (up to 6 GeV). Much data was obtained, and the results point the way for further runs to be made in 1967 using improved detection equipment.

27. Precise Measurement of Momentum and Direction of π^+ and p^+ with the aid of a spectrometer employing wire chambers (Osborne et al).

MIT physicists were constructing and testing digitized wire chambers to be used in an especially precise investigation of the distributions of momentum and direction of π^+ and p^+ particles produced when energetic photons strike a hydrogen target. Data taking is expected to start late in 1967.

28. Small Angle Scattering of Electrons by Carbon (Pipkin, Faissler, et al).

Harvard physicists completed an investigation of the small-angle scattering of electrons by a carbon target, and thus obtained additional information on the form factor of the carbon nucleus. They employed an external electron

beam and a single-arm spectrometer that detected and analyzed the scattered electrons. Data-taking was completed in September 1966 and the spectrometer was then dismantled. Results have recently been presented in thesis form, and will be summarized in a forthcoming article in Phys. Rev. or other journal.

29. Photoproduction of Charged Kaons (Pipkin, Joseph et al).

Physicists from Harvard determined the number of charged kaons that are emitted from a target of carbon or liquid hydrogen as a function of the energy of the incident photon and the direction of the emitted kaon, with the purpose of discovering the dominant characteristics of the kaon photoproduction process. They employed photons of 3 to 5 GeV energy and a single-arm spectrometer capable of distinguishing kaons from the (much more numerous) pions and muons and also from protons. The spectrometer included focusing magnets, scintillation counters, and two gas-filled Cerenkov counters. Data-taking was completed in August, 1966. Results have been presented in thesis form, and a summary is to appear in an early issue of Phys. Rev. Ltrs.

30. Wide-Angle Electron Pair Production (Pipkin, Tenenbaum, Randolph, et al).

Harvard physicists continued preparations for the study of wide-angle electron-positron pair production with greater accuracy than was achievable earlier--with the

purpose of making a decisive determination as to whether breakdown of quantum electrodynamics occurs in the range of four-momentum transfer available at the CEA. Platforms for an especially sturdy two-arm spectrometer were procured and installed, and Hovair pneumatic lifting devices, for assisting in adjusting the positions of the arms, were procured. Data taking began in April 1967.

31. Wide-Angle Electron Pair Study with Tagged Photons and a Wide-Gap Spark-Chamber (Strauch et al).

Harvard physicists continued preparations for a new and ambitious approach to the study of possible breakdown of quantum electrodynamics at large four-momentum transfer. The method involves use of a tagged photon produced with the aid of momentum-analyzed positrons; the individual positron (of known energy) strikes a thin target and radiates by bremsstrahlung process; an open-sided tagging magnet (momentum analyzing magnet) and arrays of scintillation counters permit determination of the energy of the spent positron and, by subtraction, the energy of the bremsstrahlung photon. This tagged photon is put to use as follows: it is caused to strike a target of carbon (or liquid hydrogen) and produces here an electron-positron pair; an adjacent spark chamber shows initial directions of these two particles, and a second spark chamber, situated within the large gap of a 200-ton H-type magnet, permits determination of the momentum of each particle; an array of 8-ft wide spark chambers and

high-Z plates permits distinguishing electrons from pions. Trial runs made late in 1966 revealed a problem as to how to achieve high efficiency for sustaining, within the wide gap chamber, two or more tracks at very different angles.

32. Production of Baryon-Antibaryon Pairs (Von Goeler et al).

Physicists from Northeastern University continued the study of photoproduction of baryon-antibaryon pairs by the reaction: $\gamma + p \rightarrow \bar{n} + d$, using photons of 4 to 6 GeV energy. The deuteron was detected by the Moby Dick spectrometer and the decay products of the antineutron were detected by six scintillation counters surrounding an iron absorber. The data-taking runs were completed in mid-September, and the results are being analyzed.

33. Photoproduction of Antiprotons (Von Goeler et al).

Physicists from Northeastern University performed a brief exploratory experiment on the photoproduction of antiprotons, using a variety of target materials. Much effort was devoted to achieving adequate discrimination against pions. Data taking began in August 1966, and was completed a few weeks later. Results are being analyzed.

34. Total Cross-Section for Photoproduction of Electron-Positron Pair, with Low Momentum-Transfer (Walker and Knasel).

Harvard physicists continued preparations for measuring, with 20-fold improved precision, the total cross-section of photoproduction of electron-positron pairs. Tagged

photons, produced with the aid of equipment described in a previous paragraph, are employed. By the end of 1966 the investigators had taken data with a precision of about $1/2\%$ in terms of momentum, and were attempting to improve the precision to about 0.1% .

35. Precise Elastic (e,p) Scattering (Wilson, Goitein, et al).

Harvard physicists measured the absolute cross-sections of the proton at very high four-momentum transfer. An external beam of 5.5 to 6.0 GeV electrons was used. Principal attention was given to electrons scattered at forward angles. A half-quadrupole spectrometer (with scintillation counters, a shower counter, and a Cerenkov counter) identified the electron and determined its momentum. A satellite spectrometer detected the proton in coincidence. Data taking began in mid-1966 and was completed in December. Analysis of the results is underway.

36. Precise Quasi-Elastic (e,d) Scattering Study Involving a Coincidence Method (Wilson, Budnitz, et al).

Physicists from Harvard completed an especially accurate determination of the electron-neutron elastic cross-section by measuring the quasi-elastic scattering reaction $e + d \rightarrow e + p + n$ with the aid of an external electron beam, a liquid deuterium target, and a coincidence method of detection and analysis. A checkerboard array of 144 scintillation counters determined the polar and azimuthal

angles of the recoiling proton; the electron was detected by means of a spectrometer that included a threshold-type Cerenkov counter and a lead-scintillator-sandwich shower counter. Data were analyzed on-line by a PDP-1 computer. The experimental work was completed in August 1966. A preliminary report was given at a September 1966 Conference at Berkeley, and a full report is in preparation.

37. Determination of the Pion Form Factor through Study of Inelastic (e,p) Scattering Near the First Pion-Nucleon Resonance (Wilson, Mistretta, et al).

Harvard physicists made great progress in their program to determine, with high accuracy, the form factor of the charged pion. They employed an external electron beam, a liquid hydrogen target, and a two-arm spectrometer. One arm (Kontiki), which included a focusing magnet, arrays of scintillation counters, a gas-filled Cerenkov counter and a shower counter, detected the electron. The other arm, employing a sweeping magnet, a 144-element scintillation counter hodoscope, and a Lucite Cerenkov counter, detected the pion in coincidence with the electron. Data taking began in October 1966, and continued into the first weeks of 1967.

38. Search for Violation of Time-Reversal in Electromagnetic Interactions, with the Aid of a Polarized Target (Wilson, Chen, et al).

Harvard physicists prepared to ascertain whether, in electromagnetic interactions among strongly interacting

particles, any violation of time-reversal invariance occurs. They will analyze events in which electrons are scattered inelastically by protons. The polarized target, under development by Pound and others at Harvard, will consist of ethyl alcohol or toluene in which perhaps 30% of the effective protons are polarized (with the aid of a 26 kilogauss magnet and an rf field). Just the inelastically scattered electrons will be detected, by a single-arm spectrometer.

PART III. EQUIPMENT AND FACILITIES.

During the half-year in question important improvements were made in the CEA equipment and facilities. The principal improvement was the construction of a radial tunnel to house the new linac to be supplied by Varian Associates. Excavation work was completed in June 1966, and construction of the new tunnel was completed early in August. The linac power building, situated just above the tunnel, was completed in October. By December 31 construction of the new linac itself, at the Varian plant, was 75% complete; CEA engineers visited the manufacturer's plant from time to time to inspect components and judge the extent of completion, and came to the opinion that the equipment was being built in competent manner and would be completed perhaps a few months behind the original schedule. They expected delivery to take place early in 1967.

In July we began installation of vacuum chambers of ceramic type. Our original chambers, employing fiberglass cloth and epoxy resin, had been exhibiting increasing amounts of radiation damage; they caused frequent shutdowns due to leaks, and required a large amount of maintenance work. The ceramic chambers proved to be far superior; even when placed at locations

where radiation is particularly intense, such chambers showed no radiation damage to the ceramic segments. By November our experience with these chambers was so promising that arrangements were made to order 55 additional units.

In September and October two coils of the 60-ton reactor of the magnet power supply failed, and were replaced.

In September we ordered 18 General Electric Company 500-liter high-vacuum pumps. Many other improvements were made in our vacuum pump, vacuum foreline, and bake-out equipment.

In October we received a 45-ton, H-type analyzing magnet for use in spark chamber experiments, and a General Motors "Hovair" air-bearing system for use in varying the position of a heavy spectrometer arm. Also, the installation of two 1.2 megawatt power supplies for experimental magnets was started. Five large power supplies were received in November. In that same month we ordered a spare TTU-1B transmitter for the accelerator rf system.

An entire re-survey of the ring of 48 magnets was made in December, and the positions of all magnets were readjusted accordingly. It was found that no significant

change in magnet position had been caused by the excavation work (for the new linac tunnel) closely adjacent to the northeast quadrant of the synchrotron ring.

We completed construction of a breadboard model of a control unit to link two of our SDS-92 computers, situated in the Second Floor Counting Room, to the IBM 360/50 computer at the Harvard Computation Center, with the overall purpose of making it possible for several groups of experimenters at CEA to connect their hodoscopes, etc., on-line to the IBM computer. The breadboard model performed well, and we proceeded with the construction of a four-channel unit which, by December 31, was ready for trial use.

In July, construction of the CEA-designed pair spectrometer for use in determining the spectral energy distributions of multi-GeV bremsstrahlung beams was completed and the equipment was put into operation. In November and December the equipment was used successfully in studies of the quasi-monochromatic, partially polarized bremsstrahlung beam that resulted when a single diamond crystal was interposed (by means of a special goniometer) in the orbiting electron beam. The equipment was then dismantled and removed from the Experimental Hall to make room for forthcoming experiments by Osborne et al and by Frisch et al.

In the fall of 1966 we transferred stored equipment from the Mrytle Street, Somerville, storage warehouse to a larger and more convenient storage site on Dane Street, Somerville.

During the four-week shutdown of accelerator operation from December 4, 1966, to January 4, 1967, important maintenance work was done and various improvements were made. Much of the vacuum ring was overhauled; twenty-four of the 48 vacuum chambers were repaired or replaced, many high-vacuum pumps and forepumps were overhauled, new gate valves were installed and vacuum gages were recalibrated.

PART IV. OPERATION

During the half-year in question the accelerator ran exceptionally well, and the efficiency of use (through beam sharing among prime users and first and second parasite users) was especially high. The number of user-hours made available in July was 823, which is greater than in any previous month. New records were achieved in October (839 user-hours) and in November (909 user-hours). For the six months, the figures were as follows:

<u>Month in 1966</u>	<u>Number of user-hours</u>
July	823
August	741
September	760
October	839
November	909
December	131
(4 days only)	
Total for 6-Month Period	<hr/> 4203

In July a new electron beam run (Beam #9) was set up and made ready for use. It has since been used extensively by a group from Northeastern University.

In November, because of limitations on funds available, we began a review and analysis of all major expenses contemplated for the subsequent seven months. The decision was made that, starting in January 1967, accelerator operation on behalf of experimental groups would be limited to ten shifts per week.

PART V. SAFETY

In the six-month period in question there were no lost-time accidents at the CEA. Periodic meetings of the CEA Safety Committee were held and many new policies and regulations were established. Equipment for sensing smoke and/or fires was considerably improved. A number of training sessions for Operations Division men and others especially concerned with safety were held. Periodic inspection tours were made by officials of the AEC and of Harvard University.

Radiation levels in outdoor areas and indoor work areas were held well below the permissible limits, and personal film badges showed that all doses to persons were well within permissible limits. Radiation interlock systems were inspected periodically and performed excellently. Radiation-safety training sessions for Operations Division men were held in December. We found that when the new tunnel for the forthcoming 100 MeV linac was being constructed and much earth fill adjacent to the northeast quadrant of the ring was removed, no significant radiation problems arose.

PART VI. STUDY OF BEAM STORAGE

During the six-month period in question we made good progress in our "Project Bypass" effort to plan and develop a colliding beam facility that does not require the construction of an entire new ring and does not involve the many years of work that such construction would entail. We plan to inject electrons into the existing ring in counterclockwise sense and inject positrons in clockwise sense, and we plan to accelerate and store both kinds of particles simultaneously in this same ring. During the storage period (of the order of an hour) the beams will traverse a short detour, or bypass, in which the two streams of particles will collide head-on. The efficiency of collision and the efficiency of observing the results of the collisions will be especially high because (1) extra strong focusing will be provided in the bypass, so that the beam diameters will be especially small and the current density will be especially high, (2) a very long straight section will be provided at the interaction station, to allow room for versatile detection equipment, and (3) especially high vacuum will be maintained in the interaction station, to minimize background events.

Crucial to the success of the project is the provision of some means of damping the horizontal oscillations of

the orbiting particles. Specially designed damping magnets were constructed in the spring of 1966, and in tests made in June of 1966 we demonstrated that damping could be achieved. In July we succeeded in storing 1.8 GeV electrons for five minutes, and in August we improved the damping magnet and achieved a storage time of $\frac{1}{2}$ hour. In September we stored 3.0 GeV electrons and achieved a half-life of six minutes; this constitutes a world record for storage of multi-GeV particles. Indications are that, when we are able to improve the vacuum to the extent planned, very much longer storage periods can be achieved without difficulty.

The process of injecting, accelerating, and storing electrons entails changing the powering of the ring of 48 magnets from a.c. mode to d.c. mode, and it is essential that, in the interval in which the transition is being made, the efficiency of retention of particles in orbit be high. This problem was investigated experimentally in November, and we soon learned how to achieve an efficiency of 40%: starting with a 5 milliamperere beam, we succeeded in retaining and storing 2 milliamperes. More recently we have increased the efficiency to 70%.

Much effort was devoted to the design and construction of various special devices needed for the Bypass project as a whole. Much work was done on vacuum chambers and straight section tanks, bake-out methods, performance of high-vacuum pumps, design of the bypass proper, including special vacuum chambers, focusing magnets, bending magnets, ejection magnets, and instruments for sensing beam position and sensing the size and shape of the cross-section of the beam. The new, 100-MeV linac will be of great importance to the project; the status of this linac is discussed in an earlier section of this report. The purchase of a positron source is essential also, and by December 31 we had devoted much effort to exploring possible designs of a positron source and were seeking to identify the most promising supplier.

PART VII. PLANNING FOR THE SIXTH INTERNATIONAL
CONFERENCE ON HIGH ENERGY ACCELERATORS

Planning for the Sixth International Conference on High Energy Accelerators, to be held in Cambridge, Massachusetts, September 11 - 15, 1967, with the CEA as host, progressed satisfactorily. Revised quotas as to numbers of persons to be asked from the principal regions of the world were agreed on, and key persons in the various regions were invited to submit names of persons to be invited. Preparations for sending out the invitations were made. Commitments were made by officials of Harvard University to make the desired lecture halls, lounge areas, and lunch area available. A preliminary budget was drawn up.

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