SLAC-65
UC-28, Particle Accelerators
and High-Voltage Machines
TID-4500(48th Ed.)

TWO-MILE ACCELERATOR PROJECT

Quarterly Status Report

1 January to 31 March 1966

June 1966

Technical Report

Prepared Under

Contract AT(04-3)-400 and

Contract AT(04-3)-515

for the USAEC

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I. INTRODUCTION

This is the sixteenth Quarterly Status Report of work under AEC Contract AT(04-3)-400 and the tenth Quarterly Status Report of work under AEC Contract AT(04-3)-515, both held by Stanford University. Contract AT (04-3)-400 provides for the construction of the Stanford Linear Accelerator Center (SLAC), a laboratory that will have as its chief instrument a two-mile-long linear electron accelerator. Construction of the Center began in June 1962, and the present schedule calls for first turn-on of the electron beam in the summer of 1966. The principal beam parameters of the accelerator in its initial operating phase are a maximum beam energy of 20 BeV, and an average beam current of 30 microamperes (at 10% beam loading). The estimated construction cost of SLAC is $114,000,000.

The work of construction is divided into two chief parts: (1) the accelerator itself and its related technical environment; and (2) the more conventional work associated with site preparation, buildings, utilities, etc. To assist with these latter activities, Stanford has retained the services, under subcontract, of the firm Aetron-Blume-Atkinson, a joint venture consisting of Aetron, a division of Aerojet-General Corporation; John A. Blume and Associates, Engineers; and Guy F. Atkinson Company. In these reports this architect-engineer-management firm is often referred to as "ABA."

The terms of Contract AT(04-3)-400 provide for a fully operable accelerator and for sufficient equipment to measure and control the principal parameters of the electron beam; in addition, provision is made for an initial complement of general-use research equipment with which it will be possible to perform certain exploratory studies, such as measurement of the intensity and energy distribution of various secondary-particle beams.

Contract AT(04-3)-515 provides support for the various activities at SLAC that are necessary in order to prepare for the research program which will eventually be carried out with the two-mile accelerator. Among the principal activities covered in the scope of Contract AT(04-3)-515 are theoretical physics studies, experiments performed by the SLAC staff at other accelerators, research-equipment development programs (such as particle separators, specialized magnets, bubble chambers, etc.), and research into advanced accelerator technology. Contract AT(04-3)-515 went into effect on January 1, 1964, so that this development work is presently in an early stage.

Contract AT(04-3)-515 also provides for the initial stages of operation of the Center after construction is completed.

II. PLANT ENGINEERING

A. GENERAL

All construction contracts for the project's conventional facilities have been placed and most of the work is done. The present status of a number of these facilities is shown graphically in Figs. 1 through 5. The remaining effort is largely concentrated in the Research Area and will be finished in the next quarter. Phasing out of the Aetron-Blume-Atkinson forces has begun.

Construction of the 220-kV feeder line to the accelerator site was continued and is now 60% along. All the poles have been installed. This work was contracted for by the Atomic Energy Commission and is being supervised by that agency.

B. DESIGN STATUS (ABA)

The design effort for the project is complete. A minor amount of engineering remains to be done on field changes, "as-builts," inspection, and miscellaneous contract matters. In addition to the principal structures in the Research Area, this includes follow-up on the erection of concrete shielding doors, the installation and testing of cranes and the materials handling system, and various items relating to the site improvements and utilities.

The preparation of Title II design for a proposed extension of the Data Assembly Building was finished during the quarter. Subject to review by SLAC, this work completes ABA's responsibility for the facility.

C. CONSTRUCTION (ABA)

The status of major conventional facilities now under construction is as follows, those shown at 100% having been completed during the quarter.

Facility	Percentage of Completion
Beam Switchyard	100
Landscaping	
Increment IV	100
Increments V and VI	77
Klystron Gallery Utilities	
Electrical (600-Y-2)	99
Cooling Towers (600-Y-3)	99

Facility	Percentage of Completion
Area Lighting	100
Master Substation	96
End Station A	94
End Station B	99
BSY Site Improvements and Utilities	90
Material Handling System (BSY)	99
Cryogenics Facility	77
End Station Site Improvements and Utilities	47
Beam Dump East	40
Site Fencing	15

Work on the site fencing, which was the final contract to be awarded by ABA, began March 23, 1966. All major construction items are either complete or have reached the stage indicated in the listing above. Field completion of the remaining facilities is now scheduled for approximately June 1, 1966.

Completion of the Master Substation will occur as soon as the installation of the 220-kV transmission line is finished. The new transformers have been tied into the Switch House and electrical services for the site continue to be provided from the existing 60-kV transmission line.

Two cells of the Research Area cooling tower which were damaged by fire last November have been rebuilt. A view of this facility and the water treatment equipment is shown in Fig. 4.

Work on the End Stations, Cryogenics Facility, Beam Dump East, and associated utilities is proceeding satisfactorily. Remaining construction work for the project is principally located in this part of the site (Fig. 1).

D. PLANT ENGINEERING SERVICES

The department continued its activities in support of SLAC's operational program and the acquisition of new facilities. Several items of significance are reported below.

An architect-engineer firm was selected and placed under contract in February for the design of the General Services Building and the Fire Station. Preliminary engineering on the two structures is underway. Construction of these facilities is scheduled for completion in 1967.

The service program of alterations and minor construction work was continued throughout the quarter. An architect-engineer assistance subcontract for support of this and other engineering work items is being established.

The 1966 Master Plan was completed and issued to various interested parties. The Plan has been prepared to illustrate how the SLAC site may be developed to provide facilities for an expanding research program. It established a land use pattern and shows how individual buildings may be expanded and new buildings sited.

The time-and-materials subcontract successfully used as an auxiliary program in support of the Crafts Shops effort expires next month. A new subcontract of this type, expanded to accommodate research area work, will take its place.

Temporary Building A, now located near the Fabrication Building, will be removed and relocated in two sections in the Target Area during the next quarter. Preliminary work for the move has started.

A visitors' alcove is to be established on the north side of the Klystron Gallery at Sector 28 to facilitate inspection of the accelerator installation. Bids on the work will be invited in April.

An enclosure of approximately 5600 sq. ft. will be installed east of End Station B to house the 82-inch Lawrence Radiation Laboratory hydrogen bubble chamber. Completion of construction is scheduled for mid-1967. Preliminary site and utility plans are now under review.

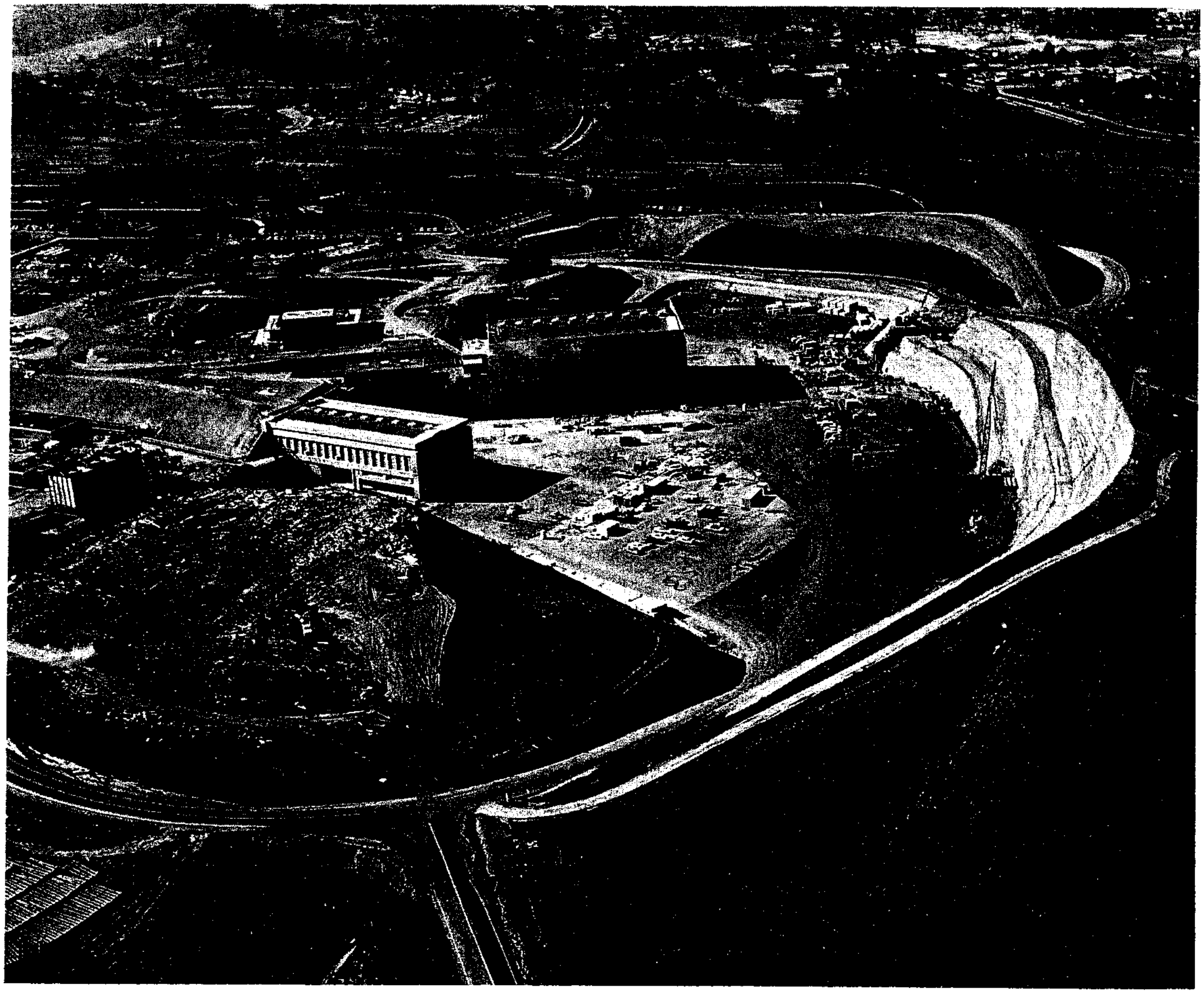

Fig. 1--Target area and end stations, looking northwest.

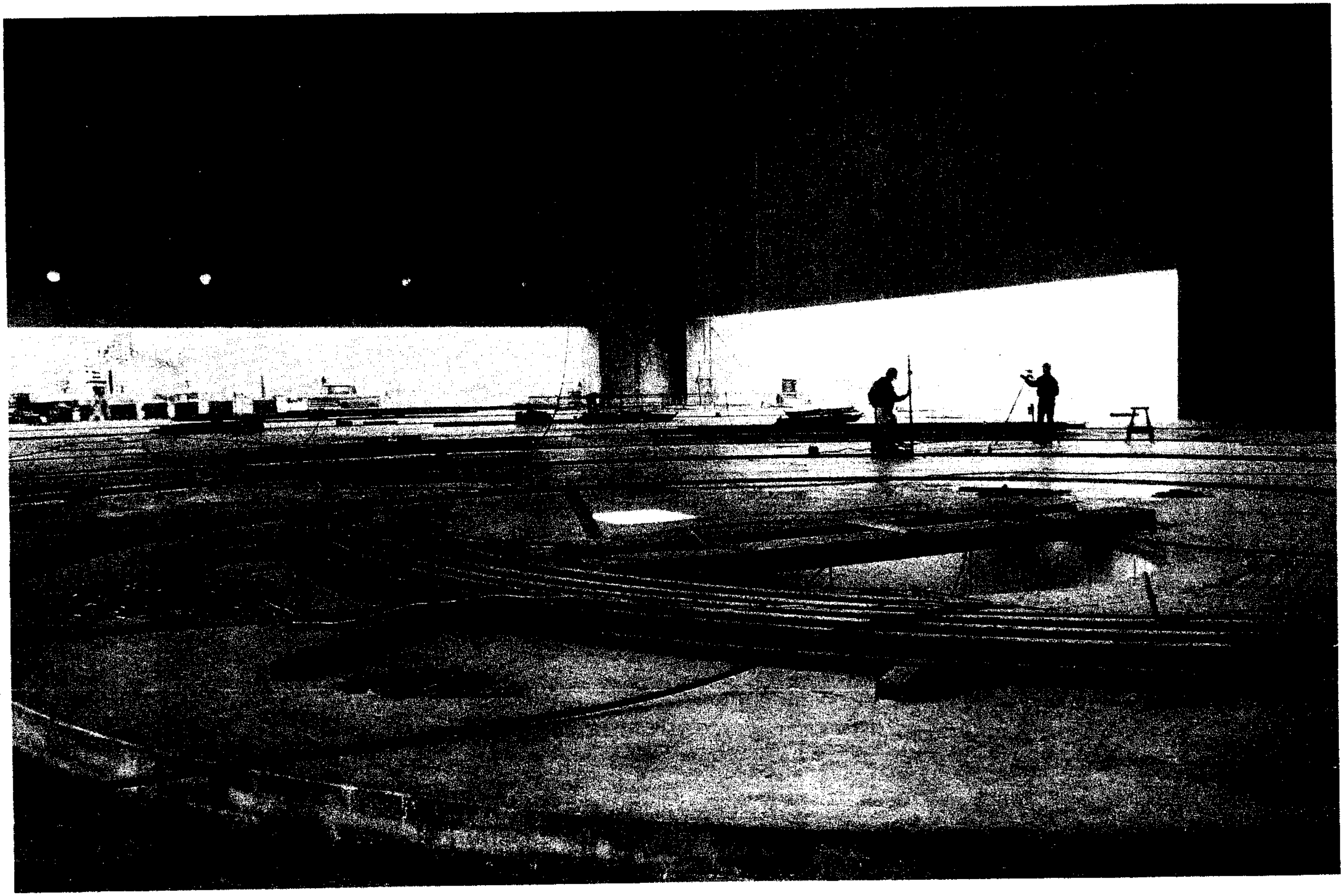

Fig. 2--Interior of End Station "A" showing pit for spectrometer hub.

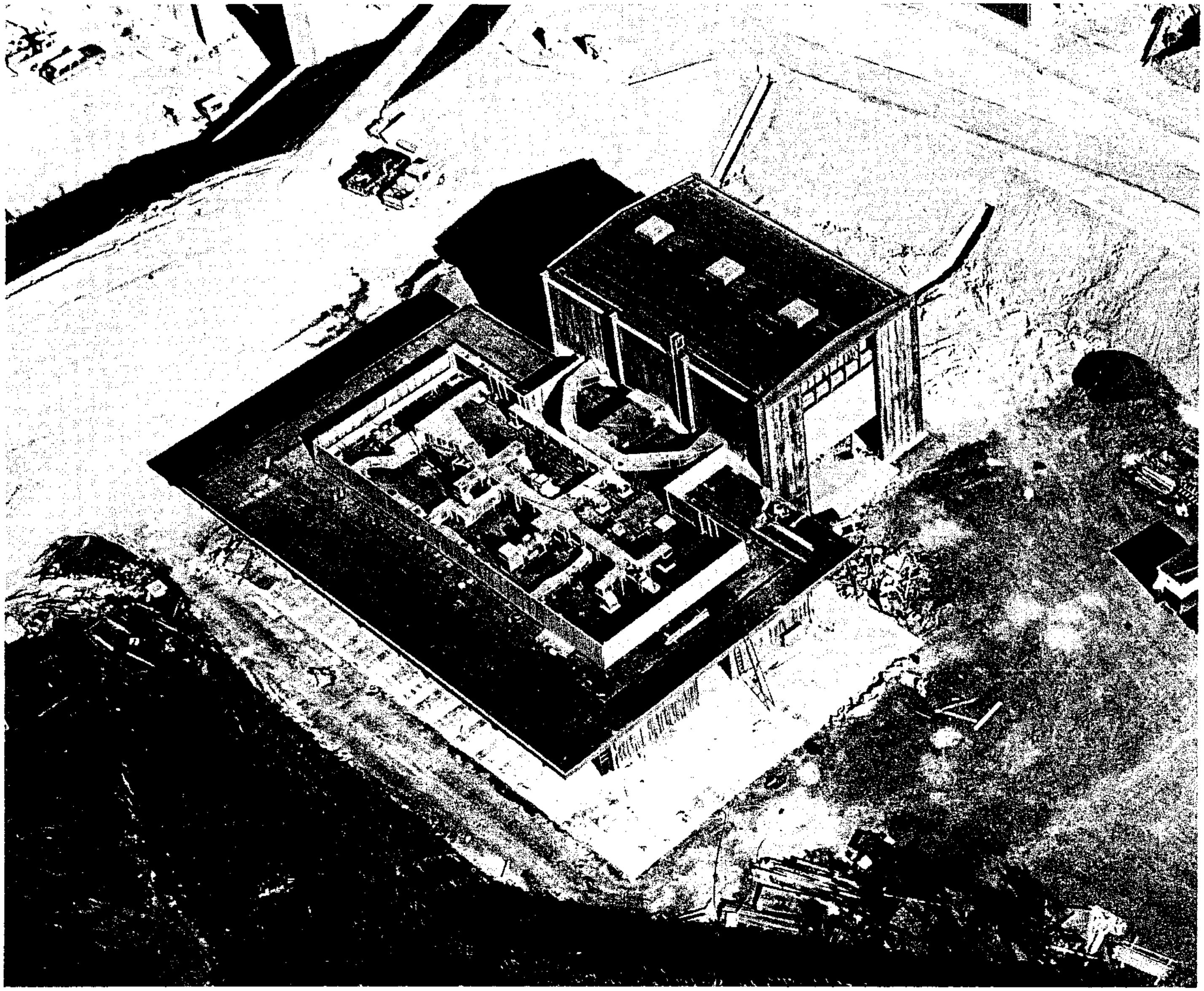

Fig. 3--Aerial view of cryogenics facility.

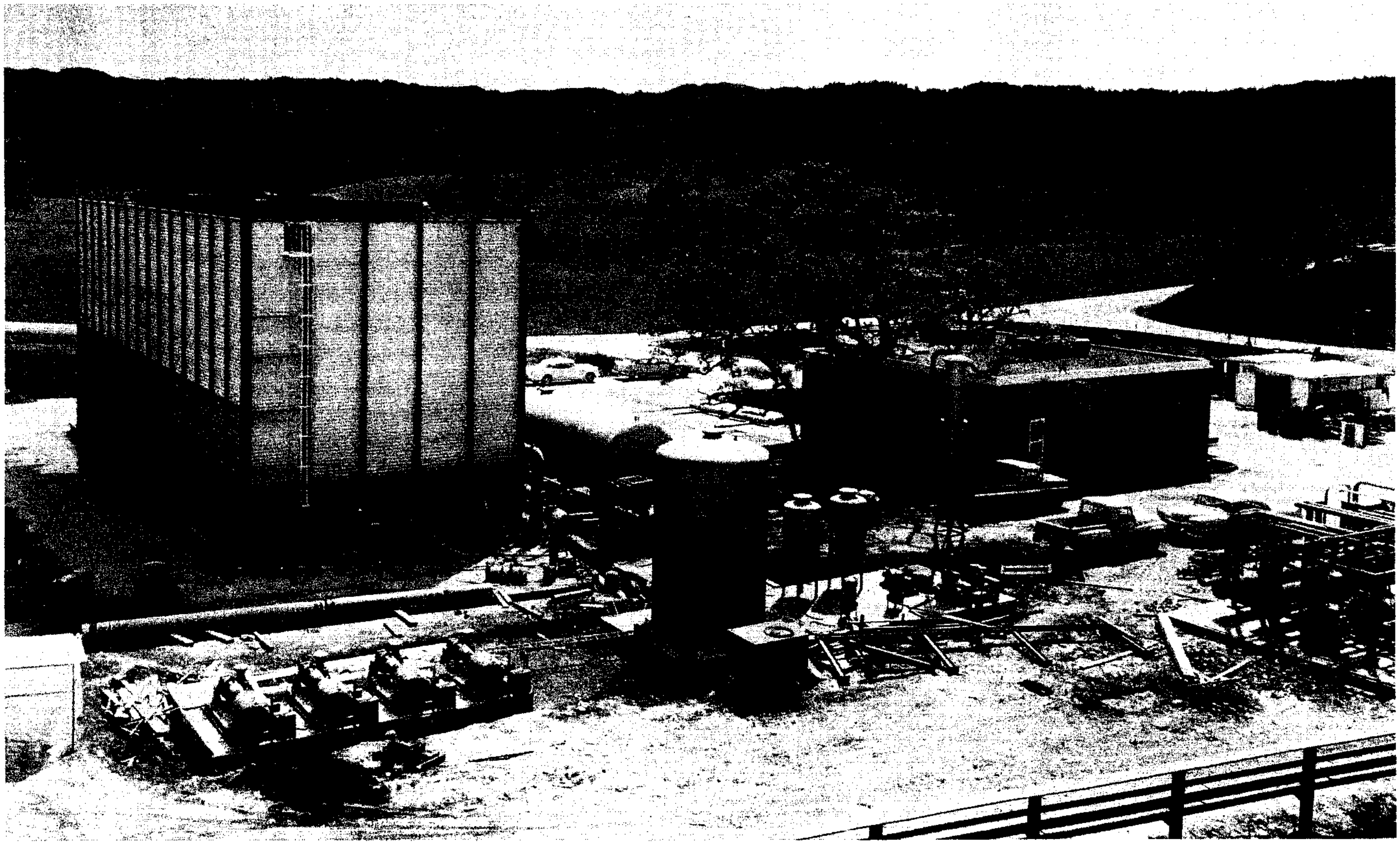

Fig. 4--Research area cooling tower and Beam Switchyard electrical substation.

Fig. 5--Panoramic view of project, looking east.

III. SYSTEMS ENGINEERING AND INSTALLATIONS

A. SUMMARY

The overall department work is 91% complete. Positron source cooling water and instrumentation and control work are still in progress. Beam Switchyard electrical and electronic work is proceeding on schedule; cooling water and vacuum installation speeded up and equipment installation is underway. Accelerator design work is 98% complete; construction work is 98% complete. Beam Switchyard design work is 91% complete; construction work is 68% complete.

B. ACCELERATOR

1. Design Coordination and Equipment Installation

The penetration shielding in the Accelerator Housing was completed. Installation of the beam take-off No. 1 and No. 2 shielding plugs was completed. Installation of shielding blocks in the material accessways was completed in Sectors 0, 5, 9, 19 and 30; blocks were not installed in Sectors 14 and 24 for access purposes. Sectors 3, 4, 7, 8, 9 through 12, and 19 through 24 were turned over to the Accelerator Operations Group.

Coordination of instrumentation and control, water, vacuum, and electrical work on the positron source and beam analyzing station No. 2 was performed.

Drawings for the Klystron Gallery visitors' viewing alcove were started.

The design coordination work is 98% complete.

2. Vacuum

The alignment vacuum pumping system became operational after the solenoids were changed and minor control wiring problems were corrected (see Figs. 6 and 7). Negotiations are underway to install new cable connectors in the ion pumps. Tests were conducted on the cryosorption roughing pump.

Vacuum system work is 99% complete.

3. Cooling Water

The cooling water system for the positron source is 99% complete in the Accelerator Housing. Piping in the penetration and the trench is 90% complete. Alcove piping is underway. Insulation of the drive line package proceeded slowly due to a manpower shortage. Installation of synthetic, reinforced fiber insert diaphragms in accelerator valves continued. The solenoids in the fast valves were replaced. A piping change for the beam analyzing station was completed in Sectors 3 and 20. Cooling water work is 98% complete.

4. Electrical

All of the conventional and variable voltage substations are now energized. Rework on the pothead terminations for VV2 and C-1 has been completed. The 12-kV switches have been reworked on substations 4A and 5A at the Central Laboratory. The alignment vacuum station in Sector 30 is complete, as is the main injector exhaust system.

Electrical work is 99% complete.

5. Electronics

Beam monitor racks have been installed through Sector 14. Drawings for beam monitor racks and IDF racks for Sectors 10 through 14 are being revised to incorporate the positron instrumentation and control requirements. Two racks for the alignment observation room were checked out and reworked. Work continued on drawings to modify 13 fiat racks in Sectors 11, 12, 13, and 14 to incorporate the positron requirements. Work on the use of two spare racks in Sector 11 and two in the Sector 11 alcove for positron source controls was begun.

The beam analyzer station at Sector 20 is now ready for checkout.

Increments of the public address system continued to be installed and tested in the Klystron Gallery. Final checkout of the service channels, which have been modified to remove the interconnecting wire used during the construction period, is underway.

General telephone facilities and service channels have been installed in the laser room.

Electronic work is 98% complete.

C. BEAM SWITCHYARD

1. Design Coordination and Equipment Installation

The definitive drawing program for the Beam Switchyard was phased out and is inactive. The major effort through February was devoted to change orders and documentation of field changes.

Equipment installation is underway. The alignment light pipe, instrument stands, magnet supports, and miscellaneous brackets and hardware are installed.

2. Vacuum

All chamber and mounting plates were delivered. All vacuum fingers to the drift section connections were delivered except PS-6. Divergent sections 1 and 5 were delivered.

A subcontract for the isolation valve was awarded and preliminary drawings have been received. Mating flanges have been ordered.

The first refrigeration unit for the differential pumping system refrigerated accelerator section is ready to be tested.

A decision was made to add a six-inch valve in the A-beam dump line for window protection. This valve is to be controlled from the water surge tank low level alarm.

Vacuum system work is 68% complete.

3. Cooling Water

X-raying of longitudinal welds of stainless steel pipe was completed. It was decided to weld the stainless steel manually, and the welding procedures were approved. Welder qualification tests have started.

Installation of the copper systems is virtually complete, and instrument panels for these systems were delivered and installed. Pumps for the magnet systems were delivered and installed.

Cooling water work is 63% complete.

4. Electrical/Electronic

Work continues on the wire lists for terminal connections to all electrical devices and distribution frames. Determination of the electrical wiring needed for use internal to all Beam Switchyard equipment is in progress. Radiation-resistant twinaxial and coaxial cable for the current monitoring equipment and stainless-steel-jacketed, magnesium-oxide-insulated cable was purchased.

The long haul cable run between the Data Assembly Building and the terminal cabinets in the upper beam housing and service areas is being terminated at both ends.

Work on the trays and framing is essentially complete, except for the trays to the End Stations. Schematic drawings of the overall wiring are 33% complete. A specification for trunk lines between the Data Assembly Building and the End Stations has been issued to a subcontractor to obtain a quotation.

Electrical work is 78% complete; electronics work is 72% complete.

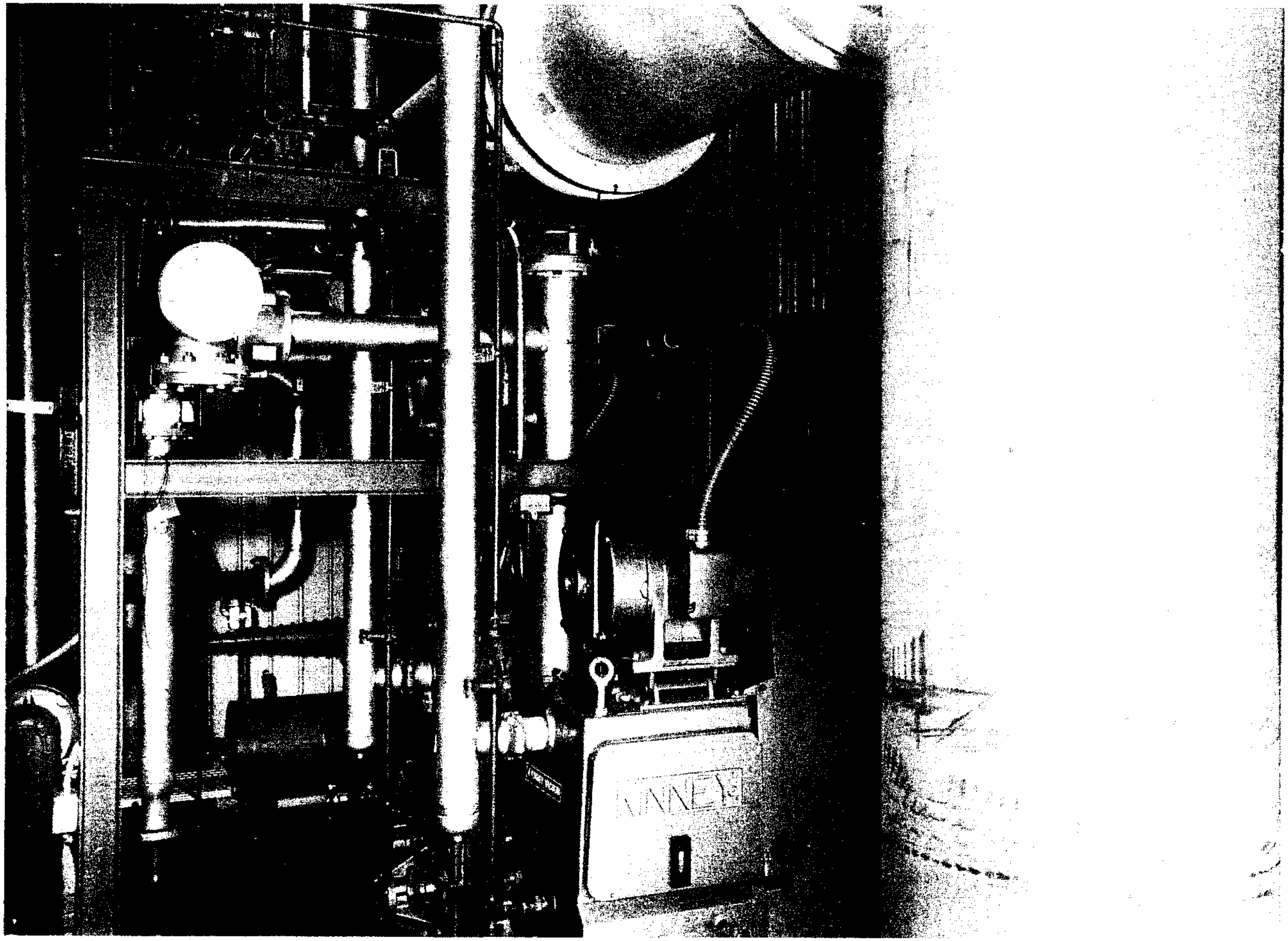

Fig. 6--Accelerator alignment vacuum system pumping station at end of sector 30 in Klystron Gallery (April 12, 1966).

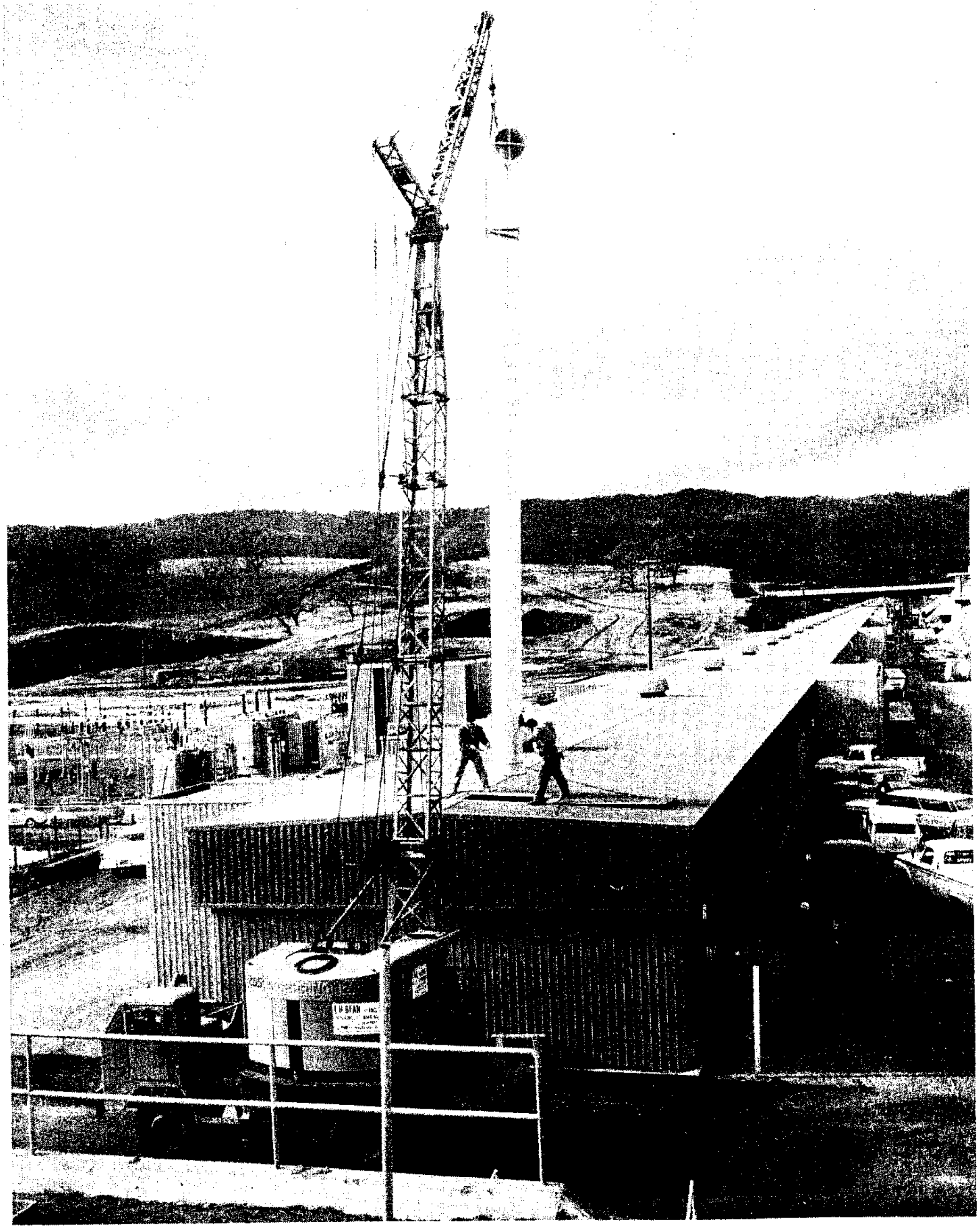

Fig. 7--Laser alignment system 24 inch diameter vacuum finger installation, end of sector 30, looking west (January 3, 1966).

IV. ACCELERATOR PHYSICS

A. INJECTION

1. Main Injection System

The following systems have been substantially checked out and made to operate satisfactorily:

a. Solenoid focus control system

b. Steering and lens supply system

c. Buncher and prebuncher phase and power control system

d. Video scope input selector system

e. RF power monitor system

f. Collimator and profile monitor system

g. Variable voltage substation control system

h. Klystron switching and phasing system

The systems requiring further checkout work are as follows:

a. CCR remote video selector system

b. Remote control, analog and status monitoring system to the Central Control Room (CCR)

c. Digital voltmeter selection system

d. Injector vacuum monitor system

e. Injector scope trigger synthesizer system

f. Injector pulse pattern display

2. Electron Guns

The bombarder diode operation which had begun last quarter was terminated on January 14 after 700 hours. There was no degradation of operation or sign of drooping emission. The same bombarder diode with a carburized thoriated-tungsten cathode was operated for about 300 hours at up to 100 watts bombarder power and fair emission efficiency. On February 4, this gun was pulsed at 40 kV peak power, 1% grid drive, and 150 watts bombarder power, giving 0.615 amps peak cathode current. On February 17, it was processed to 98 kV dc for several hours. A second carburized thoriated-tungsten cathode gave a peak cathode current of 0.63 amps with a bombarder power of 155 watts. However, this level of emission was not maintained and in less than 24 hours decreased by a factor of 3, perhaps as a result of accidental overheating of the cathode while testing a control circuit.

During the quarter, six new ceramic gun envelopes were received from Litton. These ceramic envelopes are to be used for the second generation of SLAC guns, Model 4-2.

In January, the oxide cathode gun on the main injector was temporarily transferred to the beam analyzer. Beam profiles were measured at 0.003, 0.01, 0.03 and 0.10 microperveance. The gun was then returned to the main injector. A second oxide-coated-cathode gun was prepared for conversion at the end of the quarter. This gun was intended for back-up of the gun at the main injector. Its conversion, while otherwise normal, resulted in a very poor emitter. It will be recoated and reconverted early in the next quarter.

3. Gun Modulators

The modified Manson modulator has been in place for four months and has operated for a good portion of that time. While operation has been in accordance with specifications, reliability has been of some concern. The new low level controls, logic networks, and pulse synthesizing circuits are partially fabricated and checkout is in progress. After completion of these circuits, the high level part of the modulator will be converted to operate with them. These circuits will provide the full 3-pulse-height by 3-pulse-length beam capability, with remote control of beam parameters from CCR and automatic turn-on of the modulator.

4. Beam Knockout System

The vacuum hardware associated with the injector deflector was installed. The modulator group has constructed a breadboard of the rf drive modulator and is currently testing it.

B. DRIVE SYSTEM

1. Main and Sub-Drive Lines

Approximately one-half of the 10,000 feet of drive lines have been insulated. By exercising close supervision of the installation, problems have been held to a minimum. Completion is expected during the first part of next quarter.

Installation of the extension of the main drive line into the Beam Switchyard and End Stations is scheduled for the next quarter.

2. Varactor Frequency Multipliers

The contract for the varactor multipliers has been completed. There had been some difficulty in obtaining varactor diodes, but a second source of acceptable diodes was developed. These new diodes have proven to yield the appropriate output power and they will be used throughout the machine.

3. Main Booster Amplifiers

One of the main booster amplifier klystrons failed during the quarter after 8800 hours of operation. The failure is thought to have been caused by a faulty output microwave switch, which resulted in the klystron operating into a poor VSWR. A separate tube was installed in one day and the main booster was again made operational.

4. Positron Phase Shifters

All circulators have been installed and adjusted to give a phase shift of $180^{\circ} \pm 0.25^{\circ}$. This system is now complete.

5. RF Drive System Control Circuits

Completion of the switching systems for the master oscillators, main boosters and Sector 1 sub-boosters is being delayed until the corresponding logic circuitry can be better defined.

6. Sub-Booster Modulators

The contract for the sub-booster modulators has been completed. All units have been installed in the Klystron Gallery and tested as a complete system. The only major problem noted was the unsatisfactory operation of the switch tube blowers. The main cause of failure of the modulators appears to result from failure of the blowers and consequent failure of the switch tubes.

7. Sub-Booster Klystrons

The shelf life problem mentioned in previous reports has been improved. However, conclusive results will not be obtained until testing has gone on over a period of about one year.

A new procurement program for klystrons to be used in 1967 and 1968 has been initiated. A new contract is anticipated during the next quarter.

C. PHASING SYSTEM

1. Isolator-Phase Shifter-Attenuator Units

Machine installation is complete. The components necessary to modify the units in Sector 27 for manual control from CCR have been received. All pre-production units have been modified and tested.

One injector control phase shifter unit has not been returned from the subcontractor.

2. RF Detector Panels

All units have been tested and installed in the machine. Thermionic diode detectors are being fitted as they become available.

3. Programmers and Electronics Units

All units have been received and tested. Machine installation is complete.

4. Linear Detectors

The work of aging and rf testing the diodes is proceeding. Approximately 100 diodes are installed in rf detector panels and beam position monitor detector panels in the machine.

D. BEAM POSITION MONITORS

1. In-Line Position Monitor Cavities

The cavity assemblies have been mounted on drift sections and installed in the Accelerator Housing.

Four spare cavity assemblies have been tested and delivered for storage.

2. Beam Position Monitor Detector Panels

All units have been accepted and modified for remote rf switching. Installation in the beam monitor racks along the machine has been completed. Thermionic diode detectors are being fitted as they become available.

A test set has been built to facilitate calibration of the beam position monitoring system in each sector of the machine.

3. Beam Position Monitor RF Cables

A number of the cable and connector installations were found to be unsatisfactory. These are in the process of being reworked and retested.

4. Beam Switchyard Beam Position Monitors

The cavity assemblies have been fitted with temperature sensors and quick-disconnect vacuum couplings and rf connectors. After installation in alignment support castings, the resonant frequency and Q of each cavity were rechecked. A small amount of retuning was required.

It was decided that the reliability of the rf switches installed in the beam position monitor detector chassis was unacceptable. Consequently, they were removed and replaced by new switches which, although they contain Teflon, should last for several years in their anticipated radiation environment.

5. End Station A Beam Position Monitors

A prototype microwave beam coupler was tested during January. The coupler was made of two equal lengths of S-band waveguide brazed into opposite sides of a three-inch-diameter beam drift tube. In the prototype, the waveguides were terminated by adaptors to coaxial lines, which were led to an rf phase bridge. Beam tests on the injector test stand showed that the induced power in each arm was about -40 dBm for 0.1 mA peak beam current. The differential phase shift between the signals in the two arms was 10 degrees per millimeter of beam transverse displacement near the axis of the drift tube.

Because of difficulties encountered with the cost and availability of components, the system proposed in the last report was rejected in favor of the logarithmic detection system outlined in Fig. 8. In this system, the two waveguide arms from the beam coupler are joined to a Magic Tee, one arm being longer than the other by a quarter of a guide wavelength at 2856 MHz. The sum and difference arms of the Tee are fed to balanced mixers, where the signals are heterodyned down to 120 MHz IF. Each IF channel contains a wide-band low noise linear preamplifier, followed by a logarithmic amplifier and a video detector. The detected logarithmic outputs may be normalized with respect to beam current by the use of a differential video amplifier. The output of this amplifier is proportional to the logarithm of the beam displacement. The proposed system will permit position resolution in the beam pulse to within 50 nanoseconds.

One dual channel (single beam displacement coordinate) system is being constructed for evaluation.

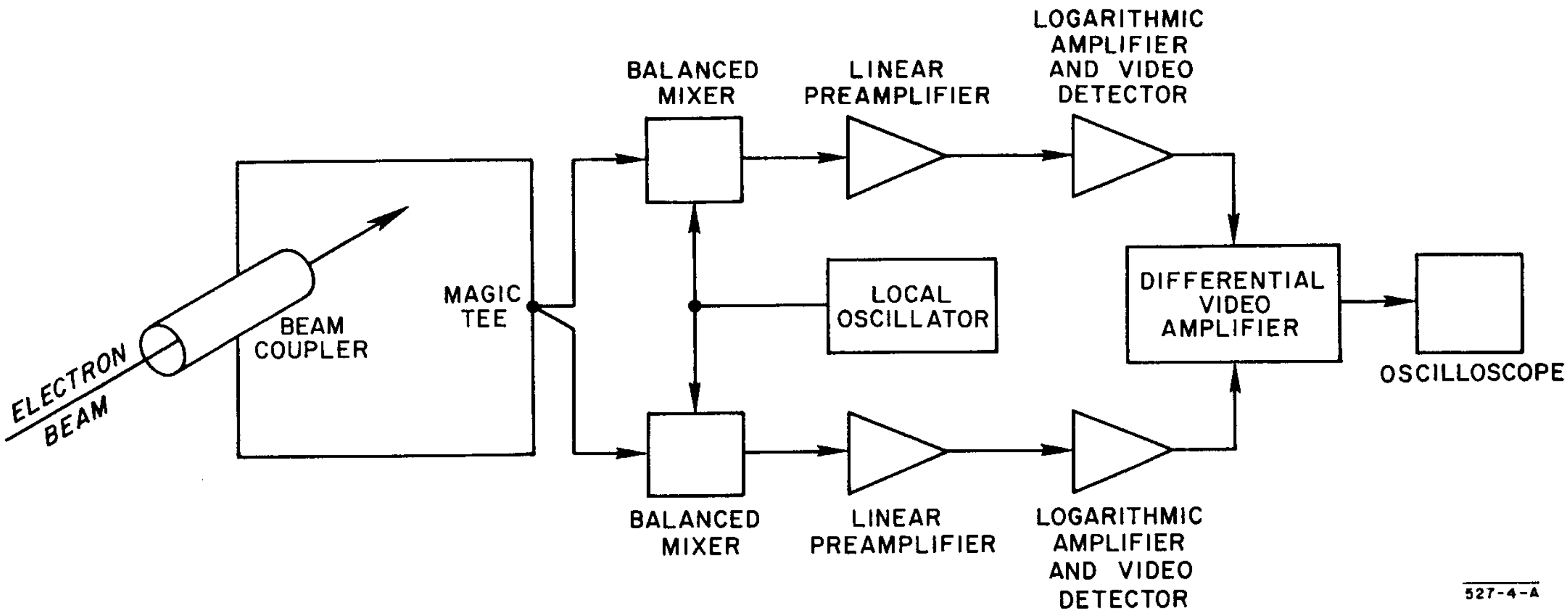

FIG 8 - END STATION A BEAM POSITION MONITORING SYSTEM

E. BEAM ANALYZING STATIONS

1. Beam Analyzing Station 1

The station has operated satisfactorily during the quarter. A new scan foil assembly has been installed. This assembly has 24 foils, $\Delta P/P$ being 1/3% for each foil. The present foil scanner limits the readout to 11 foils. A new scanner, identical to the one built for BAS-2, will be constructed later in the year.

2. Beam Analyzing Station 2

The station has been built and installed on girder 20-1. Electronics equipment for local and remote (CCR) control and readout has been completed and installed. The control equipment includes an automatic degaussing programmer and a beam interlock system.

The entire system has to be checked out before beam turn-on.

F. GENERAL MICROWAVE SYSTEMS

The rf deflecting structures for the separation of electrons and positrons downstream of the positron source have been completed. The characteristics of the structure are:

$$Q = 9930$$
$$\ell = 52.5 \text{ cm}$$
$$I\ell = 0.0493 \text{ nepers}$$
$$v_g/c = -0.0321$$

G. OPTICAL ALIGNMENT SYSTEM

The alignment system was checked out and used for the first time during the past quarter with the following results:

1. The vacuum system appears to be adequate. Even with some significant known leaks, it was possible to get pressures below 20 microns over the entire length of the machine.

2. The laser has sufficient intensity to permit viewing of the images on the ground glass screen. However, a more optimum choice of lenses will be made to improve the visibility.

The laser has operated for several weeks with only minor periodic cleaning and adjusting.

3. All images from the Fresnel lenses appear to be in focus, which confirms that they were correctly made and installed.

4. Some problems remain with the actuator system and with the target status monitor system. New springs may be required for the actuators.

5. The scanning system, which includes the traverse mechanism, the scanner proper, and all associated electronics, was tested and successfully operated. The stability is very good and resolution of images to 0.0001 inch is reliable.

The initial survey of all the accelerator targets showed that there was some systematic deviation (up to about 0.5 inch) in the horizontal survey to which the accelerator was installed. The vertical survey did not show any systematic error but the random scatter of points was about $\pm$ 0.25 inch. These results are shown in Fig. 9.

The BSY laser was delivered and tested. Installation of the BSY system is currently in progress. The tape bench has been completed and some tests made to determine the repeatability of the facility. Improved tape handling equipment and other accessories have been procured and tests are underway.

H. THEORETICAL AND SPECIAL PROJECTS GROUP

1. High Intensity Electron Beam Studies

Several aspects of high intensity bunched electron beams are being studied. The topics include space charge debunching, space charge defocusing, and beam break-up in uniformly loaded waveguides.

2. Wave Propagation Studies

The coupled-resonator model of slow-wave propagation discussed in the previous quarterly report is being used to investigate transient filling and beam loading effects in tapered structures such as the SLAC constant-gradient structure. One finds the appropriate dispersion equation, equivalent to the result given in the previous report, after evaluation of the source term and transformation back to the time-domain, to be:

$$\left(\frac{\partial}{\partial t} + i\omega' - i\omega_{on} + \alpha_n\right) W_n + \frac{i}{2}\left[\Omega_{n-\frac{1}{2}}\, e^{i\Delta_{n-\frac{1}{2}}}\, W_{n-1} + \Omega_{n+\frac{1}{2}}\, e^{-i\Delta_{n-\frac{1}{2}}}\, W_{n+1}\right]$$

$$= -\alpha_n r_n I(t)\, e^{-i\omega' t}$$

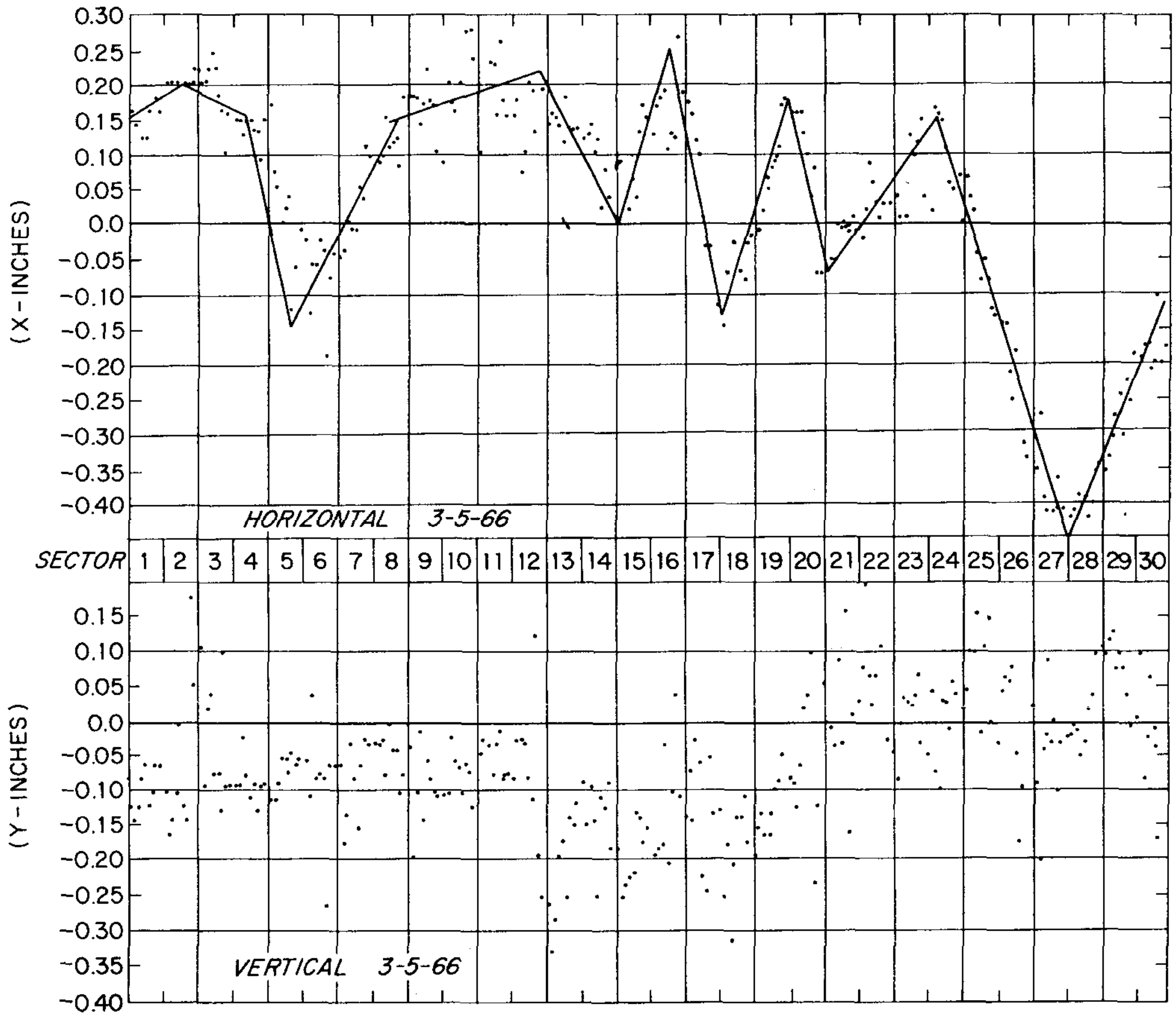

FIG. 9 - INITIAL HORIZONTAL AND VERTICAL SURVEYS OF ACCELERATOR ALIGNMENT TARGETS.

517-1-C

where

ω' is an arbitrary reference frequency,

ω_{on} is the mid-bandpass frequency in the vicinity of the n^{th} cavity,

$\alpha_n = \omega_{on}/(2Q_n)$,

Ω_n is the half-bandwidth in the vicinity of the n^{th} cavity,

$\Delta_n = \omega' \ell_n / c$,

ℓ_n is the cavity length (disk spacing),

r_n is shunt impedance per unit length,

$I(t)$ is the beam current, and

$W_n(t)$ is the rf field amplitude seen by a relativistic electron traveling in the +m direction (the rf field is given by $E_n(t) = W_n(t)e^{i\omega' t}$).

The energy gain for an electron having an initial phase angle of $\omega_b t$ is given by

$$V(t) = \mathrm{Re} \sum_{n=1}^{n} W_n(t) e^{i(\omega' - \omega_b)t}$$

The numerical solution of the dispersion equation has been programmed for the B5500 computer. The program has been tested by running several cases of uniform structures which were calculated by a different method by Leiss, and the agreement is satisfactory. The present method has the advantage of being able to handle nonuniform structures readily.

Figures 10 through 13 show some results of a preliminary computer run simulating the SLAC 10-foot constant gradient structure. The conditions for these curves are:

(a) a step-function rf driving voltage is applied at cavity No. 0 at $t = 0$, with an amplitude corresponding to an energy gain of 1 MeV/cavity;

(b) beam current is negligibly small;

(c) the waveguide frequency ($\omega_{on}/2\pi$) is in error by about 0.06 MHz.

3. Storage Ring Feedback System

Two complete feedback systems, each comprising a 0-5 Mc helical resonator filter, a 60-dB preamplifier, a negative linear phase shifter, a coarse and a fine adjustable constant-phase shifter, a 30-dB voltage amplifier, and a power amplifier, have been constructed. They are now under laboratory testing.

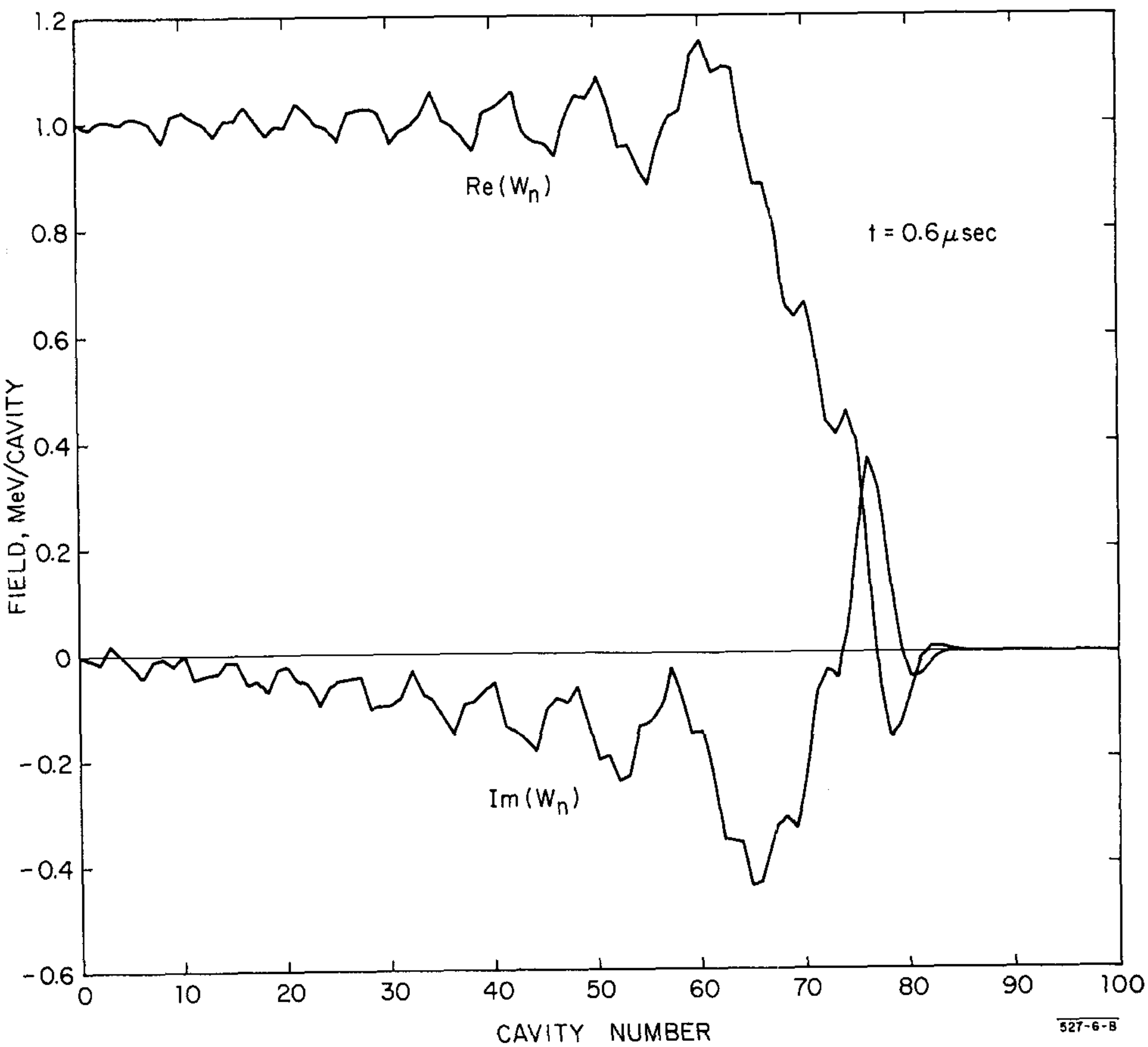

FIG. 10 - FIELD DISTRIBUTION ALONG WAVEGUIDE 0.6μsec AFTER RF POWER IS TURNED ON.

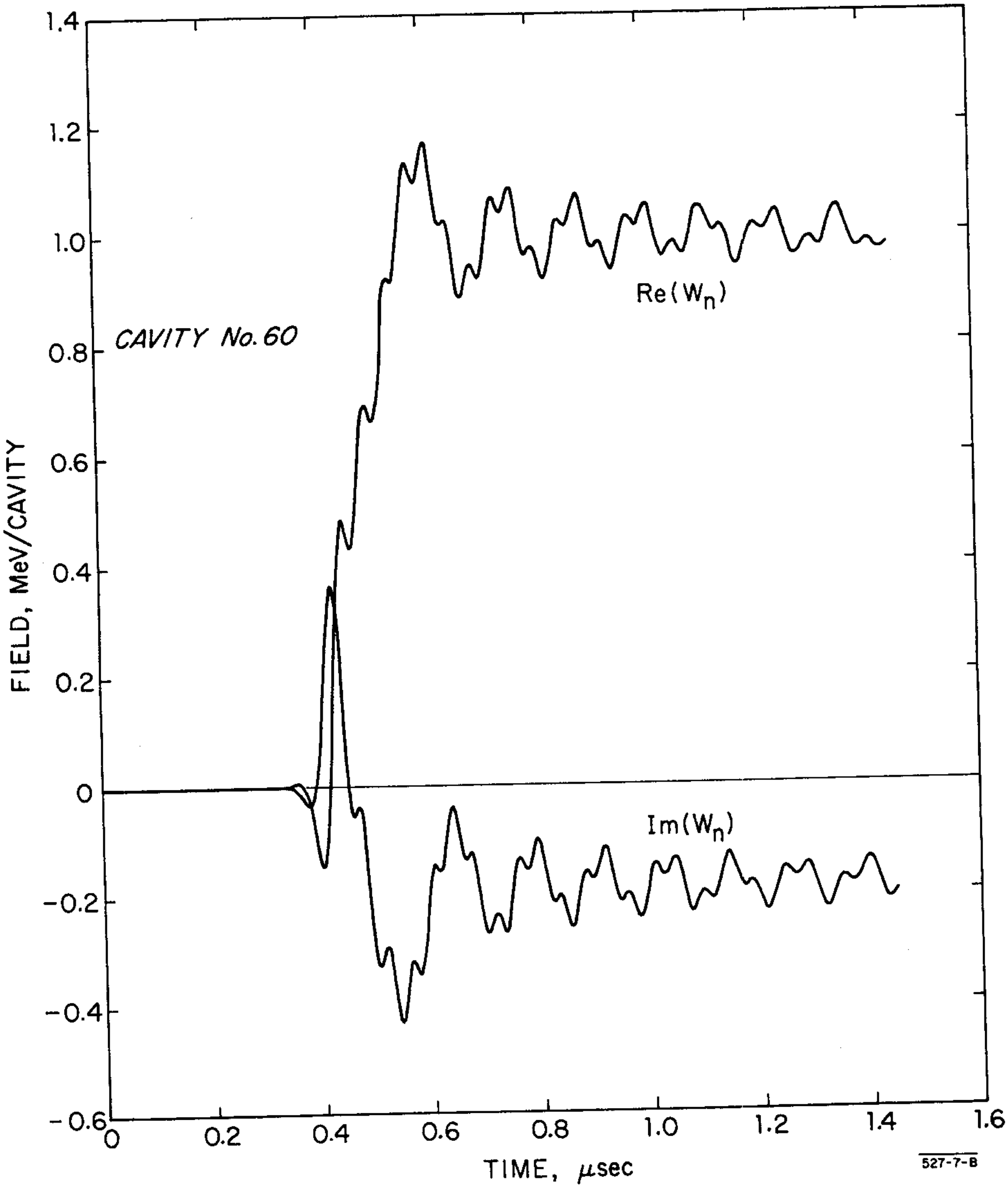

FIG. 11 - ARRIVAL OF RF PULSE AT CAVITY No. 60 (6.9 FEET), SHOWING DISPERSIVE EFFECTS OF PERIODICALLY LOADED STRUCTURE.

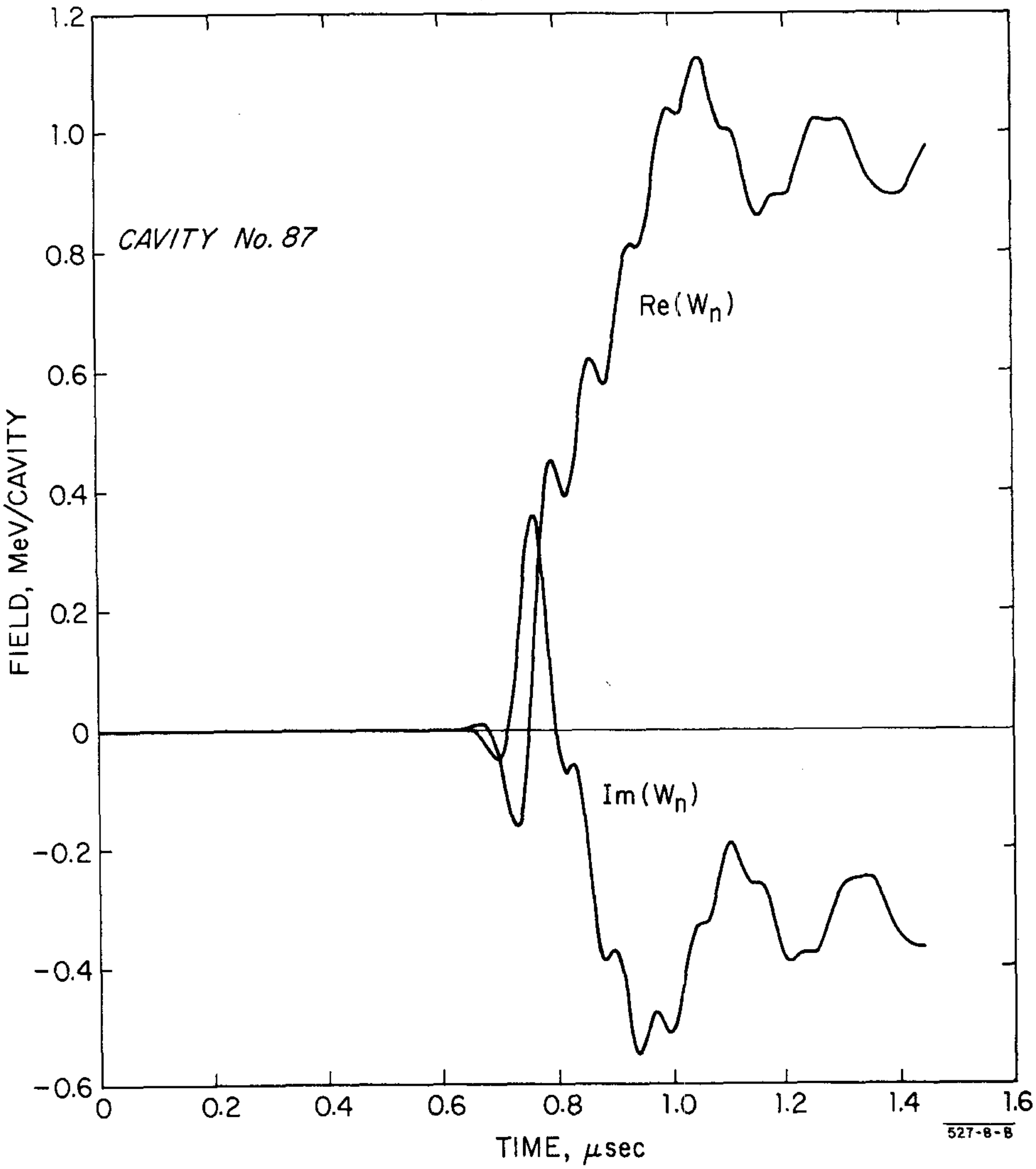

FIG. 12 - ARRIVAL OF RF PULSE AT CAVITY No. 87 (10 FEET).

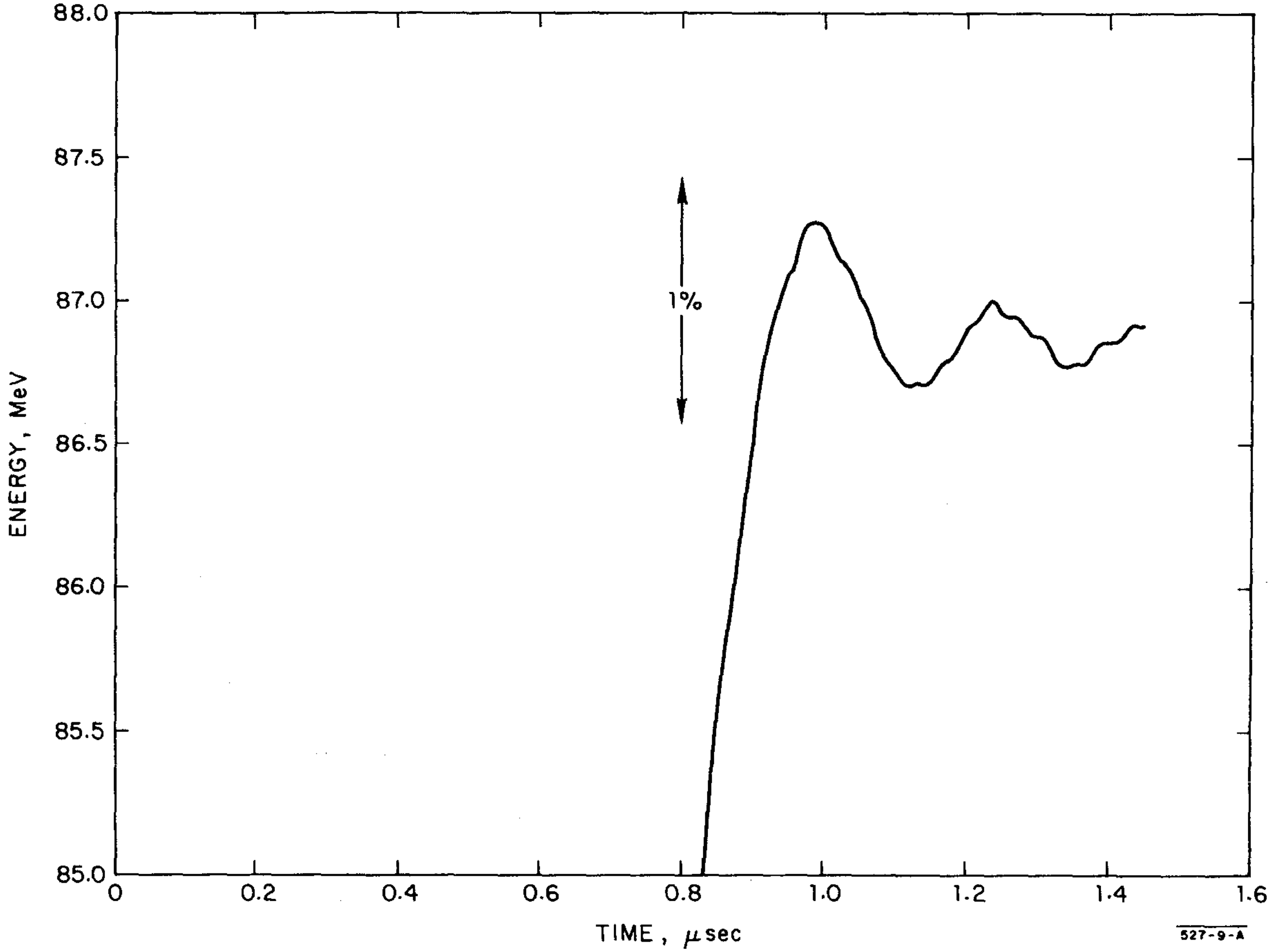

FIG. 13 - ENERGY GAIN vs. TIME FOR SYNCHRONOUS ELECTRONS

I. MAGNETIC MEASUREMENTS

During the past quarter, the Magnetic Measurements group completed the measurements and tests of the spare accelerator quadrupole triplets and the pulsed steering dipoles.

Measurements and tests of seven additional BSY 3° bending magnets were completed. Thirteen magnets have been completed so far, and the data on these have been analyzed and transmitted to the Research Area Physics group for evaluation and selection of magnets. The fourteenth magnet, which is the reworked prototype, will be on hand at the end of April.

Measurements and tests were performed for two of the beam dump magnets and for one of the BSY $\frac{1}{4}^{\circ}$ emergency magnets. The data was analyzed and transmitted to the Research Area Physics group.

Measurements of the last two pulsed steering magnets with the hastelloy beam pipes were completed.

Seven of the BSY dc steering magnets were measured and the data analyzed.

Magnetic alignment of the constant field coils of the positron source solenoids was performed. Only the tapered field section remains to be aligned, and preparations for that alignment have been completed.

The development of an NMR system for the magnets of the Experimental Group A spectrometers is underway.

Preparations for measurement of the spectrometer magnets and Research Area Operations group magnets are in process.

J. RESEARCH AREA PHYSICS GROUP

The preliminary activities of this group continue to center around the completion of the Beam Switchyard and in planning its initial operation. The status of the construction of the Beam Switchyard and its instrumentation and control are reported in Sections II, III, V, and IX of this report. The following are group activities not reported elsewhere.

1. Beam Switchyard Coordinates

Coordinates of essentially all Beam Switchyard components have been calculated and double-checked using the Vertex and Layout computer programs. Information such as component locations, elevations, angles, tape lengths, etc., required by the Precision Alignment group for the alignment of components, has been calculated. For example, the computer programs necessary to determine the shop alignment of the 3^{o} bending magnets have been generated, and methods and programs for checking the accuracies of this alignment have been developed.

2. Beam Switchyard Analysis

A system is being set up for maintaining the Beam Switchyard component coordinates on IBM cards. The results of measurements of the magnetic properties of the Beam Switchyard magnets and the mechanical properties of the slits and collimators are being recorded on IBM cards as the data becomes available. Analysis of the data is progressing satisfactorily.

3. 3^{o} Bending Magnet Assignment

A program has been written which uses the results of magnetic measurements to determine the optimum location-assignment of the 3^{o} bending magnets. For the assignment of A-Beam magnets, the program uses the following criteria:

(a) At the time when the location assignment was required, there were available four magnets from heat 60, three magnets from heat 86, and several magnets from heats 73 and 25. The program was required to select three magnets from heat 60 plus one magnet from heat 86 for the first four magnets (the energy-defining magnets) of the A-Beam. The heat 60 magnet remaining was assigned as the A-Beam reference magnet. The last four magnets for the A-Beam were selected by the program from heats 86, 73, and 25 with the requirement that all the heat 86 magnets be used.

(b) The program selected that permutation which results in a minimum deviation of the deflection of the exit beam from the ideal as the beam energy is changed from one energy to another. The A-Beam magnets have been assigned according to the following table:

TABLE I

BEAM SWITCHYARD A-BEAM MAGNET ASSIGNMENT

BSY Number	A Ref.	B-10	B-11	B-12	B-13	B-14	B-15	B-16	B-17
Magnetic Measurement Number	2	3	8	6	5	11	12	4	9
Heat Number	60	60	60	60	86	86	25	86	73

4. <u>Initial Beam Switchyard Testing Program</u>

Preliminary plans have been prepared for initial testing of the instrumentation and optics of the Beam Switchyard.

V. INSTRUMENTATION AND CONTROL

A. CENTRAL CONTROL ROOM (CCR)

The Operations Console contains injection controls, beam monitoring displays, beam guidance controls, a panel which can be switched to display status and analog signals and to operate controls in any one sector at a time, and a summary panel to alert the operator which sector is likely to contain the source of trouble when he cannot obtain a beam.

During the past quarter, the operation of sector functions from CCR by means of one of the switched sector panels became a matter of routine. The switched sector panels and other controls and indicators in CCR made it convenient to keep track of most personnel safety activities in CCR. Many of the remote controls and status and analog indicators connected with the main injector were tested successfully in CCR.

The Maintenance Console contains two more panels for monitor and control of individual sectors, a continuous display of much of the status information from all thirty sectors, more details of the injector, and Beam Switchyard monitors and controls.

The Backup Console contains continuous display of some analog signals from all thirty sectors, the trigger programming equipment, and display and control panels for specialized equipment such as the master trigger generators, the master oscillator and main boosters, water towers, etc.

Check-out of data transmission and control equipment in all sectors has been accomplished from CCR.

During the last quarter, equipment installation and rack wirings have been completed for the injector systems and the second switched sector-by-sector system. Three data transmission and personnel protection racks have been wired and tested. These will be installed in the Data Assembly Building. Most of the units for the trigger system have been installed and checked out. Rate and pattern signals are being transmitted from CCR for use along the machine.

The steering oscilloscopes and their driving logic have been installed in CCR and are performing satisfactorily. Position and intensity signals from the 10-foot and 30-foot monitors have been observed in CCR.

The Protection Long Ion Chamber (PLIC) display, the linear Q display, and two video displays have been installed and checked out but have not displayed authentic signals yet.

Design of the spectrum displays has been completed and the system is being assembled.

B. DATA HANDLING

1. Status Monitoring

Binary status information at each sector is transmitted to Central Control on a time-shared multiplex system. Delivery of production units has been completed.

Transmitting units have been installed in all thirty sectors and in the injector. Receiving equipment has been installed in the Central Control Room for two switched sector-by-sector display panels. Receiving equipment for continuous display of status has been installed for all 30 sectors and the injector.

2. Analog System

Slowly changing analog signals are transmitted to standard panel meters in Central Control by means of individual hardwire pairs. A few signals are switched to the sector-by-sector display panels. Six switching chassis have been installed in the CCR and are operating satisfactorily. These chassis enable as many as 15 analog signals from any sector to be displayed on the console.

Signals have been received and displayed from 30 sectors.

3. Remote Control System

The remote control system consists of a transmitter which transmits binary codes and a receiver in each sector which translates the code into a signal to actuate a relay or motor. Delivery of production units is complete.

Receivers have been installed in all sectors and are operating normally.

All transmitting system equipment has been installed and checked out in the CCR.

4. Beam Monitoring

Beam monitoring signals are transmitted to Central Control in two forms:

(1) An FM signal which gives an accurate representation of the charge per pulse (Q) at each sector.

(2) A multiplexed baseband signal which transmits pulses representing log Q, x, y for each beam pulse.

Delivery of FM equipment is complete and all receiving units have been installed in the CCR. Installation of sector transmitters is in progress.

Representative complete signal paths in the x, y, log Q, and linear Q beam monitoring systems were operated, including the signal sources and the transmission, multiplex, and special oscilloscope systems.

5. Video Cable System

Tests carried out in the Klystron Gallery using prototype units of the video repeater amplifier showed that the filtering on the supply lines was not adequate. A redesign of the amplifiers was carried out which allows them to be run from a smaller voltage, thus leaving a larger voltage to be used up in the filter with a consequent improvement in performance.

Laboratory tests on cascaded amplifiers, using a combination of prototype units and some early breadboard models, showed that TV signals could be successfully transmitted through ten amplifiers, the maximum number which will be encountered. Specifically, this test showed that the low frequency performance of the amplifiers is adequate for transmitting frame and field information, the waveforms received at the output end of the cascaded amplifiers being satisfactorily clamped.

Tests were carried out on the 1/2-inch heliax cables installed in the Klystron Gallery. The cables were jumpered in the instrumentation and control alcoves so that continuous cable runs – without any repeater circuits – were obtained from the injector to the Central Control Room. It was demonstrated that satisfactory TV pictures could be transmitted over this distance.

In another series of tests, fast rise time pulses were transmitted down one heliax cable to Sector 12 from the Central Control Room and then back there again on the other heliax cable. The rise time of the received signal was consistent with theory.

C. MACHINE PROTECTION

The machine protection system provides three gun interlock circuits: a one-millisecond network using a carrier tone, a 50-microsecond network using permisssive pulses, and a long ion chamber interlock.

All subsystems of the Protection Long Ion Chamber (PLIC) have been installed with the exception of certain sections of the PLIC cable. The PLIC electronics panel contains an interim compensation network, mounted on a breadboard version of a printed circuit card. If the interim compensation network performs satisfactorily, it will be assembled on a finished p.c. card. Otherwise a more sophisticated version (i.e., a more complicated version) will be fabricated according to the design prepared by G. Temes of SLAC.

D. TRIGGER SYSTEM

The trigger system consists of a master clock near the injector, a distribution system for master clock signals, multiple trigger generators near the equipment to be controlled, and trigger programming equipment in Central Control.

The Beam Switchyard trigger generator has been installed in the Data Assembly Building and final tests are due to take place in April.

The pattern generator subsystem, including one of four program selector and driver units, was installed in CCR in mid-January, and has been functioning satisfactorily since then (serving the injector and the first ten sectors) with no significant failures or malfunctions.

The other three program selector and driver units, fabricated outside SLAC, have been delivered and are now being installed and tested.

Design of the counting house trigger generator has been started. Breadboard testing and evaluation of crucial circuits is essentially complete.

E. BEAM GUIDANCE

Beam guidance equipment includes the electronics for intensity and position monitors and the power supplies and controllers for degaussing, quadrupoles, and steering dipoles.

Installation of nearly all of this equipment has now been finished.

All forty beam monitor sector electronics units have been received from the vendor. Of these, 36 have been checked and 26 of the 33 units for the Klystron Gallery have been installed there.

The majority of the control units for the beam steering power supplies have been checked and installed in the Klystron Gallery.

Modifications to the beam steering power supplies are still being carried out by the vendor in order to bring the units within specification. Reference shunts have been changed, matched transistors are being used for the first stage of the control amplifier, and selected pass transistors have been installed. These supplies are the most serious instrumentation problem remaining in the Gallery.

Of the units tested by SLAC, about 50% have been accepted, and some of these have been installed in the Klystron Gallery.

Engineering inspection of the last of the beam intensity monitors was completed. Out of approximately 33 units tested, only one was rejected.

F. PERSONNEL PROTECTION SYSTEM

The Personnel Protection System has a machine shut-off circuit, access controls, radiation monitors, and warning devices.

The system has been completed through Sector 30 and is operating satisfactorily. The circuits being installed in the Data Assembly Building allow the Chief Operator in the Central Control Room to turn over control of entry into the Switchyard and End Stations to the operator in the Data Assembly Building. An additional feature of the End Station circuits will allow entry to one End Station while experiments are being conducted in the other, if the appropriate slit is closed, a beam stopper inserted in the beam path through the switchyard, and if the pulse magnets are interlocked so that a beam can not be deflected toward that End Station.

G. CHECKOUT OF GALLERY INSTRUMENTATION

The Instrument and Control group provides supervision of the systems tests of wiring and subsystem operation in the sectors. No check-out of gallery instrumentation in all 30 sectors has been completed with the exception of a few vacuum and beam guidance circuits for which the equipment has not yet been installed.

H. CONTROL SYSTEMS

The signal interfaces between the Switchyard Data Assembly Building and the Central Control Room have been identified. Final design is still incomplete for a few of the signals. In general, information handling between DAB and CCR is the same as between individual sectors and CCR.

The Beam Switchyard instrumentation providing signals to CCR or receiving signals from CCR can be divided into the following categories:

1. Spectrum Monitoring System
2. Beam Monitoring System
3. Beam Guidance System
4. Collimator System
5. Magnet System
6. Machine Protection System
7. Trigger System
8. Personnel Protection System
9. Personnel Communication System

Much of the equipment is contained in four racks being wired at the Central Control Room. These racks contain the personnel protection logic for the Switchyard, End Station A and End Station B, and the data handling equipment for analog, status and control signals. The interface between this equipment and the spectrum monitor, beam monitoring system, etc., in the Switchyard is being firmed up as the schematic diagrams of the individual systems become available.

I. POSITRON SOURCE

The time spent on the Instrumentation and Control portion of the Positron Source control resulted in production drawings for a regulator on/off control and status panel, a solenoid power supply water interlock panel, a steering pulser panel, a vacuum analog panel, linear Q and log Q, x, y panels, a steering and water supply control panel, and modulator 3-B and C control and status panels.

The installation requires modifications in fiat racks in Sectors 11, 12 and 14 to accommodate special equipment for the positron beam. The layout of the positron control racks in Sector 11 was firmed up.

Control concepts for wheel control and new protection requirements were completed. Proximity switch circuits were designed for positioning the target for withdrawal from the beam axis in order to measure the trolling speed of the target. A circuit was laid out which protects the ceramic insulators in the magnet cooling water system from the thermal shock that would result from continuing to circulate cold water when the magnet power is turned off.

VI. HEAVY ELECTRONICS

A. MAIN MODULATOR

Checkout and water-load testing of all modulators were completed during this quarter. In addition, all modulators were operated into klystron loads by the Sector Test Team, and pulse-forming networks were tuned for a flat output pulse in almost all modulators.

Work on the fire alarm circuits to be installed in each modulator is proceeding. All purchased parts were received, and a subcontract for making up subassemblies was let. Installation should begin early in May.

The four life-test modulators in the Test Laboratory (Serial Numbers 2, 3, 21, and 22) continued to run around the clock. At the end of the quarter they had 12,509, 13,534, 7587, and 8413 hours of running time on them respectively. Such life testing has revealed a life problem in the main rectifiers. We have lost five rectifiers with lives ranging from 32 hours to 8015 hours. We are working with the manufacturer in an effort to improve the life of these units.

1. Switch Tubes

Both manufacturers continued to deliver tubes this quarter. Deliveries continued to be ahead of our requirements; by the end of the quarter, we had about 60 spares on hand.

2. Pulse Transformer Tank Assemblies

Seventy-one pulse transformer tank assemblies were completed during this quarter, bringing the total to 235, and we continued to maintain a small margin over the Klystron Group's requirements. Among these completed assemblies are all the old-style tanks which had contained rubber tube oil expansion chambers; these assemblies were removed from the accelerator and reworked with the new external reservoir tanks.

B. SUB-BOOSTER MODULATOR

The sub-booster modulators operated several hundred hours this quarter. The blower vibration problems mentioned in the previous quarterly status report were solved by straightening the rotor shafts and balancing the rotors. However, to ensure future stability, we have ordered a new set of higher-quality blowers.

Improved switch tubes were also procured from two manufacturers to replace the 4PR1000 tubes. The new tubes have "beefed-up" cathodes which are capable of higher pulse currents. Two of the improved tubes do the job of three of the old 4PR1000 tubes.

C. GUN MODULATOR

The work on this modulator was brought to the point where it could be used on an oxide-coated cathode gun, and it was installed on the accelerator on January 26, 1966. Since then, it has been in operation for injector tests. More modifications must be made before it can be used with a bombarded cathode gun.

D. CAPACITOR CHARGER POWER SUPPLY

We are designing and constructing two capacitor chargers for use on a spark chamber. These power supplies will be capable of charging a 3/4-microfarad capacitor to 50 kilovolts within 80 milliseconds, after allowing a 20-millisecond dead period for de-ionization of the spark gap switch which connects the capacitor to the primary of an autotransformer.

E. MAGNET POWER SUPPLIES

Essentially all magnet power supplies for the Beam Switchyard and the accelerator were delivered during this quarter. Some of them were tested in the Heavy Assembly Building. All passed tests satisfactorily with the exception of the A Beam Dump power supply which, at the end of the quarter, was still being worked on by the manufacturer.

The Research Division power supplies remained fairly well on schedule. Most of the End Station B beam transport power supplies were delivered this quarter. One of them was checked out rather thoroughly with our regulator. It operated satisfactorily with jerry-rigged loads, as the magnets that are to be used on the power supplies are not yet available. We were asked to regulate these power supplies through a Hall probe. This work was well underway, and regulation into jerry-rigged loads was accomplished.

VII. MECHANICAL DESIGN AND FABRICATION

A. GENERAL

The fabrication of all remaining rectangular waveguide spare components was completed during the reporting period, together with the eight spare thin vacuum valves. These included four fast-acting and four slow valves.

The 10- and 20-foot solenoid assemblies and the bare 10-foot girder for the positron source were completed and installed at the first of the period. The bare girder was fitted with a drift pipe and strongback supports for the positron source, which was in work by the end of the reporting period. The solenoid A housing, which forms the main part of the source, was 30% complete by the end of March, and it is anticipated that all positron source hardware will be done by mid-July.

Work on BSY components and hydrogen targets was also being done during the quarter and is either reported on elsewhere in this report or will appear in the mid-year Quarterly Status Report.

B. MAGNET ENGINEERING

The magnet engineering group was concerned primarily with magnet processing and vendor follow-up during the reporting period, and a major portion of the magnets were ready for installation or installed.

1. Pulse Steering Magnets

Final magnetic checks were completed on all pulse steering magnets, and they had all been installed by the end of the quarter.

2. Emergency Bending Magnets

All emergency bending magnets were received during the reporting period and were processed and readied for installation. They are to be installed early in the next period when associated items of equipment are received.

3. Three-Degree Bending Magnets

All of the three-degree bending magnets, with the exception of the reworked prototype, were received during the reporting period. The position designations were made for all but the five B-Beam bending magnets, and when this is complete, all of the magnets will be ready for installation as soon as their vacuum chambers are installed. The chambers were in but were awaiting position designation before they were installed.

4. Pulse Magnets

The cores for the pulse magnets were completed during the period. The coils and packaging assemblies were not delivered as had been anticipated, but they are expected during the next reporting period so that the magnets should be ready for installation in July. The vacuum chambers for these magnets have also been delayed slightly but delivery is expected during the next quarter. If the chambers should not prove adequate, it has been determined that the magnets can be enclosed in a vacuum can.

5. Quadrupole Magnets

Five cores for the 8-cm quadrupole magnets and two for the 18.6-cm magnets were received during the reporting period. The cores for the latter were not complete because the formed end plates had not been delivered, but the plates are expected early next quarter. It is anticipated that the 18.6-cm magnets will be completed by the end of the next quarter and the 8-cm magnets should be ready shortly after mid-year.

6. Photon Beam Stripping and Bending Magnets

The coil for the B-28 bending magnet was not received as anticipated. It will be delivered in the next quarter and the magnet will be installed at that time.

The B-29 and B-29A stripping magnets were received during the reporting period. During acceptance tests it was determined that modifications would have to be made. The drawings and parts for these modifications are being completed, and it is anticipated that the magnets will be completed and readied for installation during the next quarter.

7. Dump Magnets

All four of the dump magnets were received during the reporting period. Two of them were magnetically measured and all four were precision aligned and given locational designations. Cracks were found in the coils of all four magnets and these had to be repaired. The magnets will be reassembled and ready for installation next quarter. The thermal interlocks for all of the magnets were relocated to provide greater protection against the cracking condition.

8. BSY DC Steering Magnets

The processing of the BSY dc steering magnets was completed during the reporting period and the magnets are ready for installation.

9. End Station A Alcove Steering Magnets

The A-400 and A-401 magnets used in End Station A to steer the beam to the mass spectrometer target were completed during the reporting period, but were waiting on attaching hardware delivery prior to installation.

10. Beam Dump East Steering Magnets

The coils for Beam Dump East steering magnets A-402 and A-403 are being wound at SLAC. The work is well along and the magnets are expected to be completed during the next quarter.

11. Associated Magnet Hardware

All of the remaining ceramic water tubes and bellows connectors for the BSY magnets were on hand by the first of April. The delivery of quick-disconnect couplings for the vacuum chambers was also completed during the reporting period. The vendor for the ceramic vacuum chambers had improved his fabrication techniques and chambers were being delivered in time to meet installation schedules.

C. PRECISION ALIGNMENT

1. Laboratory Targeting of Components

Shop aligment procedures were finalized during the reporting period and the bending magnets and dump magnets for the A-beam were targeted together with the beam instruments, steering magnets, and High-Z collimators and slits for the A, B and central beams.

Shop alignment procedures were also developed and work was started on the alignment of collimator C-O and high-power collimator C-1 and their supports. The support for the pulse magnets was shop aligned together with various instrument stands to complete approximately 50% of the work for the BSY alignment requirements.

The fabrication and installation of the tape bench facility was completed during the reporting period and preliminary scribing and stability evaluations were performed.

2. Field Activity

The prototype hardware for second-level alignment in the BSY was tested and evaluated during the period. Final design was established and the hardware for two alignment teams was fabricated.

Installation alignment began on the central and A-beam equipment; instrument stands, pulse magnet supports and divergent chambers were the principal beam transport components aligned. Training for the unique methods of second-level alignment began and procedures were improved as it progressed.

The preliminary horizontal survey for alignment was carried eastward from the BSY into End Stations A and B, which were still under construction. Installation of a 10-foot grid pattern was started in End Station B.

VIII. KLYSTRON STUDIES

A. SUMMARY

During the quarter, 108 klystrons were installed in the Klystron Gallery, bringing the total number of klystrons initially installed to 240. Some tubes had to be removed for modifications of their pulse transformer tanks. The deliveries from our three vendors have continued at a rate satisfactory to permit completion of installation with the addition of SLAC-built tubes.

Thirteen tubes failed in the Gallery during the quarter, bringing to 25 the total number of failures during operation to date. In addition, three tubes failed on the shelf during the quarter, bringing the total number of shelf life failures to 19 to date. Approximately 11,000 klystron hours were registered during the quarter in the Gallery, bringing the total operating hours to 38,000. The SLAC klystron activity resulted in a total of 22 SLAC tubes accepted during the quarter, bringing the total to 49.

During the quarter, the Klystron Group was given the additional responsibility of maintenance of the accelerator vacuum system. This activity is still much in the planning stage.

B. KLYSTRON PROCUREMENT

The manufacturers' performance has continued satisfactorily during the quarter, with a total of 87 vendor tubes delivered.

1. Sperry Subcontract

Sperry has continued to have some problems in manufacturing, particularly with regard to sparking and gassiness. During the quarter, the trouble was probably corrected by changing some of the manufacturing techniques in the anode region. As a result, the last shipment of tubes appears to be much improved. Some difficulties were also experienced due to contaminated output waveguides resulting from a deposit left from the last rinse water.

The window problem appears to have been solved by careful attention to the coating process. One notable exception was one window which was sandblasted prior to shipment because of the dirty appearance. That window exhibited multipactor and broke during tests at SLAC.

Another result of the gradual improvement at Sperry is that, on the average, the tubes delivered have not been through processing as often as previously, which makes their repairability more likely.

All of the magnets drop-shipped by Arnold Engineering for use with Sperry tubes have been delivered and only one failed to meet specifications.

2. RCA Subcontract

The manufacturing yield at RCA has not increased as expected because of a sudden rise in the number of windows which show multipactoring and either run too hot or break during tests at RCA (hot windows are not shipped to SLAC). A conference was held at RCA to discuss this very serious window problem, but to date the real cause of the problem has not yet been found. Some tests will be carried out at SLAC, as well as at RCA, in an attempt to determine the change in conditions which resulted in this dramatic change in performance. To date, the only indication is that the window problem started at about the same time as a new batch of ceramics and a new batch of titanium coating wire were received at RCA.

On the repair program, RCA has experienced some difficulty with spongy collectors. The repair tube goes through bake satisfactorily but gasses during the beam and rf processing. The difficulty was traced to a sponginess in the collector, probably caused by excessive power density near the end of the collector. Several solutions to this problem are being considered to obtain an optimum long-life design. For the present, the end of the collector will simply be replaced when needed.

Magnet deliveries to RCA have still been slow, so that at the end of the quarter RCA had not yet been able to ship the full complement of magnets for their tubes.

3. Litton Subcontract

Litton has experienced a higher manufacturing yield than the other vendors and has had adequate magnet deliveries to meet their contractual delivery requirements to SLAC.

The only problems observed on Litton tubes concerned some marginal instabilities. At reduced drive level, heater hum is close to the maximum allowable by specification, and occasional pulse instabilities (also close to the maximum allowable) appear. These problems have not been observed at Litton because their test stand was not sufficiently sensitive to observe such phenomena. After demonstration at SLAC, Litton made adjustments which appear to have solved the potential problems.

C. KLYSTRON RESEARCH AND DEVELOPMENT

Most of the effort during the quarter was directed toward "standard" tubes for eventual use in the Gallery. A total of 42 tubes went through bake (including two extended interaction experimental tubes). Of 40 "standard" tubes which started processing in electromagnet, 38 successfully passed all electromagnet tests. Thirty of these were tested in permanent magnet and four of the thirty failed permanent magnet tests. Finally, the acceptance rate of SLAC tubes was approximately 94%. Overall, this gave us a significant improvement over the previous quarter's record. The main reason for this improvement was the better control of the window coating and the decision to recoat the windows on all reworked tubes. As a result, there were no SLAC window failures through acceptance test during the quarter.

In general, very little trouble is experienced during tube bake of SLAC klystrons. However, a few leaks have developed at the input seal, and, in addition, the rf input loop does not appear to be as stable as desired for easy reproducibility. To alleviate both problems, a new input feedthrough has been designed, built, and tested, and will be incorporated in a few tubes built during the next quarter.

The results of the experimental extended interaction output cavity tubes this quarter were very discouraging. We were unable to duplicate the good performance observed last quarter because of instabilities and oscillations observed in these tubes. The reason for these problems is not fully understood, but a modified version of the output cavity has been redesigned and is ready for assembly. Tests will continue next quarter.

The work on permanent magnet improvements is continuing. The magnetizer power supply is performing satisfactorily and has been of great value in remagnetizing a number of magnets, not only for SLAC tubes but for vendor tubes as well. We are also working on modifications in the magnetic field shape in the gun region in an attempt to approach more closely the tube efficiency observed in electromagnets. In parallel with this work, we have started design of a beam tester (one-third scale and approximately one-tenth voltage) to enable us to better understand the beam dynamics in the gun and to investigate the possibility of field reversal focusing, with a potential savings in magnet weight and cost.

D. KLYSTRON TEST AND MEASUREMENTS

The activity in the test stand area continues to be high, with a total of 90 individual tests for Stanford tubes and 320 individual acceptance tests (both vendor and SLAC tubes) performed during the quarter. These tests include initial measurements of tube performance, 20-hour runs, and final test on pulse transformer tank. The total high voltage running time exceeded 7900 hours, with approximately 1290 hours accumulated on window life test.

In general, good agreement is still obtained between vendor and SLAC measurements of power output; however, the vendors do not usually have sufficiently accurate equipment to measure the detail phase and amplitude jitter and drift which is required for satisfactory accelerator operation. Careful maintenance and calibration of all equipment involved continues to insure the good agreement on the power.

During the quarter, the main equipment failures involved one Powerstat, sub-booster modulator switch tubes, high voltage diodes, and trigger generator chassis. In addition, tube H-56, which is in use for the window life test, must be considered as having failed because its power output has decreased below the minimum specification. The total high voltage running time for that tube was approximately 6300 hours at the time of failure.

E. GALLERY OPERATION

1. High Power Klystrons

During the quarter a total of 11,000 operating hours were accumulated in the Gallery, bringing the total cumulative hours to 38,000. Most of the activity in the Gallery has been concerned with sector testing, and resulted in a total of 13 tube failures. Of these, five were window failures, seven were caused by loss of vacuum in the tube, and one was caused by a leak in the water circuit in a SLAC-built tube, which has since been repaired. Only one loss of tube vacuum can readily be explained; it was caused by operation of the tube without water cooling as a result of water interlock failure.

In addition to the tubes removed from the Gallery because of tube failure, 29 klystrons were removed either to modernize the pulse transformer tanks or to investigate other potential failures.

Figure 14 gives the mean time to failure, the total number of tube failures, the total number of tube replacements in the Gallery, and the average number of hours of operation per socket installed.

One of the main difficulties experienced during the maintenance of the operation in the Gallery has been related to water flow and pressure drop in the klystrons. Some of the tubes installed probably have a pressure drop a few pounds in excess of the specifications (30 psig at 10 gpm), but at least 15 reports of an inability to close the flow switch interlock have been received. Obviously much more serious is the experience mentioned above where an interlock circuit was completed although no water was flowing in the cooling loop.

2. Sub-Booster Klystrons

The total number of operating hours (Klystron Gallery and Test Laboratory) for sub-booster klystrons was 107,000 at the end of the quarter, with an accumulated total of 28,000 hours during the quarter. One tube failed in operation during the quarter; in addition, there was one shelf life failure during the quarter, and two tubes which had been used at Manson in testing the sub-booster modulator were found to have failed by the time they were returned. In total, we have experienced 18 plate life failures and 32 shelf life failures to date. If the failures can be considered as random, we are experiencing a mean time to failure of 6000 hours for the sub-booster klystrons in operation.

The order for sub-booster klystrons from Eimac was almost complete at the end of the quarter. It is expected that adequate spares are, or will be, on hand through the end of the year. Procurement has been initiated to assure a continuing supply of tubes after January 1967.

The main difficulty experienced in maintenance of the sub-boosters appears to come from the discrepancy between the beam voltage indicated by the capacity divider and that which would be expected from the readings of the modulator power supply voltmeter. Also, a few cases of phase instability were reported.

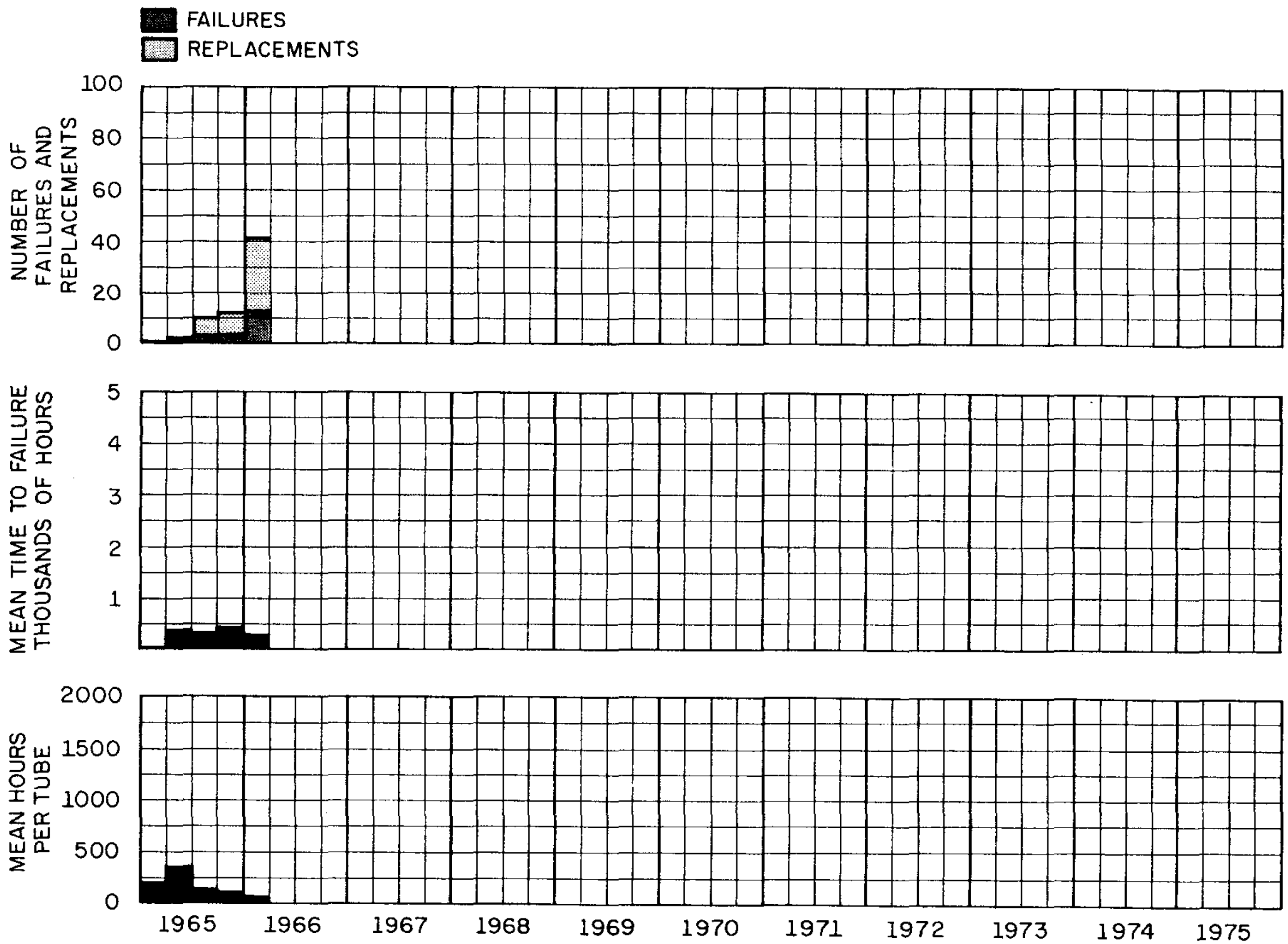

FIG. 14 -KLYSTRON QUARTERLY OPERATING EXPERIENCE-
ALL HIGH POWER KLYSTRON VENDORS

3. Main Booster Klystrons

One of the two main booster klystrons failed during the quarter after almost 9000 hours of operation. A review of the handling problems and maintenance problems of the main booster is underway to facilitate replacements in the future.

4. Vacuum System

During the quarter, the responsibility for the maintenance of the main accelerator vacuum system and the differential pumping system between the accelerator and the Beam Switchyard was transferred to the Klystron Group. In addition to the general planning of equipment which will be needed to perform the leak checking and maintenance, we already have helped in completion of the activation of the system; specifically, all the manifold gauges were valved into the vacuum system, and we supervised the replacement of new connectors for the 500-liter/second pumps. In addition, some leak hunting has been done. Up to now, all the leaks were found to be at flanges and could be easily fixed by tightening up the bolts to the standard torque.

F. HIGH POWER KLYSTRON WINDOWS

1. Window Failure

Recent SLAC window performance has been encouraging as no failures have yet occurred on any of the 42 klystrons built or rebuilt here during the past quarter. Several window failures occurred or were discovered during the period, but all of the tubes and windows involved were carry-overs from past production. Two klystrons were rejected because of overheated windows, one of which eventually cracked. Both of these windows had been exposed to multiple bake cycles prior to the decision that windows were to be removed from tubes being reprocessed. This procedural change and tighter limitations on coating thickness have been largely responsible for the recent decrease in the window failure rate of SLAC klystrons. Disturbingly high window temperatures ($\approx 130^{o}C$) were observed during initial tests of two klystrons off bake late in the quarter, but both windows survived all full power tests and the window temperature of one dropped to a reasonable level ($95^{o}C$ - $100^{o}C$) during subsequent tests.

A new category of window failure was added to the repertory with the discovery of invisible leaks on several windows removed from tubes returned for reprocessing for reasons not recognized as window failure. One of the three windows with invisible leaks is believed to be part of a group of insufficiently coated windows produced late in 1964 before the crystal technique of coating control had been instituted. Several other windows coated at that time have shown up with visible punctures when removed from tubes. The other two leakers were coated just last quarter, however; and neither coating nor ring test data provides a significant clue to these failures. There is at present no apparent pattern for this new type of failure; windows of all rejected tubes are being examined for additional examples.

2. Resonant Ring Tests

a. Klystron Window Pre-Test

Routine ring pre-tests of all SLAC klystron windows continued through the quarter. Forty-nine windows were tested, six of which were rejected for tube service because of high operating temperature, visible symptoms of multipactor, and/or coating thickness in excess of our present upper limit of 150 Å. Most of the rejected windows have been held for comparison testing in the double-window test structure (see below).

It is worth noting that the two klystron windows which ran at alarmingly high temperatures during initial tube test, as mentioned in the preceding section, had operated at temperatures slightly above normal (10^o - 15^o) during initial ring tests. These two windows had been released for tube service only after a second ring test in which their temperature fell within the normal range. As a consequence of this correlation, the ring test criteria for window rejection have been tightened.

b. Double-Window Test Geometry

Work was begun during the quarter on a new window testing technique which permits a much closer approach to duplicating actual tube conditions during ring operation. The double-window test structure, consisting of two klystron windows connected by a short section of waveguide evacuated by a small ion pump, permits us to ring-test windows which have been through the tube bake process without having to expose both sides of the windows to atmosphere. In this way, it is possible to analyze the effect on the window coating of high temperature vacuum bake, the illusory phenomenon which was responsible for so many tube window failures last year. This test technique should provide realistic comparative evaluations of window coatings of various materials, varying thicknesses, or various methods of application.

The first double-window assembly was built, assembled, and tested during this quarter. The two windows used had nearly identical coatings, marginally greater than our 150 Å limit of coating thickness, but otherwise typical of the SLAC window coating. In the test which followed vacuum bake of the assembly, both windows operated at temperatures significantly higher than during the test which preceded bake, just above the normal range of tube window operating temperature. In a third test, following admission of air to the inter-window section, operating temperatures dropped to nearly the pre-bake levels. Results of this initial test provide encouraging indications that the double-window technique will be an effective experimental tool.

c. Window Coating Tests

Work is continuing on alternative window coating materials and techniques. Two samples of tungsten carbide coating were tested in the ring during the quarter. Both of these windows performed well during initial tests, behaving quite similarly to windows with the standard SLAC coating. One window was also exposed to two vacuum bake cycles in order to establish the relative temperature stability of this coating material. Ring test following the first bake showed little or no deterioration of the coating. However, following exposure to the second bake, surface resistance dropped and window temperature rose significantly in the test which followed. These results indicate that tungsten carbide is effective as a coating material, but is not immune to the deterioration during vacuum bake which is the main liability of our present coating. Future tests in the double-window test assembly should provide quantitative comparison of these and other coating materials. Further work on striped coating as an alternative technique is also scheduled for test in the double-window structure.

d. Other Ring Tests

Earlier observations indicating a possible correlation between decreased window temperature and fringing fields from permanent magnet focusing appear on further consideration to be spurious. Additional window temperature data during tube tests shows no clear association with the method of magnetic focusing. Ring tests performed early in the quarter also showed no significant effect of magnetic field on window temperature.

A test program on RCA windows and coating was begun late in the quarter. Possible variations in the window material, the coating, and/or the processing cycles are being investigated. No conclusions can be drawn from the partial tests performed to date.

3. Window Life Test

Window life test operation continued for an additional 1280 hours during the quarter, bringing the overall operating total to approximately 9000 hours. However, the output power of the klystron driver continued to decline (from 17 - 19 MW to 14 - 16 MW) and the windows are not really under significant strain at this point. On the basis of observations made before klystron power began to decrease, at least one failure and possibly more can be expected if the present klystron is replaced with a tube capable of 24 MW or more.

4. Other Window Work

Window coating activity was largely devoted to processing SLAC klystron windows; 49 windows were coated this quarter. Sputtered titanium coatings were also provided for nine RCA klystron windows and four windows for Stanford Mark III klystrons. In addition to the coating analysis provided by the double-window test described above, one resistance-versus-temperature measurement was made on a window with 100 Å and 300 Å coatings on opposite sides. The measurement was made with the window in the double vacuum system during a tube bake. Resistance data was poor because of leakage between terminals of the feedthrough to the vacuum chamber, but the test did show qualitatively the superior temperature stability of the thinner coating. Further temperature-versus-resistance tests should not be necessary now that the double-window test structure is available.

The problem of window removal from klystrons being reprocessed now seems to be under control, permitting installation of newly coated windows on rework tubes with a minimum of inconvenience. Copper gaskets with a light layer of oxide are being used to prevent formation of diffusion bonds between the gasket and the steel surfaces of the all-metal seal. An effective oxide film for this purpose compromises between the minimum thickness of oxide required to prevent diffusion and the maximum amount tolerable in a leak-tight seal.

IX. ACCELERATOR OPERATIONS

A. SUMMARY

Formal sector test (see SLAC-59, page 61, for definition*) was completed in Sectors 25 through 30, 3, 4, and 7 through 12. Sector test began in the final block of six sectors, Sectors 19 through 24, and is scheduled to be completed by April 20, 1966. Use of the Central Control Room for operation has been continually increasing.

B. OPERATION – SECTORS 1 AND 2

Testing continued in Sectors 1 and 2 while waiting for completion of Sectors 19 through 24. It has been difficult to conduct a formal sector test in this area because of continual wiring changes going on (to bring S-1 and S-2 wiring into line with the S-3 to 30 wiring package), scarcity of klystrons, and work going on in the injector area. By March 18, most of the important parts of the testing program had been completed. Flattening of the pulse forming networks has to await availability of klystrons.

C. OPERATION – SECTORS 3, 4, AND 7 THROUGH 12

Testing of the eight sectors, 3, 4, and 7 through 12, began on February 1. Work on these sectors was complicated by the great amount of construction work necessary on the positron source in Sector 11. In general, testing on Sectors 3, 4, 7, and 8 was done during the day shift; Sectors 9 through 12 were run at night.

This method of operation required special connections for and very careful control of the personnel protection system.

Testing of these sectors was completed by March 3, although it was not possible to do any work on Stations 1 through 4 of Sector 11 because of positron source construction work in that area.

D. OPERATION – SECTORS 13 THROUGH 18

Testing of Sectors 13 through 18 was completed in early December. During the latter half of March, these sectors were again turned on to determine the

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*Two-Mile Accelerator Project, Quarterly Status Report, 1 October to 31 December 1965," SLAC Report No. 59, Stanford Linear Accelerator Center, Stanford, California (March 1966).

effect of a three-month layoff on operation. It was encouraging to find that the sectors could be brought up to a reasonably high power level in a short period of time with relatively few equipment problems.

E. OPERATION – SECTORS 19 THROUGH 24

Sectors 19 through 24 were turned over to the Accelerator Operations Group (AOG) on March 21. Testing proceeded normally to the end of the quarter, with completion scheduled for the third week in April.

F. CENTRAL CONTROL ROOM

Since the first of February, the Central Control Room has been manned by an operator. This has simplified sector testing, served as operator training (all members of the AOG will have had at least a week in the Central Control Room by the end of April), and has allowed evaluation of the concept of Central Control Room layout and design during the practice sessions. All facets of the personnel protection system have been controlled from the Central Control Room since the first of February.

X. BEAM SWITCHYARD

A six-month progress report of Beam Switchyard work will appear in the next Quarterly Status Report.

XI. RESEARCH AREA OPERATIONS

A six-month progress report of Research Area Operations work will appear in the next Quarterly Status Report.

XII. PRE-OPERATIONS RESEARCH AND DEVELOPMENT

A. EXPERIMENTAL GROUP A

1. 8- and 20-GeV Spectrometers

During this period the fabrication of all the major pieces of structure was continued, with an intended completion day of about May 1, when the final installation will begin in End Station A. Smaller pieces of the structure, such as bulkheads, drive and magnet supports, detector supports, and so on, continued in design.

The design of vacuum chambers was completed and fabrication started.

The quadrupole magnet cores were received, and the bending magnet core fabrication proceeded satisfactorily. All of the coils, however, progressed so slowly that it became apparent that these will be the pacing items on the spectrometer assembly.

All of the water-cooled cables were ordered, and design of the cooling-water distribution system is almost complete. Some of the prefabricated piping elements were built.

Construction of the power supplies continued somewhat slower than scheduled owing to the difficult procurement of some items. These also are a lagging item, since some of them are required early enough to be used for magnet measurements.

2. 1.6-GeV Spectrometer

Contracts were let for the fabrication of the structure and for the magnet. The copper was ordered separately and was ready for delivery at the end of the period.

3. Instrumentation and Control

Construction of the primary beam instrumentation and status display panel is 50% complete; with the delivery of racks during May, installation will commence in the Counting House. Construction of the magnet current control system has been started and should be completed by July. Wiring lists are being generated using the 9300 computer. Design of experiment-to-computer interface electronics is completed. Construction has begun and the electronics is approximately 25% complete; initial testing is underway.

4. Shielding

Design work on the shielding was finished, and a bid package was being prepared at the end of the period.

5. Programming for the On-Line SDS-9300 Computer

An executive program system, SPECTRE, is being written for use with on-line data logging, analysis, and display of data gathered from the various experimental detectors associated with the spectrometers. The basic programming properties of SPECTRE are:

a. Data logging (reading the hodoscope counter bits, pulse-height analyzers, scalers, etc., into memory and then onto tape) is done within high priority interrupt programs. These programs are written in METASYMBOL, and take less than 2.8 msec for execution per event.

b. Analysis subprograms may be written in FORTRAN IV or METASYMBOL, and events will be analyzed on a sampling basis if the data enters faster than the analysis computation speed.

c. Analysis subprograms can be loaded or deleted concurrent with data logging and without disturbing other existing analysis programs in memory.

d. Results of any of the various analysis programs can be displayed on an oscilloscope, x-y plotter, or line printer concurrent with data logging.

Debugging is currently in process on an executive program which will load and connect a specified set or string of programs to a specified priority interrupt level. The specifications come from either the typewriter or card reader. A resident loader program has been written which is executed whenever the executive program recognizes that a new program is to be loaded into memory. A METASYMBOL dump program has been written which writes a block of events stored in memory onto magnetic tape. The program requires no FORTRAN I/O and uses a data channel reserved only for this purpose, so that data recording never waits on other programs. Different possible methods for a centralized display program executive are being studied at present. Some analysis programs for decoding hodoscope bit patterns have been written.

B. EXPERIMENTAL GROUP B

From February 12 to 17 of this quarter, we made an exposure in the Brookhaven National Laboratory 80-inch bubble chamber. We extracted a beam of negative pions at 16 GeV/c from a beryllium target placed in the external proton beam of the AGS; using magnets in the rf-separated beam, the pions were brought to the 80-inch chamber, and 60,000 pictures were obtained.

Analysis of these pictures is underway in collaboration with members of Experimental Groups D and E. We are presently scanning and measuring the four-prong plus V-zero topology. The computer programs used in the analysis are TVGP and SQUAW. Based on a full scan of the first few rolls of film, we find the following topological cross sections:

2-prong	5.2 mb
4-prong	9.4 ± 1.0 mb
6-prong	5.2 ± 0.7 mb
8-prong	1.3 ± 0.3 mb
10-prong	0.3 ± 0.2 mb
2-prong with V-zero	0.6 ± 0.2 mb
4-prong with V-zero	1.1 ± 0.3 mb

A proposal was submitted to BNL for a π^+ exposure in the 80-inch chamber at 16 GeV/c. Such an exposure requires use of the rf-separated beam. Initial studies of the separation problem indicated the feasibility of this exposure. Studies in detail are now underway. This exposure would especially complement the π^- data because many asymptotic relations should be valid in this energy region.

Work continues on the K^-D exposure. Measured events, after analysis by TVGP, SQUAW and ARROW, are being reviewed on the scanning table by physicists for final event selection.

A collaboration with the Lawrence Radiation Laboratory was begun this quarter using π^-p pictures from the 72-inch chamber at ten incident energies between 0.9 and 1.2 GeV. To date, 45,000 two-prong events have been found in the scan, and 25,000 of these have been measured on the spiral reader in Berkeley. The purpose of the experiment is to study inelastic processes in the neighborhood of the 1688-MeV N^* resonance. Two states are known to resonate in this energy region (F-5/2 and D-5/2) and suggestions of a third have been reported (S-1/2).

Work continues on equipment for the annihilation photon beam. Sweeping magnets for this beam are under fabrication, as are various pieces of counting gear, traversing tables (for counters), and the Lithium Hydride beam hardener. Design of the beam detector complex is underway. The lead "Sandwich Counter" has been completed, and we plan to test its resolution properties at the Mark III accelerator this summer.

Studies are now in progress (using events from the 16-GeV/c π^- exposure) to simulate measurements from the spiral reader for long, high-energy tracks. The purpose of this study is to optimize the radius of the spiral for use with high-energy pictures.

Considerable work is now being done to make a smooth interface between the raw measurements of bubble chamber pictures and the analysis computer programs. This "pre-analysis" subjects the raw measurements to many tests before allowing their admission into SQUAW, the kinematical fitting program. One particularly useful test is the matching of tracks in all three views for stereo consistency.

C. EXPERIMENTAL GROUP C

1. Storage Ring Work

a. Vacuum

The new cryopanel was placed in operation and tested with a simulated heat load from a longitudinal filament. Tests were made with LN_2 (Liquid Nitrogen) and refrigerated helium. A new LN_2 system was installed.

During this and previous quarters, a two-dewar, pressurized system was used to provide LN_2 for the cryopanel thermal radiation shield. A foam-insulated, 35-liter dewar was constructed, and LN_2 was piped from the bottom of the dewar to the cryopanel. The LN_2 was forced through the cryopanel due to the pressure built up by the heat leak into the dewar and was discharged to a standard 50-liter dewar. When the level in the 35-liter dewar dropped a predetermined amount, a solenoid valve was actuated, and the 50-liter dewar was pressurized with gaseous N_2 to drive the LN_2 back into the 35-liter dewar, which was vented to atmosphere. The gross heat leak was determined by measuring the evaporation of LN_2 from the 35-liter dewar. This system was satisfactory for automatically supplying LN_2 to the cryopanel for 6- and 8-hour test runs with and without helium refrigeration and for making a gross estimate of the heat leak to the LN_2 shield. It was, however, found to be unsatisfactory for future tests for the following reasons:

(1) Since the LN_2 in the dewars was at saturation pressure and temperature, any heat leak evaporated LN_2, and gas was permanently trapped in the upper tube of the LN_2 shield.

(2) The pressure variations during reversals of LN_2 flow caused saturation-temperature variations of sufficient magnitude to cause the vacuum chamber pressure to fluctuate from 1.3×10^{-9} torr to 4.9×10^{-9} torr, and steady-state runs were impossible.

(3) The external heat leaks to the system were so large that it was not possible to accurately measure the heat leak to the cryopanel proper.

Therefore, it was decided to install a pressurized recirculating system with a cryogenic LN_2 pump. This system has been installed, and preliminary operating tests are being made.

Difficulty in maintaining stable cryostat operation early in the quarter was traced to a faulty diffusion pump on the helium transfer line vacuum jacket. The vacuum jacket pressure was found to cycle between 3×10^{-5} torr and 3×10^{-6} torr when the helium temperature approached $7^{o}K$ to $9^{o}K$. Correcting the diffusion pump operation established a jacket base pressure of 1×10^{-6} torr to 3×10^{-6} torr before refrigeration and permitted stable operation of the cryostat.

A computer program was written to facilitate calculation of the relatively large number of data points taken during heat-transfer tests. The results from 32 data points now indicate that the transfer line heat leak is 18.8 watts $\pm$ 3.8 watts.

A test was made to determine the effectiveness of LN_2 cooling of the shield. The heat leak to the helium cryofin was measured to be 4 watts greater with room-temperature gaseous N_2 in the shield cooling tubes than with LN_2 in the tubes. This result was confirmed by calculation.

The heat load to the helium cryofin from a longitudinal filament dissipating 330 watts was measured as 2.1 watts or about 0.6%, which is less than the amount indicated by the photo-analog tests discussed in the report of the previous quarter.

Finally, a test was made to determine the effect of carbon monoxide "frost" on the helium fin. Coating the helium fin with CO, as described elsewhere, increased the heat load to the fin by 0.6 watts-i.e., a 28% increase in the incident heat load or 0.2% of the heat load from the longitudinal filament.

It should be noted that all measured values of the heat leak to the helium cryofin are less than the 3.5-watt data scatter for the transfer line and therefore should be treated only as indications of the relative magnitude of the various heat leaks.

b. Princeton-Stanford 500-MeV Storage Ring

The 50-liter LH_2 dewar and the coaxial vacuum-jacketed transfer line for the interaction region cryogenic pump were bench tested and installed in place. The dewar and transfer line were pressure tested, leak checked, and filled with LN_2. A dummy cryofinger was installed, and a heat load of 7 watts applied. The gross heat leak for the system was crudely measured as 20 watts maximum. The carbon-resistor LH_2 level detector was checked out with LN_2. A differential pressure transmitter with a 3-inch H_2O range for level indication with a "bubbler" tube was tested with LN_2.

c. Storage Ring RF Design

The detailed cavity design continues. A one-tenth scale model of the prototype cavity has been fabricated. Measurements of this cavity at 324 Mc/sec will predict the performance of the prototype cavity at 32.4 Mc/sec. The ceramic window assembly will be fabricated by subcontract using a seal design developed at SLAC. The quarter-wave test cavity has been fabricated and will be brought into operation when the high power rf source is available. The 40-kW source of rf power will now be two Collin's type 205G-1 transmitters which have been obtained from Government surplus. The 205G-1 is a linear amplifier capable of a 20-kW continuous wave over a 20- to 60-Mc/sec frequency range. It requires 0.5 watt input. The power amplifier stage uses two 6166 tetrode tubes in parallel. All stages are designed for linear operation with low distortion. Two 205G-1 transmitters with the power combined in a duplexer (also supplied from surplus) will provide sufficient power (40 kW) to perform all prototype cavity tests. Also, because of its linearity, this unit will be useful both for prototype control circuitry testing and driver amplifier developments for the storage ring. The transmitter was delivered in the last month of the quarter and will be in operation after the first month of the ensuing quarter. Extremely stable exciter units were delivered with the equipment and are in operation. They allow variable-duty-cycle operation of the transmitters.

Theoretical study is in progress on the effect of rf frequency on the bunch lengths in the storage ring.

2. Streamer Spark Chamber Development

a. Pulsers

It has been established that pulsers (particularly those used for driving low-impedance chambers) should be made of two parts: A high-voltage source capable of delivering the required voltage and energy, and a separate pulse-shaping device.

A pulser using a Marx generator and a coaxial capacity with series-shunt gaps was completed and gave 600 kV on 50 ohms. It will be used to drive a $125 \times 100 \times 60$-cm chamber, which is near completion. We are also experimenting with other types of pulsers.

b. Chambers

An experimental chamber ($45 \times 45 \times 30$ cm) was constructed using 7-mil mylar. The construction was light and simple, and the chambers worked very well. This construction is very suitable for filling large-volume detectors with chambers without adding too much material.

c. Chamber Properties

The investigation of the ionization-measurement capability of the streamer chambers was extended in two different ways:

(1) By reducing the pressure in the chamber down to approximately 1/30 of 1 atm, we found two main regions, a flat region from 1 atm down to 1/4 atm where the number of streamers remains about 2 - 3/cm, and a linear region from 1/4 atm down to 1/30 atm. If one extrapolates the latter region to 1 atm, one obtains approximately 12 streamers/cm. However, this linear region is not very useful because of the poor light output.

(2) By delaying the high-voltage pulse, thus allowing the ionization electrons to diffuse, it is hoped that we can prevent saturation or "robbing", which is the main source of error in ionization measurements.

It was found that the number of streamers per cm for minimum ionizing particles (cosmic rays) increased from 2/cm at 1/4-μsec delay to 12/cm at 40-μsec delay and stayed approximately constant from 40- to 200μsec delay. Delaying the high-voltage pulse between 50 to 100 μsec appears to be a very promising method for improving ionization measurements. It is much simpler than pressure reduction, and the loss in light output is not serious.

3. Photoproduction Experiments

a. Counter System

Design and construction of detection equipment for photoproduction experiments on the 20-BeV/c spectrometer are continuing. The pressure vessel for a 2.0-meter differential Cerenkov counter is under construction, and a focusing spherical mirror is presently in the test stage. The freon gas system is in the design stage.

A sandwiched lead and scintillator shower counter is being constructed. Design of a range counter for detecting muons has been completed. The momentum- and angle-defining scintillation counter hodoscopes are under construction at the Massachusetts Institute of Technology. In addition, two other hodoscope arrays required for better definition of particle trajectories, the x and ϕ hodoscopes, are being designed by Experimental Group C.

b. Data Analysis Programs

Some analysis programs have been written for the SDS-9300 computer to be used on-line with the spectrometers. These programs decode the bit patterns derived from the various scintillation counter hodoscopes into bin numbers. Each of the momentum- and angle-defining counters on the 8- and 20-BeV/c spectrometers has two (or three) layers of parallel counters staggered one behind the other so that a single particle normally strikes two (or three) counters. The counters are connected so that tracks normally appear as two (or three) adjacent bits in a memory word. Hence, the program searches for adjacent bits and when found, determines their location. Also considered are crack losses, isolated bits due to noise pick-up, tracks which straddle two bins, and edge effects. Typical execution time is approximately 150 μsec per hodoscope array, and each hodoscope program occupies approximately 150 words of memory.

D. EXPERIMENTAL GROUP D

1. Large-Volume Magnet

This magnet is presently under construction. Machining of the iron cores is apparently on schedule. The fabrication of the coils is behind schedule, and it appears that there is no possibility of making the June delivery date.

2. 5.8-Megawatt Power Supply

The delivery of this power supply is expected about the end of June.

3. Modulator

A self-shielded Blumlein transformer for delivering 10-nsec pulses greater than 800 kV is being tested. It has operated successfully to a 500-kV level with an improvised drive from a Marx generator, and little difficulty is anticipated in getting above the 600-kV level when properly coupled.

4. Mark III Program

a. N* Photoproduction

A paper entitled "Photoproduction of the N* (1238) by polarized bremsstrahlung" will be presented at the 1966 Congress of the Canadian Association of Physicists. An article is under preparation.

b. Triplet Production

Photographs have been taken of pair and triplet production in the neon of a small streamer chamber. These will be analyzed to determine the ratio of these interaction cross sections.

E. EXPERIMENTAL GROUP E

The following experiments are being analyzed:

1. Proton-proton interactions at 6 GeV/c, in the 72-inch Lawrence Radiation Laboratory hydrogen bubble chamber (J. Brown, F. Martin, M. Perl, T. H. Tan).
2. Neutron-proton elastic scattering from 1 to 6 GeV/c, in spark chambers (M. Kreisler, F. Martin, M. Perl).
3. K^--deuterium interactions, in the 72-inch Lawrence Radiation Laboratory bubble chamber (F. Martin).
4. Proton-antiproton annihilation to $e^+ + e^-$ and other modes, in spark chambers at the Brookhaven National Laboratory AGS (T. Zipf).

5. 16-GeV/c $\pi^- + p$ interactions in the 80-inch Brookhaven National Laboratory hydrogen bubble chamber (T. H. Tan, F. Martin, M. Perl).

Design and construction continued on the following:

1. A muon + proton elastic and inelastic experiment at SLAC (J. Brown, J. Cox, M. Perl, W. T. Toner, T. Zipf).

2. An experiment to search for new particles at SLAC (A. Barna, J. Cox, F. Martin, M. Perl, W. T. Toner, T. Zipf).

3. A large spark-chamber magnet (L. Cooper, T. Zipf).

4. A neutron-proton elastic scattering experiment at 8- to 25-GeV/c to be carried out at the AGS of the Brookhaven National Laboratory. Spark chambers will be used. This is a continuation of the 1- to 6-GeV/c experiment listed above (M. Kreisler, J. Cox, W. Toner, T. Zipf, M. Perl).

A dual mercury-relay module was built for use in experiments at SLAC.

F. EXPERIMENTAL GROUP F

Bids have been accepted for the coils and iron of the 1.6-GeV/c spectrometer. The copper has been delivered to the coil manufacturer, and construction should now be underway. The iron is now in shipment. Design of the shielding for the spectrometer is presently in progress. A laboratory has been set up, and test work on phototubes and counters has begun. Design of the counter system for the 1.6-GeV/c spectrometer is currently in progress. Computer studies of the optics of a focusing Cerenkov counter are now being completed.

G. 40-INCH HYDROGEN BUBBLE CHAMBER

Emphasis in the bubble chamber activities since the last report has been on procurement and fabrication activities. All the major components are in process, and the progress on each is discussed below.

1. Chamber

All major forgings and castings have been ordered. Vendor delivery of the chamber body, bellows ring, and back plate is scheduled in April. Machining of the piston and optics window flange is underway.

2. Vacuum System

Fabrication of the vacuum tank is proceeding in the SLAC shops. Preliminary design of the vacuum pumping system is complete, and procurement of materials has started.

3. Beryllium Beam Window

There has been little activity on the beryllium window since the procurement of the 1/8-inch window shells.

4. Expansion System

A prototype expansion system has been built and is running. The hydraulic expansion valve required by this system is not available on a commercial basis. However, modification and testing of commercial valves have provided sufficient information to enable us to design and fabricate a hybrid valve which should prove satisfactory for two-cycle-per-second operation.

5. Instrumentation and Refrigeration

Both the 15,000-gallon bulk-storage vessel and the 500-gallon transportable dewars for liquid hydrogen have been ordered, with delivery expected during August and September, respectively. Chamber piping and control panel layout are nearly complete, and the majority of components are on order. Operation of the chamber has been simulated.

The electrical and electronic power and control requirements of the system have been established, and some components have been ordered. All the pneumatic components have been ordered.

6. Magnet System

Fabrication of the magnet coils is behind schedule. Fabrication of the 240-ton magnet core is proceeding satisfactorily, and delivery is expected on schedule.

Components for the separation and support system are on order, and fabrication of the magnet platforms has started. The 3.4-megawatt magnet power supply is on order and is to be installed on a surplus trailer. Design of magnetic measurement equipment has started.

7. Camera and Optics

Receipt of the first 43-inch-diameter glass window blank is expected during early April. A subcontract for polishing the blanks has been let. Camera lenses have been received. Coated vacuum-tank ports are on order. Development of the camera prototype and associated electronics is proceeding satisfactorily. The format of the data board has been tentatively fixed, and development of a prototype is expected to start during the next quarter.

A test fixture employing liquid hydrogen to evaluate Scotchlite retrodirector is being fabricated.

8. Enclosure

The 40-foot × 50-foot enclosure and 7-1/2 ton crane are on order, and installation is expected during the next quarter. Site utilities and power distribution drawings for the enclosure are being prepared.

During February, H. P. Hernandez and R. A. Byrnes of the Lawrence Radiation Laboratory, together with the SLAC Bubble Chamber Group and the SLAC Hazardous Experimental Equipment Committee, reviewed the basic mechanical criteria and test conditions of the 40-inch chamber from a safety standpoint.

H. PHYSICAL ELECTRONICS

1. Relativistic-Rise Detector Study

During this quarter the following papers were submitted for publication:

1. "CsI as a High-Gain Secondary Emission Material," J. Edgecumbe and E. L. Garwin, to be published in J. Appl. Phys., June 1966 (SLAC-PUB-166).

2. "A Simple Bakeable Thin Foil Vacuum Window," J. Edgecumbe, submitted to Rev. Sci. Instr. (SLAC-PUB-185).

During this quarter experiments designed to probe more deeply the physics of secondary emission from low-density alkali halides were initiated. Measurements being performed on both low-density KC1 and CsI dynodes include the dc gain measurements reported in previous reports as well as pulsed-beam gain measurements, secondary-electron energy distribution measurements, charging effects, and effects of dynode-collector spacing on gain.

All measurements have been conducted in an ion-pumped, bakeable vacuum system at pressures less than 10^{-8} torr, using an electron gun to supply the primary beam. Evaporations of the alkali-halide dynodes were carried out in an ion-pumped, sorption-roughed, bell-jar system, and the dynodes were transferred to the measurement system in an atomosphere of dry nitrogen. Gain (δ) measurements under dc bombardment obtained with this system are similar to results reported earlier in the diffusion-pumped vacuum system used for preparation, but differ from earlier results in which a high-pressure mercury lamp was used to generate the primary current via photo-emission from a gold photocathode. The major difference in the data obtained by these two measurement techniques is that results obtained with the electron gun exhibit breakdown at lower collector voltages than when the mercury lamp is used (100-volt vs 300-volt breakdown potentials). This is consistent with ultraviolet-light-induced conductivity limiting of the internal field in measurements employing the mercury lamp.

Measurements of δ using a pulsed electron beam of 50-μsec to 100-msec duration have revealed some very interesting and important differences between low-density CsI and KCl. This difference appears to be due to leakage current through the film, resulting in discharging of the exit surface. Whereas low-density KCl is observed to remain charged for long periods of time (resistivity $\approx 10^{17}$ ohms-cm), as reported elsewhere,* low-density CsI discharges quite rapidly (time $\lesssim 20$ μsec). The interesting aspect of these results, from a practical point of view, is that low-density KCl breaks down at low collector potentials ($V_c \approx 100$ volts) even under pulsed beam operation, and must be charged to exhibit high gain. Low-density CsI, on the other hand, does not break down at low values of collector voltage and does not need to be charged to obtain high gain. Results showing δ vs V_c for a low-density CsI sample using a pulsed beam are plotted in Fig. 15. Unfortunately, an arc occurred at $V_c = 2500$ volts, and the dynode was destroyed. From this data it appears that it will be possible to build a multiplier structure by cascading dynodes without requiring grids between the films to avoid breakdown. This is an important consideration for minimizing the rise time of such a multiplier since the low field over the region between the exit surface and the grid adds greatly to the transit time spread. (Further improvements might be obtained if an impurity were added to the alkali halide to increase the conductivity.)

Secondary-electron energy distributions have been determined using the circuit shown schematically in Fig. 16a. Measurements are made as a function of V_d, the potential between the dynode and the first grid, and by sweeping G_2 linearly from 10 to 20 volts positive with respect to V_d down to ground potential (or slightly negative). The duration of this retarding potential ramp is 1 msec, which appears to be rapid enough so that a negligible amount of charge is returned to the dynode to affect the exit-surface potential. The high speed of the ramp (relative to standard techniques, where retarded secondaries have no effect on the emission of the target) results in a capacitive current of the same order of magnitude as the currents being measured. Thus C_b and R_b in Fig. 16a are used to balance out this capacitive current via a difference circuit ahead of the differentiator. Typical data obtained in this manner are presented in Fig. 16b. The upper two traces in this photo are the output of the difference amplifier

*G. W. Goetze, A. H. Boerio, and M. Green, J. Appl. Phys. 35, 482 (1964).

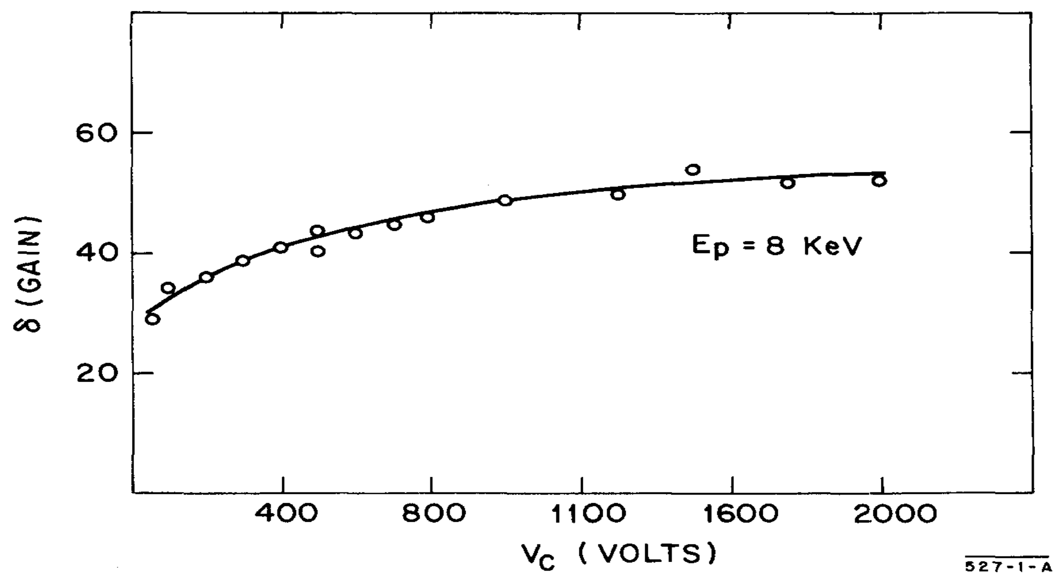
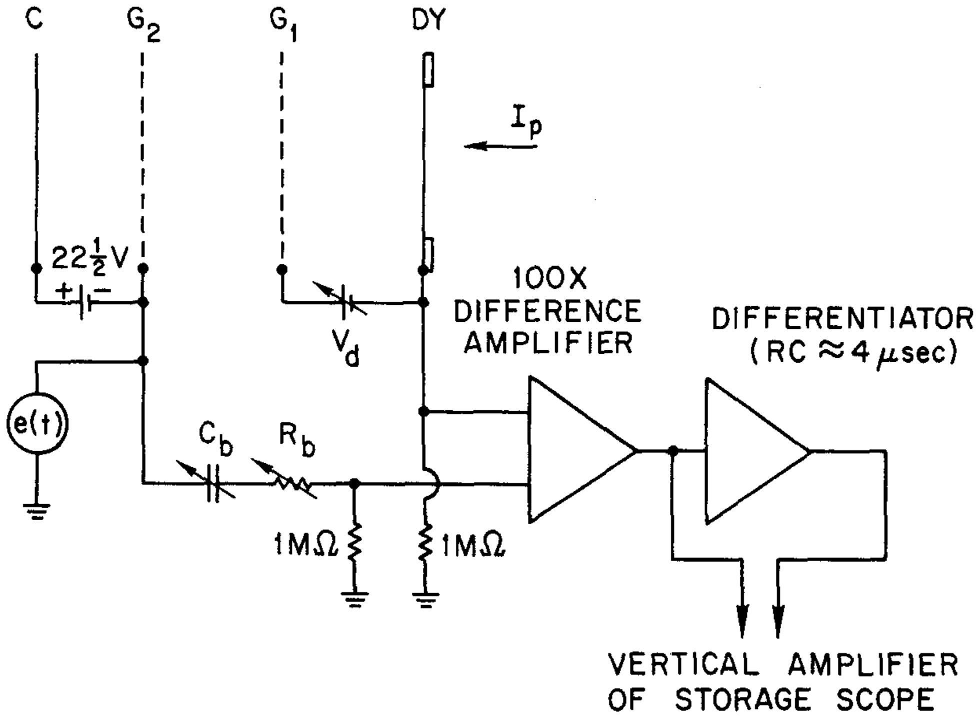
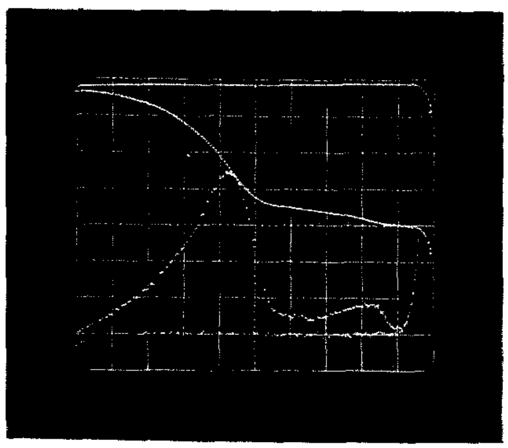


FIG. 15 - GAIN vs COLLECTOR VOLTAGE FOR A LOW-DENSITY CsI DYNODE USING A PULSED ELECTRON BEAM OF 100 μsec DURATION



(a) SCHEMATIC DIAGRAM OF THE CIRCUIT USED TO DETERMINE SECONDARY ELECTRON ENERGY DISTRIBUTIONS.



(b) TYPICAL ENERGY DISTRIBUTION OBTAINED FROM LOW-DENSITY KCl UNDER dc BOMBARDMENT. PHOTO TAKEN AT V_d = +60 VOLTS; HORIZONTAL CORRESPONDS TO V_{G_2} BEING DECREASED FROM +70 VOLTS TO -17 VOLTS.

527-3-A

FIG. 16

(beam on - beam off), and the lower two traces are the output of the differentiator (beam on - beam off). The horizontal is time, and corresponds to 8.7 volts/cm starting at 10 volts above V_d . The small peak at 5 eV is believed to result mainly from secondary emission from the grids.

The most probable secondary-electron energy has been found to be dependent on the state of charge of the exit surface. Typical data for low-density CsI is shown in Fig. 17 for dc bombardment (fully charged exit surface) and pulsed beam (where the beam is turned on $\approx 100\ \mu$sec before the start of the ramp, so that the exit surface has acquired negligible charge). Similar data has been found for low-density KCl. From this figure it appears that the measured energies are characteristic of acceleration of low-velocity secondaries between an uncharged exit surface and G_1 , in the pulsed beam case; and acceleration of low-velocity secondaries between an exit surface charged to a potential V_d (for $V_d \lesssim 40$ volts) and G_1, in the dc case. If this is true, then the enhanced emission from these low-density dynodes apparently results from the penetration of the external electric field into the pores of the emitter.

Further study of the differences in pulsed gain from CsI and KCl are planned for the coming quarter. Also, a number of new projects have been started which include measurements of the statistics of the secondary-emission process; a detailed study of the physics of high-gain secondary emission, including measurement of the exit-surface potential directly; and construction of a four- or five-stage electron multiplier structure.

2. Development of a Gridless Multiplier Structure (DBM)

As of March 1, 1966, the Physical Electronics project began work for the Division of Biology and Medicine of the AEC on development of a fast-transmission electron multiplier without the need for grids to avoid breakdown. Initially it was believed that this could most easily be accomplished by deposition of a very thin conducting film (overlayer) on the surface of the alkali halide. This would minimize the region of space over which the electric field is low, prevent high-field buildup with its attendant breakdown, and decrease the overall transit-time spread of the tube. During this quarter a number of attempts were made to deposit Al on bulk-density CsI dynodes 2000 Å thick. In all cases the overlayer was shorted to the conducting backing, but the short could occasionally be "burned out" by passing ≈ 100 mA through it. One dynode was successfully

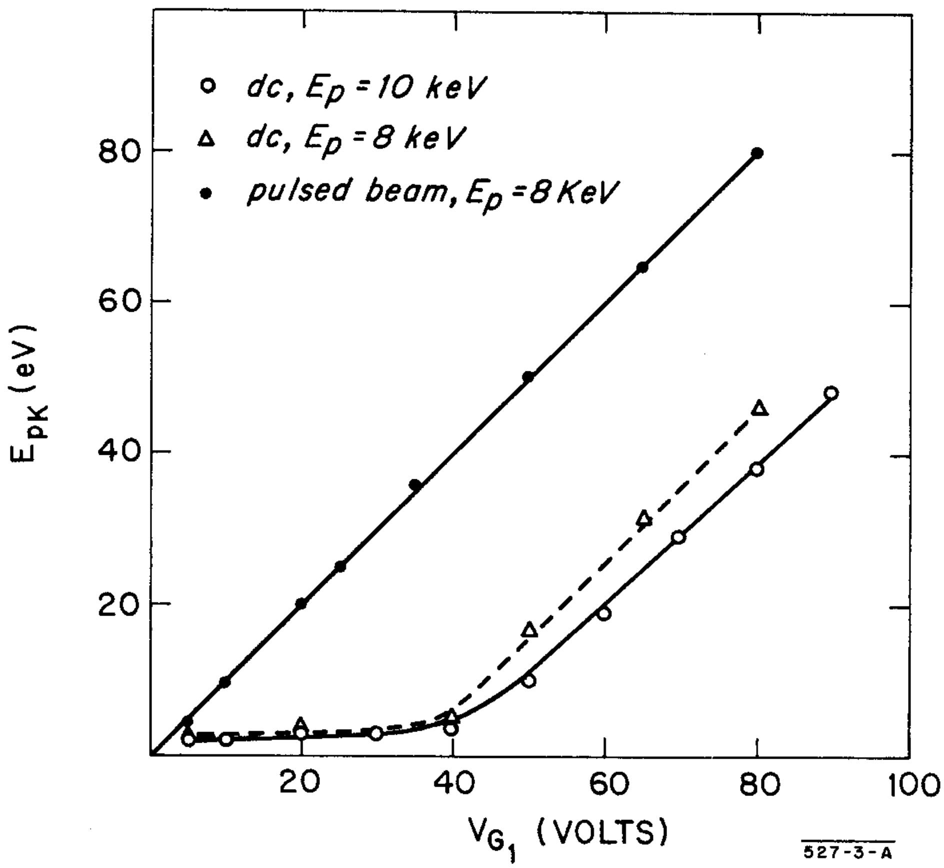


FIG. 17 - MOST PROBABLE SECONDARY ELECTRON ENERGY, E_{pK}, AS A FUNCTION OF "Collector Potential" FOR A LOW-DENSITY CsI DYNODE

fabricated, but no enhanced emission was observed and the gain was low (apparently due to the overlayer being too thick). In the coming quarter attempts will be made to put both Al and Au overlayers on low-density KCl and CsI dynodes.

In light of the results presented in Fig. 15 and discussed in Section 1 of this report, it is believed that the planned multiplier structure employing low-density CsI dynodes, discussed above, will be a valuable parallel experiment to the overlayer study.

I. MAGNET RESEARCH

1. Water-Cooled Magnets

a. Positron Source Magnets

A prototype edge-cooled magnet has been immersed in high-purity water and tested periodically. Insulation resistance, corrosion effects, and the influence of water impurities have been tested. The prototype coil has not changed its insulation resistance for the past 2-1/2 months and is usable.

Production double pancakes have been immersed in high-purity water for two weeks and have performed satisfactorily.

b. The SLAC Computer Program NUTCRACKER

The computer program for two-dimensional and axially-symmetric iron magnets has been improved, and several iron magnets, including the 2-meter spark chamber magnet, the 3° bending magnet, and a spectrometer magnet, have been recalculated. In the case of the 3° bending magnet, experimental data were available, and the computer program could be checked for its accuracy. The agreement between calculation and measurement was better than three percent. A report describing the computer program is being prepared.

2. Superconducting Magnet Research

A 40-inch dewar for location of the 12-inch, 70-kG superconducting magnet is in the procurement stage. The winding of the outer coil section with stabilized Nb(25%)Zr will begin soon.

Short sample tests with various heats and sizes of NbTi have now been completed. The current density of various superconductor sizes as a function of external transverse field has been measured. In the range of 10-30 mils, NbTi did not show any size effects. Further experiments to extend this work up to fields of 75 kG are under way. If no size effects exist up to these higher fields, we may be able to obtain superconducting coils at a considerably reduced price.

3. Reports

H. Brechna, E. Burfine, R. Mizrahi and A. Wolff, "Two-Meter Spark Chamber Magnet Model for the Determination of Field Distribution in Space," SLAC Report No. 57, Stanford Linear Accelerator Center, Stanford, California (January 1966).

J. THEORETICAL PHYSICS

1. J. D. Bjorken, "Applications of the Chiral U(6) $\otimes$ U(6) Algebra of Current Densities," submitted to the Physical Review; SLAC-PUB-165.
2. J. D. Bjorken, "An Inequality for Electron and Muon Scattering from Nucleons," submitted to Physical Review Letters; SLAC-PUB-167.
3. W. I. Weisberger, "Recent Work on the Renormalization of the Weak Axial-Vector Coupling Constants," Proceedings of the International Conference on Weak Interactions (1965), p. 409.
4. H. Harari, D. Horn, M. Kugler, H. J. Lipkin, and S. Meshkov, "W-Spin for any Spin," to be published in the Physical Review; SLAC-PUB-164.
5. H. Harari, "Current Commutators and Representation Mixing," submitted to Physical Review Letters; SLAC-PUB-173.
6. Y. S. Tsai and Van Whitis, "Thick Target Bremsstrahlung and Target Considerations for Secondary Particle Production by Electrons," submitted to the Physical Review; SLAC-PUB-184.
7. S. D. Drell and A. C. Hearn, "Peripheral Processes," to be published as Chapter 9 of High Energy Physics (Academic Press, New York); SLAC-PUB-176, ITP-200.
8. S. D. Drell and J. S. Trefil, "Determination of ρ_0-Nucleon Total Cross Sections from Coherent Photoproduction," submitted to Physical Review Letters; SLAC-PUB-170, ITP-202.
9. S. D. Drell and A. C. Hearn, "Exact Sum Rule for Nucleon Magnetic Moments," submitted to Physical Review Letters; SLAC-PUB-187, ITP-208.
10. R. G. Moorhouse, "Photoproduction of N* Resonances in the Quark Model," submitted to Physical Review Letters; SLAC-PUB-180.

The dynamical part of the three-body problem has been explicitly separated from the kinematics and shown to depend on the solution of coupled integral equations in two variables defined on a finite domain. All the singularities and complexity of the functions depend on a single variable, and can be isolated from a part which is determined by real, non-singular functions of the two variables. For strongly interacting spinless particles of arbitrary mass with significant interactions between any pair in L + 1 angular-momentum states, the maximum number of coupled components for a state with total angular momentum J is $3(2J+1)(L+1)^2$; inclusion of spin will require only a modest increase in the number of coupled components. Since the coupling explicitly depends only on kinematics (geometry), it is conjectured that the number of coupled components can be reduced to 3(J+1)(L+1), and this possibility is being explored.

Study of the Gell-Mann chiral U(6) $\otimes$ U(6) current algebra continues.[1] The role of terms in the commutators of local densities proportional to derivatives of the δ-function has been clarified. A sum rule for inelastic electron scattering has been derived, and the divergent part of the electromagnetic mass differences and weak-interaction radiative corrections isolated, calculated, and shown to be non-vanishing [on the basis of U(6) $\otimes$ U(6)]. The contribution of very virtual photons to the hydrogen hyperfine splitting has been estimated to be very small. An inequality for inelastic electron-proton scattering has been derived on the basis of local isospin current commutation relations.[2] Studies of the implications of Adler's sum rule for inelastic neutrino processes for underground neutrino experiments is being continued.

Previously reported work on unsubtracted dispersion relations and the renormalization of the weak axial-vector coupling constants has been published.[3] Work continues on examining the consequences of the U(3) x U(3) commutation rules for vector and axial-vector currents, with specific applications to processes involving pion emission.

The general "W-spin" properties of an arbitrary spin state constructed from any number of basic spin-1/2 objects have been studied.[4] Explicit formulae for expressing the eigenstates of W^2 as linear combinations of ordinary spin states have been obtained and the properties of the transformation matrices studied. The relation between W-spin and ordinary spin in the framework of the SU(2) $\otimes$ SU(2) algebra has been generalized to an arbitrary Lie algebra of the form G ⓧ G, and the case of $SU(6)_W$ and $SU(6)_S$ has been analyzed in detail using the non-chiral U(6) ⓧ U(6).

Recent applications of the current algebras suggested by Gell-Mann indicate that although the assumed commutation relations seem to be correct, the assumption that the obtained sum rules are saturated by very few intermediate states is, at least in some cases, inadequate. In particular, it is clear that the nucleon cannot be properly described as a J6 representation of $SU(6)_W$ and the (6,3) of chiral U(3) ⓧ U(3), and that the decuplet states are not sufficient for saturating the sum rules. The possibility of explaining the experimental data for the axial-vector transitions between baryons by simple representation mixing has been studied,[5] and it was found that a single free-mixing angle is capable of explaining the experimental values of G_A, G^* (nucleon-N* transition), and the f/d ratio for the axial-vector current. The nucleon, in this model, is a mixture of the (6,3) L = 0 and $(\bar{3},3)$ L = 1 representations of chiral U(3) ⓧ U(3).

Bremsstrahlung spectra as a function of target thickness up to several radiation lengths to be used for particle production in high-energy electron machines have been investigated. The shower equations are cast in integral forms which are then solved by iteration. The iterations are performed up to the second-generation photons, and the numerical results show that for most experiments the first-generation photons alone will give sufficiently accurate results. For example, for a target thickness of two radiation lengths and for $k/E_0 = 0.5$, where k is the photon energy and E_0 is the incident electron energy, the ratio of the second- to the first-generation photon intensity is 8%. This ratio decreases rapidly as one increases k/E_0 and decreases the target thickness. A very simple formula which approximates the first-generation photon spectra as a function of target thickness is derived. This approximate formula is shown to be accurate enough for estimating the secondary-beam production by electrons. As byproducts of this investigation, the first- and the second-generation electron and positron spectra were obtained as functions of target thickness. These spectra are useful in estimating the electron and positron background. Some aspects of target consideration for the secondary-beam production are given as an illustration of the usage of the formulae.[6]

The results of photoproduction experiments at CEA and DESY are being analyzed with an eye to predicting the pion, kaon, and antibaryon yields at SLAC.

In an effort to determine a more exact closed analytic expression for the positron-electron bremsstrahlung cross section, investigations are being made of the relative contributions of the angle-dependent and -independent logarithmic terms. The principal diagrams have been integrated exactly, and numerical evaluation is now underway.

Work continues on the attempt to resolve the discrepancy between theory and experiment for the hyperfine splitting (hfs) in hydrogen. As shown by Iddings, a relativistic calculation of this splitting requires the amplitude for forward spin-flip scattering of virtual photons from protons. A new set of invariant amplitudes has been found which cleanly separates the calculation into a part which may be studied in real Compton scattering and a part which is decoupled from Compton scattering. The contribution of the first part to the hfs has been estimated with the aid of the Drell-Hearn sum rule. Various model calculations of the second part involving πN and πN^* intermediate states are under investigation. Recent developments in three-particle theories are being used to determine upper and lower bounds on calculations of hydrogen hyperfine structure in which the proton is treated as a polarizable system.

Studies on the behavior of form factors for $q^2 \to -\infty$ using the Bethe-Salpeter amplitude have been completed. The results are similar to those obtained from the Schroedinger equation. In particular, vector-particle exchange in the ladder approximation leads to fractional exponential fall-off.

An investigation is in progress on the consequences of P.C.A.C. and the equal-time commutation relations between vector and axial-vector currents on electron and photo-meson production amplitudes near threshold. A relation between the vector and axial-vector form factors, and the photo-meson amplitudes, has been obtained, and its possible experimental implications are being studied.

A general review of peripheral processes has been submitted for publication.[7] It has been shown that pion-production experiments from complex nuclei can be analyzed in a systematic way to yield rough values for the ρ_0-nucleon total cross section.[8] An exact sum rule has been constructed for the nucleon magnetic moment in terms of physically measurable cross sections.[9] This sum rule is consistent with present data, but better experiments will be required for an accurate test.

It has been shown generally that it is necessary to consider the unitarity correction to first-order perturbation theory of the S-matrix even when the first order result is small compared to the parameters of the problem. The dangerous cases can be easily understood from this treatment by using the Schroedinger equation, and the corresponding prescription for the correction in the N/D formalism has been developed. The method avoids certain difficulties which have recently been encountered in applications of the Dashen-Frautschi method.

The implications of the quark model for the photoproduction of the higher N* resonances have been worked out.[10] Although the currently available experimental evidence is meager, these results give some interesting suggestions as to the assignment of quantum numbers to these resonances within the model. They also suggest further tests of the model.

K. COMPUTATION GROUP

The Computation Group has been concerned with (1) the development of numerical methods, (2) the development of executive programs for the Beam Switchyard control computer and the magnetic spectrometer on-line analysis computer, (3) graphic data analysis, and (4) general support of various application programs of the Laboratory.

1. Executive Programs for On-Line Analysis and Control

A major effort in the past two quarters has focused on the design and development of the SPECTRE system, a programming system implemented on the SDS 9300 computer for data acquisition and analysis and experimental control for the 1.6-, 8-, and 20-BeV/c spectrometers in End Station A. The SPECTRE system consists of a control language, a resident dynamic loader, a priority interrupt controller, and a cathode-ray-tube display driver, which provide a framework in which user-written programs may be easily imbedded to construct a flexible data-gathering system. Program segments form the smallest manipulatible element in the system. These may be dynamically loaded, strung together for serial execution, and attached to any of the 32 interrupts in the 9300 computer or scheduled for periodic or future execution.

The control language enables the physicist to define and modify the program strings to be executed; control statements for this purpose may be transmitted via the on-line teletype or the card reader. Consequently the entire data-acquisition and-analysis procedure may be defined at experiment set-up time by a series of punched-card statements. During the course of an experiment, as different analyses become necessary, the physicist may modify the program without interrupting data-taking. To simplify the generation of the user-written program segments, both FORTRAN IV and system-oriented macro procedures are available. A library of such programs will be built up and stored for access on a disc.

A first version of the SPECTRE system was completed March 1; more advanced versions are projected for completion on April 15 and upon delivery of a random-access disc from SDS at the end of May. The development of user-analysis programs and engineering check-out programs is in progress.

Studies are also under way on the structure of a system for controlling on-line manual film-measuring machines for use with bubble chamber film. Negotiations for the computer to be used are currently being conducted in conjunction with members of the Conventional Data Analysis group.

A theoretical analysis has been completed on the limiting conditions for real-time programs subject to absolute deadlines. A manuscript for this is in preparation.

A program, LAYOUT, in ALGOL for the Burroughs 5500 has been written for computing coordinates and orientations required for the placement and alignment of components in the Beam Switchyard. The program can do this without modification for any beam transport system.

The control program for the Beam Switchyard computer (SDS 925) is progressing and should be ready next quarter. The machine was moved to the Data Assembly Building at the end of March and is being used to check out the interlock wiring. A completed part of the program is used for this purpose.

2. Application Programs

An analysis of detector effectiveness for the proposed 3-GeV storage ring has been completed. Computer codes using Monte Carlo techniques were developed to predict the efficiency of butterfly and cylindrical type triggering systems.

Beam calculations for the SLAC User's Handbook were completed during the first quarter of 1966. Theoretical predictions of bremsstrahlung intensity vs. energy and production angle were computed for the high energy electron beam. Then the bremsstrahlung spectrum was folded into a variety of production mechanisms for μ's, π's, and K's to determine their energy-angle distributions from thin and thick targets.

Two programs for the analysis of electron-electron scattering data were written, the first by least squares, the second by maximum likelihood.

Magnet design programs for the two-meter spark chamber magnet and storage ring C-magnet and H-magnet have been completed.

3. Analysis of Graphic Data

Preliminary investigations have been made regarding the automatic scanning and measuring of spark chamber film. This includes the feasibility of using OS/360 systems on the Model 50 with an on-line scanning device, and determining what additions have to be made. The Basic Programming Support software for the IBM 360/50 was adapted to our configuration and is now operational. A study of the Operating System/360 has been undertaken in order to facilitate a smooth transition to that system in the next quarter.

Programs have been laid out and are now being written (in cooperation with the Automatic Data Analysis Group) for analysis of the spark chamber film data collected in the joint SLAC-HEPL colliding-electron-beam experiment. These programs accept data digitized by the HUMMINGBIRD film digitizer.

4. Publications

E. Burfine (with H. Brechna, R. Mizrahi, A. Wolff), "2-Meter Spark Chamber Magnet Model for the Determination of Field Distribution in Space," SLAC Report No. 57, Stanford Linear Accelerator Center, Stanford University (1966).

E. Burfine (with L. Anderson, H. Brechna), "A Computer Code for Variable Permeability Magnetostatic Field Problems," SLAC Report No. 56, Stanford Linear Accelerator Center, Stanford, California (1966).

J. C. Butcher, "On the Convergence of Numerical Solutions to Ordinary Differential Equations," Mathematics of Computation 20, 1 (1966).

J. C. Butcher, "A Multistep Generalization of the Fourth Order Runge-Kutta Method," submitted to the Journal of the Association for Computing Machinery; SLAC-PUB-161.

J. C. Butcher, "A Seventh Order Method for the Numerical Solution of Ordinary Differential Equations," submitted to the Journal of the Association for Computing Machinery; SLAC-PUB-171.

L. AUTOMATIC DATA ANALYSIS

Use of the "Hummingbird" off-line film digitizer to develop programs continued in this quarter. A preliminary comparison of automatic vs. hand measurement of approximately 100 events in Group E's n-p spark chamber experiment implies that the Hummingbird measurements are as accurate as the hand measurements. Results of a calibration stability study indicate that rectilinear coordinates with an accuracy of at least 10 microns can be produced by the film digitizer with calibration no more often than every two hours.

Program design has been started for the automatic analysis of film from the colliding-beam spark chamber experiment. In this case, the "Hummingbird" will be connected on-line to an IBM 360/50, and will both feed data to and receive a minimal set of orders from the computer.

The experience gained with the "Hummingbird" device has enabled us to develop and start building a second-generation film digitizer. This digitizer, connected to the 360/50 computer, will be under close control of the programmer. That is, the device may be instructed to scan only those parts of a spark chamber picture containing useful information. These blocks may be scanned in any sequence, with the density, length, and orientation of the scan lines under computer control. A larger, 7-inch cathode-ray tube will be used to accommodate both 35-mm and 70-mm sprocketed film. This scanner is now under construction, and initial tests on stability and precision will be conducted during the next quarter.

M. HEALTH PHYSICS

Four peripheral monitors are in place and operating. Construction of the final four is now starting. A computer program has been completed for storing and analyzing the data from these stations.

The portable chemiluminscent ozone monitor is completed and was calibrated against the State Air Pollution Board's standards. It works very well except for a slow recovery from high concentrations of ozone, probably due to a slow phosphorescence of some material near the photomultiplier.

The 1-GeV shower experiment done at Mark III was presented at the New York Physical Society Meeting and has been accepted by the Physical Review (SLAC-PUB-163).

The Research Area monitor design is complete and in construction in our own group. We expect to receive some tissue-equivalent plastic from Dr. Francis Shonka of St. Procopius College. We have received the first plates and are building a prototype chamber. When our design is tested, 10 chambers will be built in-house. Commercial portions of the electronics are in procurement.

Monthly measurements of the environmental neutron and γ-ray radiation fields are now being made with our mobile lab truck. We now have a small pulse-height analyzer and a large pressurized ionization chamber to add to these measurements. Environmental water sampling was started, and quarterly reports will be submitted to the Water Pollution Board from now on.

A study has been started of the best methods of monitoring the concentration of the oxides of nitrogen and of total nitrates in the BSY air. Instrumentation for this will be ready for June beam tests.

A course in Radiation Safety has been started at SLAC. The first group to take the course has been from the Operation groups, Fire Department, and Craft Shops. This course will be completed in April and will be offered again at intervals.

The water monitor is completed and ready for installation. Manway monitors have all been calibrated and require only tracking tests for the Central Control remote meters. Portable gamma monitor design has finally been completed. The first few should be available in April. Bismuth and thorium fission chambers are under construction.