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TWO-MILE ACCELERATOR PROJECT

Quarterly Status Report

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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 fourteenth Quarterly Status Report of work under AEC Contract AT(04-3)-400 and the eighth 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 the 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

The conventional facilities program was continued throughout the quarter, marking the start of the fourth year of field construction work. The present status of a number of these facilities in the construction phase is shown graphically in Figs. 1 through 4. Generally speaking, the "campus" area and accelerator facilities are already available or in use. Most of the remaining Aetron-Blume-Atkinson project effort will be directed toward completion of the structures and utilities required for the physics research program in the Target Area.

An overhead 220-kV power feeder line to the accelerator site has been contracted for by the Atomic Energy Commission and construction will start in October 1965. This facility, together with the existing 60-kV service to the site, will tie in to the SLAC Master Substation to provide the necessary electric power for the laboratory.

B. DESIGN STATUS

By the end of the quarter the ABA design effort necessary for placing the project's major construction contracts was essentially finished. A considerable amount of engineering remains to be done in connection with field changes, equipment procurement and installation, and a number of minor contracts. The current status of the significant items is as follows:

1. Cryogenics Building

Construction commenced in September. Drawings and change order specifications have been prepared for a change in roofing and roof insulation assemblies, and modifications to methods of fastening metal decking and siding.

2. Concrete Shielding Doors

Bids were opened on September 29, 1965 and are being evaluated. This package consists of one power-operated rolling door each for End Stations A and B and a pair of manually-operated swing doors for the Beam Switchyard entrance.

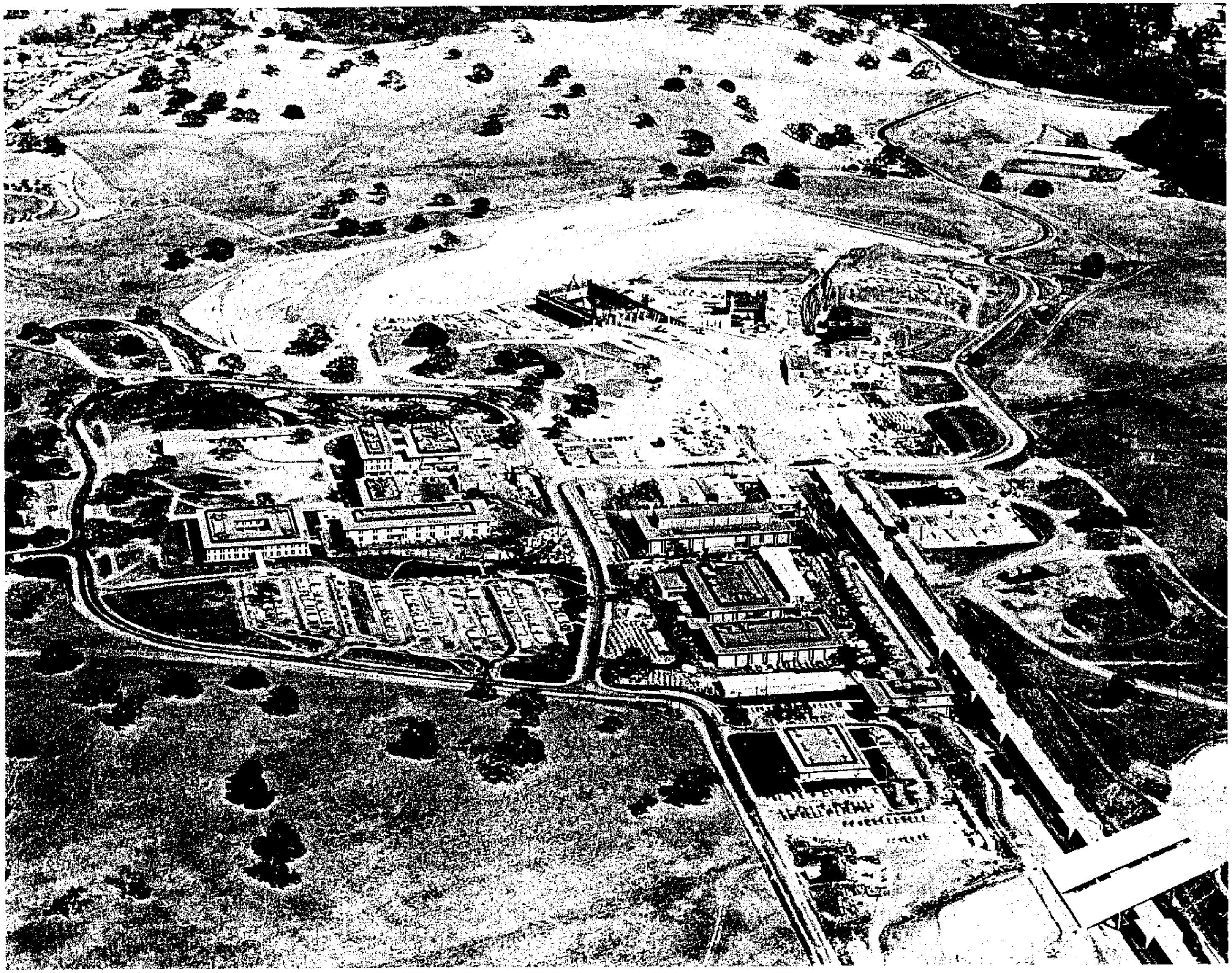

FIG. 1--Panoramic view of project; looking east.

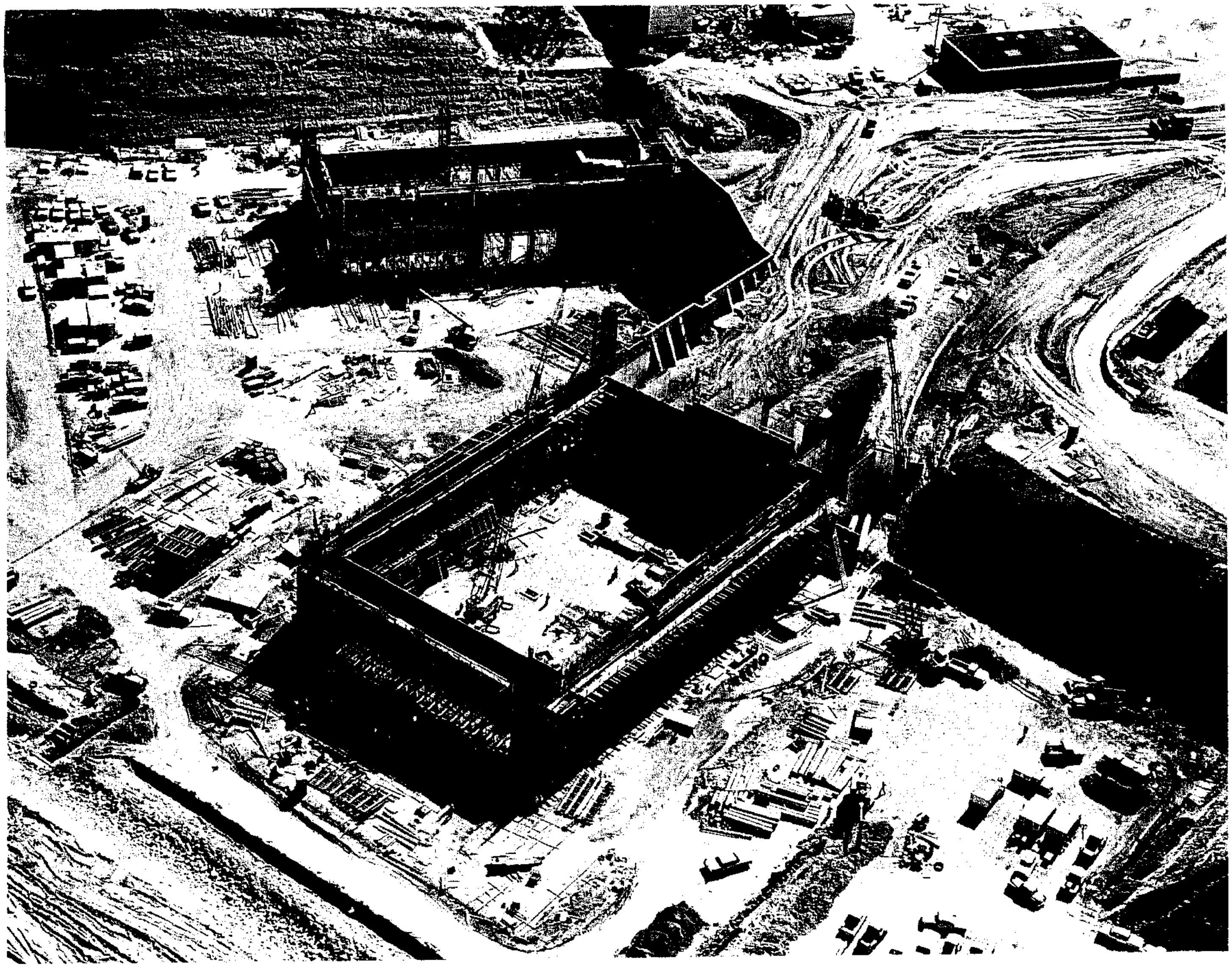

FIG. 2--Aerial view of End Stations A and B.

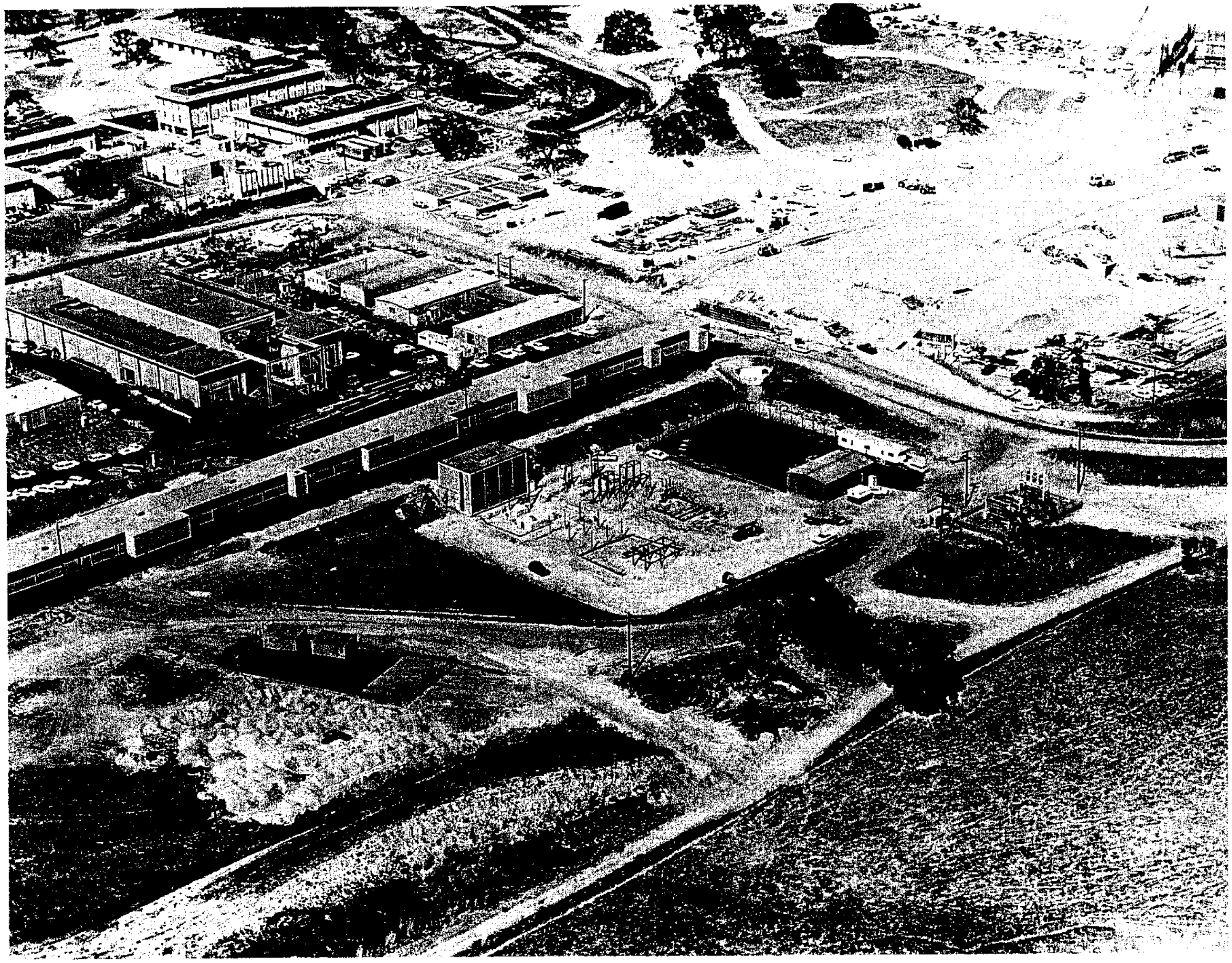

FIG. 3--Master Substation, with Klystron Gallery and "campus" area at left.

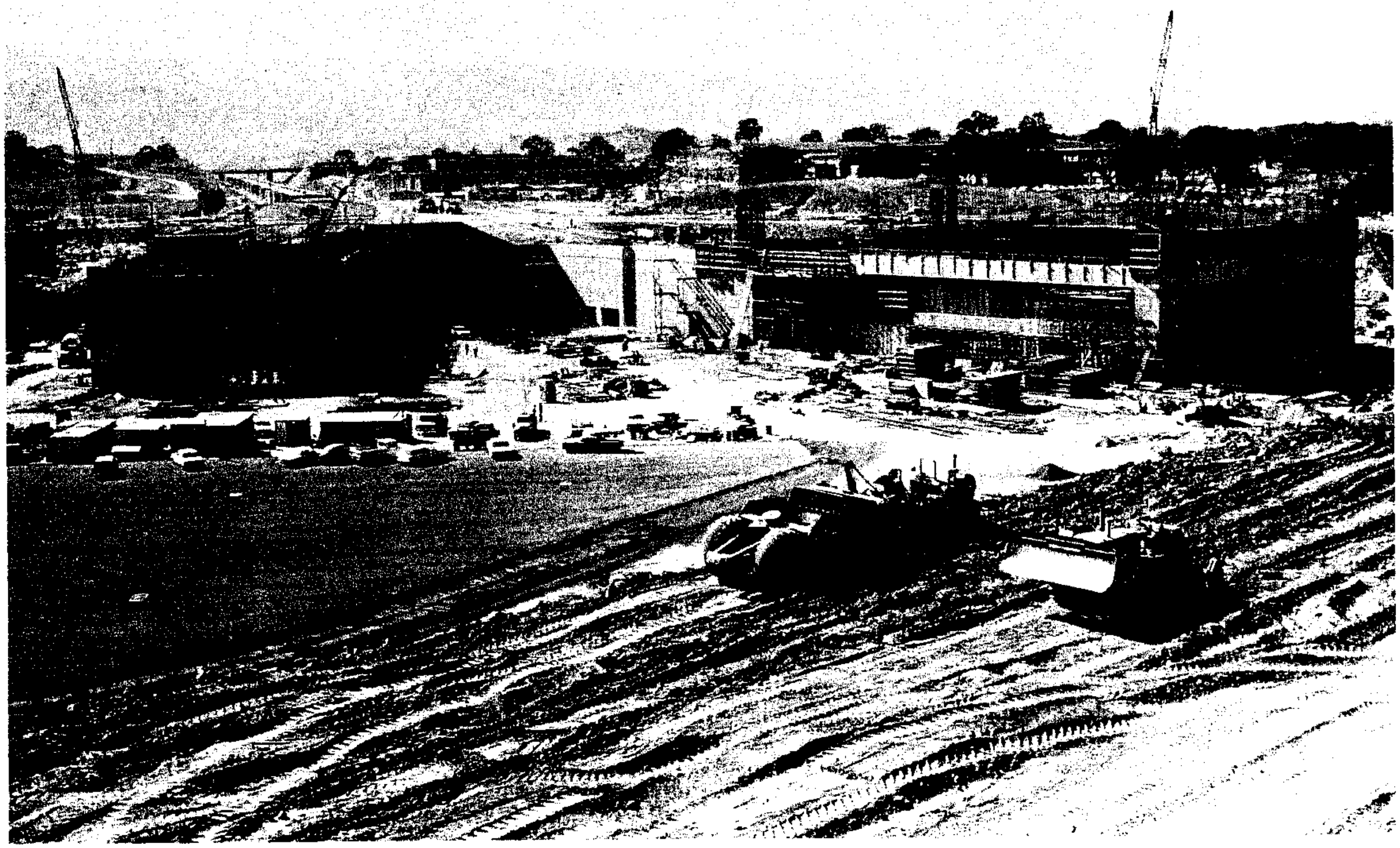

FIG. 4--Construction status of Target Area; looking west.

3. Data Assembly Building Extension

A 3000 gross-square-foot extension is planned for the south side of the original building; Title I design work is underway.

4. Beam Dump East

The construction contract for this major Target Area facility was awarded September 28, 1965.

5. BSY Materials Handling System

Track installation in the Beam Switchyard is progressing. The three cranes to be used in the system are scheduled to arrive in October 1965.

6. Target Area Cranes

Most of the shop drawing submittals have been received. Procurement of long-lead items has been verified; the first of the four cranes in this package is scheduled to arrive in late December.

7. End Station A

Design changes in the Counting House were completed late in the quarter. These provide for a 1500-square-foot mezzanine deck and extend the facility 6 feet to the west to include the loading dock.

8. Site Fencing

The 90% submittal of the Title II design is under review by SLAC. The total package will consist of two increments (Klystron Gallery and Target Area). Final installation is scheduled for April 1966.

9. Landscaping

Design of the final two increments (V and VI) of this program has been completed; bids for the installation will be invited next month.

10. Target Area Substations

Shop drawings and test data for these two substations, i.e., research area and BSY, are still being received. Installation of equipment in the latter facility is well along.

C. CONSTRUCTION

The status of major conventional facilities now under construction is as follows:

Facility	Percentage of Completion
Cafeteria - Auditorium	100
Klystron Gallery utilities	
Piping and site improvements (600-Y-1)	97
Electrical (600-Y-2)	96
Cooling Towers (600-Y-3)	99
Landscaping (Increments II and III)	98
Landscaping (Increment IV)	5
Central Laboratory (second-floor addition)	90
Beam Switchyard	89
End Stations A and B	63
BSY Site Improvements and Utilities	52
Master Substation	20
End Station Site Improvements and Utilities	7
Cryogenics Building	2

The principal construction effort during the balance of the project will be concentrated in and near the Target Area. The final major facilities under contract by ABA are now scheduled for completion by April 1966. That portion of the Beam Switchyard east of Station 107 will be made available to SLAC for installation work in November 1965.

Beneficial occupancy of the Cafeteria-Auditorium was taken in August; the facility was used for the International Symposium on Magnet Technology held at SLAC on September 8, 9, and 10. Beneficial occupancy of the second-floor addition to the Central Laboratory has begun and will carry over into the next quarter.

The cooling tower water supply and return lines from Sector 16 through Sector 30 were successfully tested on September 9 after a number of line breaks had been repaired.* This allowed the paving along the

*An engineering study and analysis of this work is presented in "Design, Installation, and Testing of the Klystron Gallery Cooling Tower Water Line," ABA Report No. 104, Aetron-Blume-Atkinson, Menlo Park, California (1965).

south side of the Klystron Gallery to be installed, with the program substantially complete at the end of the month.

Structural steel for the Master Substation switchyard (220-kV and 60-kV terminal structures) is on hand and being erected. Major pieces of equipment for use in the Switch House have arrived and are being installed. This overall facility will be tied into the existing SLAC facilities during the next quarter.

D. PLANT ENGINEERING SERVICES

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

As previously reported, planning has been underway for providing suitable housing on site for an interim computer facility and for SLAC personnel to be temporarily accommodated near the Central Laboratory. This need is being met by the installation of "relocatable classroom units" in the north yard area of the site. During the past quarter, 5000 square feet of such space were activated and are now in use. An additional 8000 square feet are to be provided in the next quarter.

A Fire Station and a General Services Building are needed on site to house several SLAC service functions. Suitable locations have now been selected, and the basic design criteria are being firmed up. These are preliminary to the selection of an architect-engineering firm to perform the Title I and II design work.

Several additional facilities, oriented toward physics research and target area placement, were the subject of cost estimating and/or engineering effort during the quarter. Of these, housing for the 40-inch bubble chamber and a 4000 gross-square-foot housing for End Station A power supplies are active project items and are being processed for procurement. Cost estimates were provided in connection with housing for a 72-inch bubble chamber, southward extension of the target area floor space, and a muon trap facility.

Work continued in preparation of a Phase II section of the revised SLAC conventional facility Master Plan. It is expected that this document will be issued later in the year.

A report entitled "AC Power System Load and Kilowatt Demand for Accelerator Operations" was issued in August 1965.* Other studies, related in general to electric power demands and cost forecasting, are being carried along by the department.

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* P. C. Edwards, "AC Power System Load and Kilowatt Demand for Accelerator Operations," SLAC Internal Report, Stanford Linear Accelerator Center, Stanford, California (1965).

III. SYSTEMS ENGINEERING AND INSTALLATIONS

A. SUMMARY

The overall department work is 75% complete. In general, satisfactory progress was made during the quarter, but lack of cooling tower water, 12.47-kV power, and sufficient instrumentation and control wiremen impeded accelerator test schedules, and EDI progress was slowed due to the impact of added rack program drafting.

B. ACCELERATOR

1. Accelerator – General

Chimney bids were received, and the installation of air seals and chimneys was started. The general layout for the positron system is 60% complete. Preliminary design was begun on a water storage tank for the positron water spillage. The laser room subcontract was awarded, and installation of the laser room started. Installation drawings for the west end observation room shielding walls were completed.

2. Vacuum

Bids were received on 230 SLAC-designed gauge control units and the subcontract awarded.

Drawings for the installation of the alignment vacuum pumping system were essentially completed.

Vacuum instrumentation for the positron source was resolved, and a subcontract modification was issued to fabricate piping.

A request for proposal was issued for the cryosorption systems.

Overall vacuum work is 92% complete.

3. Cooling Water

The positron source system was redesigned. A bid package was issued, quotations received, and engineering review is in process.

Walk-through inspection of all sectors was completed and punch-list items were given to the installation subcontractor.

Installation of tracing lines for the drive line continued. Installation of insulation is being held up pending completion of rf tests.

All systems have been turned on and are running in Sectors 1 through 15. Some circuits are being turned off occasionally for short periods for waveguide/drive line tracing, changing dummy loads, special tests, etc. Sectors 16 to 30 were shut down due to lack of cooling tower water.

Cooling water work is 92% complete.

4. Electrical

Miscellaneous work such as installation of fiat racks, sub-boosters, modulators and transformers is being completed in Sectors 1 through 30.

Modulator installation work in Sectors 0 through 18 is 100% complete; in Sectors 19 and 20, 10% complete; and in Sectors 27 and 28, 80% complete.

Wiring of switchboards in the variable voltage substation is 90% complete and time-and-material work is 85% complete. Linearity tests are satisfactory. Other tests were delayed pending completion of pothead work and 100-hour sector test. An acceptable standard for make-up of 12.47-kV potheads for SLAC use has been prepared.

Positron area design work continues. A set of drawings, 90% complete, are being prepared for completion of the positron area distribution and installation of power supplies and regulators. Work on quick-disconnects for 2000 and 4000 solenoids continued.

Modification to supports and installation of new pipe anchor frames for the drive line were completed. Effectiveness of these modifications will be observed during October.

A main ground bus inspection report was prepared. Some welds appear to be poor by visual inspection but are electrically below the 20 microohms required.

The alignment vacuum station design was completed. The mimic and relay panel is under construction, with delivery scheduled for late October.

A key bank board was fabricated to facilitate finding interlock keys.

Electrical installation work is 95% complete.

5. Electronics

Delays in delivery of rack frame components slowed the delivery of racks. A modification was negotiated with the subcontractor to fabricate 28 beam monitor racks. Work continues on updating the master trigger racks in the main injector.

Installation work on the instrumentation and control alcoves and cross-connects is proceeding satisfactorily. Sector 13 is expected to be completed in early October, with Sectors 14 through 18 following at intervals of approximately one week or less. An updated schedule was worked out for the remaining sectors which will permit completion of the sector test program on schedule.

The audio-visual system for the auditorium was completed.

Electronics work is 71% complete.

C. BEAM SWITCHYARD

1. Beam Switchyard - General

The equipment installation subcontract was awarded.

Updating of definitive drawings continues, including electrical wiring, cable trays and water piping.

2. Vacuum

Fast vacuum switch shock tube tests were performed on three aluminum foils by rupturing a six-inch diaphragm with one cubic foot of argon. Foils of 1/2-mil and two-mil thickness broke; five-mil-thick foil did not break.

All eight vacuum pumping stations were delivered after the preproduction unit had been corrected, inspected and approved.

Supports for the divergent chamber are approximately 50% complete.

An invitation for bids was issued for the Beam Switchyard vacuum chamber B.

A study is underway for a six-inch isolation valve utilizing an indium seal from the rf valve.

Requirements for fast valves were reviewed, and it was resolved that four inches is the largest size required for the Beam Switchyard. Work was then suspended on the six-inch fast valve.

3. Cooling Water

Bids for the radioactive cooling water pump were received and the subcontract awarded.

Submittal drawings for heat exchangers were received from the subcontractor. These were reviewed, corrected and returned.

A study was completed on alternate mobile retention tank designs and a memo issued giving cost comparison and recommendations.

Drawings and specifications were issued to the subcontractor for the B-beam target cooling water.

Various suppliers have been contacted relative to radiographing welded pipe joints in the radioactive water systems. Specifications are being prepared.

Preliminary cost and delivery information was obtained from the vendor for magnet cooling water pumps.

Thermal stress calculations were completed and reviewed for the radioactive water system piping. Several major categories of the radioactive water systems punch list were reviewed and resolved.

4. Electrical

The subcontract for BSY electrical installation work was awarded.

Tests are being conducted on nitric acid vapor effect on cable joints and cable tray materials. Various protective coatings for the cable trays and terminals are under test. To date, a graphite coating shows the most promise.

Work continues on the wire lists for terminal connections to all electrical devices and distribution frames.

Cable grips for use with remote-operable disconnects have been purchased.

Preproduction samples of radiation-resistant coaxial and twinaxial connectors were reviewed. Coaxial connectors are acceptable, and final production is in process. Twinaxial connectors are being modified.

A major portion of photon beam cable has been received.

IV. ACCELERATOR PHYSICS

A. INJECTION

1. Main Injection System

a. Wiring and Electronic Assembly

Assembly and wiring of the injector electrical systems are well advanced. The status of each subsystem is described below.

In the control console, all control panels are in place except for the status panels. The design of these panels was delayed in order to allow all pertinent status information to accumulate before freezing the design.

The high current power supply system is complete and is presently driving the injector focusing solenoids.

A sufficient quantity of medium current power supplies has been delivered to operate the injector. This system is operational, but some problems of controller stability remain to be solved.

The vacuum system was first turned on in August. A vacuum in the 10^{-8} torr scale was immediately obtained and has stayed in that range ever since. Because of these good vacuum conditions, further work on the vacuum interlock and monitor circuitry was delayed in order to take care of higher priority items.

The injector phasing system is fabricated and installed but has not yet been tested or operated.

Initial operation of the injector will be achieved with the modified Mark IV accelerator gun modulator.

A number of other systems related to the injector are still undergoing fabrication, installation or checkout. These include: the TV monitoring system, the profile monitor, the collimator, the bunch monitor, the communications system,the beam analyzer, the variable voltage substation control, and the remote control system from the Central Control Room.

b. Waveguide Components

The installation of the main injector waveguide system has been completed. The system was first tested with one high power klystron. The first operation of the system with an electron beam is described below.

c. Main Injector Operation With a Beam

The newly installed injector was operated twice during the quarter to observe any performance difficulties before operation of Sectors 1 and 2. For this operation, a short drift section between the injector and Sector 1 was left out and a well-shielded Faraday cup was inserted to stop the beam. Because the operation was brief, only preliminary and general conclusions could be drawn:

(1) The injector appeared to operate normally with no serious problems.

(2) The electron capture was somewhat below the expected 70%:

	Case 1	Case 2
Input Current	85 mA	360 mA
Output Current	55 mA	215 mA

(3) The radiation levels at the top of the material handling access near the injector were high enough to require installation of temporary shielding before Sectors 1 and 2 operation.

2. Electron Guns

Design and testing of the SLAC gun continued throughout the quarter. A nickel cathode was sprayed with a carbonate mixture and then assembled in a SLAC Model 4-1 gun vacuum envelope. A thin valve provided with an 8-liter/second pump was mounted on the gun. The gun vacuum envelope was baked out to 100°C and the cathode was then converted. After conversion the gun was pulsed, resulting in a 500-mA peak current at 43 kV and 1% grid drive when operated at a filament power of 35 watts. The gun perveance was measured as 0.10 to 0.12 microperveance.

The gun was moved to the beam analyzer and X and Y centerline profiles were recorded at various positions (from 7.3 inches to 10.3 inches downbeam from the gun mating vacuum flange) and for various beam perveances (from 0.05 to 0.10 microperveance). The gun was installed on the main injector on August 5 and 6. It has been performing satisfactorily, producing beams of up to 1 amp at a filament power of 40 watts.

The original carburized, thoriated-tungsten cathode was designed thick enough (0.150 inch) to help maintain the emitting surface at a constant temperature. This thickness, however, required a difference in temperature between the front and back of the cathode of about 200°F at operating temperatures. Temperature scans across the cathode face using an infra-red thermometer measured temperature variations of 13°C at 790°C and 26°C at 1400°C. A porous 2% Th-W carburized cathode was reduced to two-thirds (0.100 inch) of its original thickness. A new solid 2% Th-W cathode was reduced to one-third (0.050 inch) of its original thickness. These cathodes will be beam-welded into all-molybdenum supports next quarter. They will be used to determine the minimum cathode thickness consistent with an equal temperature emitting surface. This will permit lower operating temperatures and pressures in the bombarder region. Also, since the new cathode will be carburized after beam-welding, it should be possible to detect any emission defects which may arise from the beam welding process.

Emission tests of carburized Th-W cathodes using noncarburized Th-W filaments were performed. This required operating the filament as a W emitter in the area of 1950°C to 2000°C. Filament-to-bombarder power ratios of from 0.40 to 0.63 resulted. The highest emission achieved was a pulsed current of 45 mA at 62 kV, a bombarder power of 133 watts, and a filament power of 52 watts.

Filaments were sprayed with an aqueous solution of colloidal graphite and carburized at 2000°C. The best emission obtained using these filaments in the bombarder was 503 mA at 75 kV, a bombarder power of 144 watts, and a filament power of 5.5 watts (or a ratio of 0.038). Thus, the carburized filament was able to emit an adequate bombarder current at a low enough temperature (1600°C to 1650°C) and still function as a thin-film emitter. The ten-fold increase in cathode emission may be due to the lower temperatures and pressures in the bombarder region obtainable with the carburized filament.

3. Gun Modulators

The final gun modulator design has been frozen. The decision to keep the grid pulser circuitry in the Klystron Gallery has been reversed because of difficulties encountered in transmitting the pulse to the Accelerator Housing without deterioration of pulse quality. Virtually the entire pulser will be installed in the Accelerator Housing in close proximity to the gun, while the dc supplies, filament controls, etc., will remain in the Klystron Gallery, in the existing Manson gun modulator cabinet. Packaging of the pulser system is underway. Installation of this modulator is scheduled for next December.

4. Beam Knockout System

The conceptual design of the beam knockout system is making progress. It has been decided that this system will consist of a subharmonic deflector, to be located between the electron gun and the buncher, which will operate at the 72nd subharmonic of the bunching frequency. With such a system, only one in every 36 bunches transmitted through the sweeper will remain undeflected and thereby be accelerated through the rest of the machine. By means of this system and a high current gun, it should be possible to obtain beams with high average currents but with 36 times less electron bunches and therefore much more "intra-bunch" time available for counting experiments.

B. DRIVE SYSTEM

1. Main and Sub-Drive Lines

Final installation of the drive lines is proceeding. The A-frame anchors at the beginning of each sector have been installed. The water tracer lines for the main and sub-drive lines have also been installed, but the application of the heat-conducting epoxy required to bond these lines to the drive lines has been delayed pending completion of rf tests, installation of backup rings in the sub-drive line swivel flanges, and delivery of special main drive line segments to be connected to the expansion joints. Final testing of the complete drive line system is scheduled to take place during the next quarter.

2. Varactor Frequency Multipliers

Twenty-six multipliers have been received to date, and twelve have been tested. Two have not met the phase stability requirements and will need new diodes. Further diodes obtained from an alternative source have not been satisfactory and have been returned for replacement.

3. Main Booster Amplifiers

The cause of the failure in the rectifier stack mentioned in the previous report is still unknown. The damaged stack was repaired and returned to SLAC. During the last quarter, one of the main booster klystrons failed to provide full power output after 2500 hours of operation and it was changed. Both units are now available and are operating continuously. The faulty klystron will be repaired or replaced during the next quarter.

4. Positron Phase Shifters

Sectors 1, 2, 5 and 6 have been fitted with sub-booster isolator-phase shifter-attenuator units with 180° phase shifters incorporated for future positron acceleration. Sector 1 requires two of these units. The remaining units will be installed up to Sector 10 as the sub-booster modulators are delivered to these sectors. Two regular isolator-phase shifter-attenuator units with these 180° phase shifters are required for installation in the first two FIAT racks in Sector II. These units have been assembled and are available for installation.

5. RF Drive System Control Circuits

The master oscillator switching unit is complete except for one relay presently on order and a fault detection circuit which is being designed. In its present state, the unit can be installed and will provide manual switching of the master oscillator.

The main booster automatic switching unit is operational and takes about 16 seconds to switch.

The sub-booster switching unit has been designed to provide manual and automatic switching. It is presently being assembled.

6. Sub-Booster Modulators

During this quarter, twelve sub-booster modulators were delivered and installed in the Klystron Gallery. Six of these have been tested with resistive loads and accepted.

7. Sub-Booster Klystrons

Testing of these klystrons during the last quarter has shown some improvement in shelf life. However, shelf life failures are still too frequent to ensure that the problem has been entirely solved. Investigation of these shelf life failures is continuing.

C. PHASING SYSTEM

1. Isolator-Phase Shifter-Attenuator Units

Delivery and testing of production units have been completed, with the exception of three units which were returned to the subcontractor for repair. Modification of the preproduction units is being done at SLAC. The special control phase-shifters for the injector are expected to be delivered by the middle of October.

Components necessary for modifying units to meet the special requirements of Sector 27 are being procured.

2. RF Detector Panels

All units have been delivered and tested. Before installation in the machine, each panel is being modified so that the reference signal may be derived from either the varactor multiplier or the sub drive-line. Stability tests on a proposed switched attenuator to eliminate unbalance of the diodes are continuing.

3. Programmers and Electronics Units

Twenty production units of each type have been received, and testing is almost completed. No major troubles have arisen. All units are further tested in a sector phasing simulator before installation in the machine.

4. Linear Detectors

One hundred forty-four thermionic diode housings have been received to date and are being fitted with diodes and tested. Forty of these housings are special units for use in the Beam Switchyard.

5. Installation of Phasing Equipment in the Accelerator

Prototype rf detector panels, programmers, and electronics units have been replaced by production units in Sectors 1 and 2 for Series II tests. The additional control wiring necessary to automatically phase klystrons 1A, B and C is being completed. All phasing equipment has been installed in Sectors 5 and 6 and in 13 through 18. The installation has been tested in Sectors 5 and 6.

A special phasing system has been built to ensure that the standby injector klystron will come into service with the same rf phase as the klystron it replaces. The system has been installed in the injector area, but has not yet been tested.

D. BEAM POSITION MONITORS

1. In-Line Position Monitor Cavities

Production of in-line cavity assemblies is behind schedule, but the number in reserve is sufficient to meet drift-section assembly requirements. During the third quarter, 13 completed assemblies were tested and delivered. Seventy-five percent of the cavity subassemblies have been built. Design of the weldment flange on the position cavity probe was altered to avoid changes in coupling after welding.

2. Beam Position Monitor Detector Panels

Extensive tests have been performed to measure the errors introduced by the thermionic detectors. The measurements were made in the laboratory under conditions which were more controllable than those prevailing during machine tests earlier in the year. It was found that the errors due to diode nonlinearity which were reported earlier were based on incorrect data. The error in the "log Q" presentation, negligible at high current, is approximately 5% at low currents, rather than 20%. The nonlinearity of the diode does not affect the beam centering capability; it only changes the indicated sensitivity of the X and Y signals. If the sensitivity is set at 10-mA beam current, this error is 10% at 100 mA and 50% at 1 mA. Position errors due to changing diode balance were correctly stated as 1 to 2 millimeters. However, uncertainty due to this error has been removed by incorporating a switch in Central Control which will enable the operator to disconnect the rf position signals from the cavities and observe the spurious position signals due to diode unbalance.

3. BSY Beam Position Monitors

The seven microwave cavity assemblies required for the Beam Switchyard have been completed and tested. Work remains to be done on the quick-disconnect vacuum couplings and rf connectors. A suitable design for the quick-disconnect rf coupling has been worked out. A prototype coupling and remote handling tool have been built. A prototype beam position monitor detector has been built and tested. After some mechanical rearrangement, the design was approved. The seven chassis are being assembled. Some of the special radiation-resistant rf connectors have not yet been received.

E. BEAM ANALYZER STATIONS

1. Beam Analyzer Station 1

The magnet power supply controls and the scan and sweep foil readouts have been remoted to the Injector Control Console. Fast and slow interlocks have been reworked and coupled to the injector trigger pattern generator. An automatic degaussing system has been designed and built. This will make it possible to quickly and effectively degauss the magnet by pressing a button.

2. Beam Analyzer Station 2

This temporary installation has remained essentially unchanged since the first beam tests. The fast and slow interlocks have been reworked and coupled to the temporary beam-inhibit system.

Drawings have been completed for the permanent installation on girder 3-1.

New foil assemblies for both beam analyzer stations have been designed. These will have 23 equal width (1/3%) scan foils and one 1/4% sweep foil. New electronic foil-scanners have been designed and are being built.

F. GENERAL MICROWAVE

1. RF Deflecting Structures

The TM_{11} structure discussed in the previous report to separate electrons from positrons downstream of the positron radiator is undergoing fabrication. The TM_{01} structure with an offset beam aperture has been built and tested in the Injector Test Stand. This first model has been called Lolita I. Its dimensions and deflecting properties are shown in Table I, where a comparison is made with earlier TM_{11} structures. A more complete description of both these TM_{11} and TM_{01} structures is

TABLE I

CHARACTERISTICS OF DEFLECTORS

Designation	Symbol	LOLA II	LOLA III	LOLITA I
Mode family	–	"TM_{11}"	"TM_{11}"	"TM_{01}"
Phase shift per cavity	–	$2\pi/3$	$2\pi/3$	$2\pi/3$
Periodic length (cm)	d	3.5	3.5	3.5
Disk thickness (cm)	t	0.584	0.584	0.584
Cavity inside diameter (cm)	2b	11.7894	11.5712	7.9598
Beam aperture diameter (cm)	2a	4.064	4.732	2.324
Beam aperture offset (cm)	o	0	0	2.497
Suppressor holes diameter (cm)	2p	1.905	1.905	0
Suppressor holes offset (cm)	c	3.619	3.810	0
Length of experimental section (cm) Including both couplers	ℓ	52.5	28.0	28.0
Quality factor	Q	9030	11000	11360
Cold test frequency(75°F,air)(Mc/sec)	f	2857.0	2856.0	2856.8
Relative group velocity	v_g/c	-0.0296	-0.00779	-0.00745
Attenuation per meter (NP/m)	I	0.1105	0.3457	0.3514
$E_o/\sqrt{P_o}$ (MV/m/$\sqrt{MW}$)	$\sqrt{Z}$	1.94	3.04	4.06
Transverse shunt impedance (MΩ/m) Measured with beam	$r_{o,T}$	15.70	11.70	20.50
Measured by microwave perturbation method	$r_{o,T}$	15.50	12.4	21.58
PREDICTED PERFORMANCE FOR THREE-METER STRUCTURE				
Attenuation (NP)	$I\ell$	0.331	1.0371	1.0542
$(1 - e^{-I\ell})\sqrt{2I\ell/I\ell}$	–	0.670	0.894	0.895
Predicted deflection (MeV/ $\sqrt{MW}$)	$P_{\perp}c/\sqrt{P_o}$	4.60	5.29	7.02

given in SLAC PUB-135 (G. A. Loew and O. H. Altenmueller, "Design and Applications of RF Separator Structures at SLAC," presented at the Fifth International Conference on High-Energy Accelerators, Frascati, Italy, September 9-16, 1965).

G. OPTICAL ALIGNMENT SYSTEM

Construction work is nearly complete on the installation of the laser room. This room consists of a 10-foot-diameter steel cylinder bolted to the side of the Accelerator Housing. A manhole in the road at the east end of the Klystron Gallery gives access to the room through a penetration.

The position of the installed targets relative to the optical tooling holes is being checked using a target calibration fixture. Measurements have been consistent to within ±0.002 inch whenever they were repeated on individual girders. About one-half of the total number of target positions have been measured.

The design of the observation equipment, including the scanner, has been frozen. The traverse systems for the two scanners have been ordered. Drawings are being made for the scanner.

All optical components have either been ordered or are in final stages of procurement. These include the main window, the small window at the laser end, the 45° turning mirror at the laser end, and the mirrors for the observation equipment. The latter mirrors enable the operator to direct the image to the vertical or horizontal detector or to view the image directly.

One of the monument girders has been completely assembled, tested (including leak testing), and installed in the Accelerator Housing. Modifications to the actuator system for the monument target were made to insure operation in all expected girder positions.

H. MAGNETIC SHIELDING AND DEGAUSSING

The magnetic shielding system for the Beam Switchyard has been planned and documents for purchasing are being reviewed. The system is similar to the accelerator system except that there will be no degaussing wires. However, there will be a four-wire demagnetizing system. Sections of different diameters, ranging from 1.66 inches to 44 inches wide, will be covered by shielding pieces 14 inches wide by a length sufficient to completely surround the pipe with a short overlap. Sections 6-5/8 inches in diameter or less will be covered by 0.006-inch-thick material, while a 0.014-inch thickness will be used for greater diameters.

I. THEORETICAL AND SPECIAL PROJECTS GROUP

The following studies are presently underway.

1. Ray Tracing Program

A program to fit analytic models to measure two-dimensional fringe field maps is nearly complete.

2. Beam Blowup Studies

An attempt is being made to formulate the beam blowup mechanism in a form applicable to tapered structures such as the SLAC constant-gradient design. Because of mathematical difficulties, a computer investigation may be required.

3. Off-Frequency Bunching

Preliminary results indicate that as many as eleven consecutive rf bunches may be combined into one single bunch of length $3c/2f$, where f is the bunching frequency. For higher electron density, subharmonic bunching must be used. Published methods of developing high intensity, short beam pulses are being studied.

4. Beam Knock-Out Systems

An analysis and comparison of various resonant systems used to obtain a subharmonically bunched beam has been written. A helical resonator was designed which, when built, gave a Q of approximately 500.

5. Distributed Transformers

A study has been made and numerous prototypes were wound. They showed less than 1% droop over about 100 μsec and rise times ranging from 1/2 μsec (for small units) to 15 μsec (for high-power units). Transformers were supplied to the Beam Switchyard and the Microwave Groups.

6. Magnet Transient Analysis

A brief study resulted in a computer flow chart for calculating the voltage step response of solid core nonlinear magnets.

7. Pulse Transmission in Cables

The theoretical step-response of numerous cables has been computed and compared with experimental results. A large discrepancy has been found; attempts are being made to develop a theoretical explanation.

8. Pulse Equalization

A theory and design technique has been found for the Chebyshev equalization of arbitrary loss, phase or delay. Applications include a video cable equalizer and a compensator for the Long Ion Chamber cable.

V. INSTRUMENTATION AND CONTROL

A. GENERAL

The design of the Instrumentation and Control equipment is virtually complete. Modifications brought to light in tests during the last two quarters are being processed. Procurement and installation of equipment is well underway. We are approaching final stages of systems tests and updating of the documentation.

Sectors 1, 2, 5 and 6 have been checked out and are ready for operation. A skeleton installation in Central Control is ready for tests of operation of Sectors 1 and 2.

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 is proceeding on schedule. Transmitting equipment has been installed in Sectors 1, 2, 5 and 6.

Receiving equipment for one switched sector-by-sector display panel has been installed in the Central Control Room (CCR) and is reporting information from Sectors 1 and 2. Racks for continuous display of sector status are being installed as they are received.

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. Two switching chassis have been constructed and tested. One has been installed in CCR and is reporting signals from Sectors 1 and 2 satisfactorily.

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 proceeding on schedule. Receivers have been installed in Sectors 1, 2, 5 and 6. One transmitting system has been installed 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, and

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

Delivery of FM equipment is complete and installation is in progress. A contract for baseband equipment has been awarded for October 1965 delivery.

C. 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.

A subcontract for the construction of both the beam monitor sector electronics and the baseband receiver units and for the control units for the beam steering power supplies has been awarded. A card file for the receiver units themselves is being built in-house. Work continues on the displays for the Central Control Room.

Trouble has been experienced with failures of some of the beam guidance power supplies. A program to determine the cause of the failures was initiated. Power supply controllers installed in Sectors 1 and 2 have been tested and shown to provide suitable steering control from CCR.

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 master clock consists of three master trigger generators and a comparator which switches the main trigger line from one to another when failures or irregularities of output occur.

The three master trigger generators have been built and tested. The comparator and MTG's will be tested as a unit during October and released for installation in early November. The pattern generator is almost completed and is to be installed in CCR in October.

The injector trigger generator has been built and installed. The beam switchyard trigger generator design is nearing completion, with a prototype due late in October.

E. KLYSTRON INSTRUMENTATION

Several external monitoring and protection circuits are provided adjacent to each klystron and modulator. These monitors include vacuum, water, input and output power, de-Q'ing, reference voltage, maintenance operate switch, trigger delay, isolator-phase shifter-attenuator package, and reflected energy.

Experience in the beam tests last spring indicated a need for a few minor design changes in some of these units. These changes were accomplished during the summer.

In general, the design is now satisfactory and the procurement and installation are on schedule.

F. PERSONNEL PROTECTION SYSTEM

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

During the summer, permanent personnel protection circuits were installed in Sectors 0 (Injector), 1, 2, 5 and 6. Personnel protection circuits are not yet complete into Central Control. Simulated Central Control equipment was installed in Sector 2, for Sectors 0 to 3, and in Sector 6, for Sectors 4 to 7.

In order to run beam in Sectors 0, 1 and 2, all Sectors, 0 through 7, must be secured. RF testing in Sectors 5 and 6, however, requires that the housing be secured only in Sectors 4 through 7. In order to accomplish this, a dc sector secure loop has been provided in Sectors 4 through 7 and a dual 40-kc, 50-kc tone loop has been installed in Sectors 0 through 7.

The first production units of the fixed gamma monitor to be used at each manway entrance have been received. A prototype of the radioactive water monitor is complete, and the installation will be designed in the coming quarter. Two neutron monitors have been received and are being tested by the Health Physics group.

G. MACHINE PROTECTION

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

The one-millisecond network consists of a tone generator and tone receiver, and a set of tone-interrupt units, one at each sector. The first production units of the tone generator and receiver are undergoing systems tests in the personnel protection tone loops in Sectors 1 and 2. The long ion chamber has been supplemented by discrete ion chambers at 120 feet/240 feet in Sector 1. These chambers provide the increased resolution for steering the beam through Sector 1. Similar discrete ion chambers will probably also be used as detectors for the scanning profile monitor described in the previous Quarterly Status Report.*

H. CENTRAL CONTROL

Central Control contains a number of equipment racks and three console areas: the Operations Console, the Maintenance Console, and the Backup Console.

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.

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 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

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*"Two-Mile Accelerator Project, Quarterly Status Report, 1 April to 30 June 1965," SLAC Report No. 48, Stanford Linear Accelerator Center, Stanford, California (1965); p. 27.

display and control panels for specialized equipment such as the Master Trigger Generators, the master oscillator and main boosters, water towers, etc.

During the past quarter, installation of the central control equipment has gotten well under way. Much of the wiring to the equipment racks has been completed. Equipment has been installed to activate the switched sector-display panel in the operations console. The status, analog and control signals to Sectors 1 and 2 are operational; tests of the operation of Sectors 1 and 2 from Central Control, with beam, will commence in October.

During the coming quarter, most of the equipment in the Backup Console will be installed. Wiring of circuits is scheduled to allow monitor and control of each sector from the operations console as the sectors become available for test. The final beam monitoring displays and the maintenance console will be completed during the first quarter of 1966.

I. CONTROL SYSTEMS

The Instrumentation and Control group provides supervision of the final systems tests of wiring and subsystem operation in the sectors. In Sectors 1, 2, 5 and 6, wiring errors, faulty relays, etc., were corrected and drawing errors noted. These tests will be continual at a rate of about one sector a week until installation of the accelerator is complete.

Assistance was given to the Systems Engineering and Injection groups in testing the interface between the main injector and the rest of the control system.

Documentation of the signal runs between Switchyard and Central Control was initiated.

VI. HEAVY ELECTRONICS

A. MAIN MODULATOR

1. Modulator Procurement

Seventy-three modulators were received and installed during the quarter, bringing the total number in-house to 203. Only 47 remain to be delivered. Deliveries were about two months ahead of schedule as of the end of the quarter.

2. Modulator Testing

After installation, the modulators were started up and run about one hour each using a water load. At the end of the quarter, all modulators through Sector 15 had been tested in this manner, and we were making satisfactory progress in meeting the test schedule whereby all modulators in Sectors 13 through 18 are to be run with a klystron load on October 15, 1965.

Life testing of modulators and associated components continued this quarter. Pre-production modulators 2 and 3 had 9800 and 9060 hours running time, respectively. Production modulators (serial numbers 21 and 22) had 4353 and 4679 hours running time, respectively. Serial number 3 modulator continued to be used for switch tube acceptance testing. Serial number 2 modulator, running into a diode load, is being used to life test thyratrons, pulse cable assemblies, pulse transformers and de-Q'ing switch assemblies, as well as all other modulator components. Serial numbers 21 and 22 continued to run as test modulators for all modulator components. In addition, serial number 21 was equipped with a fire prevention and fire alarm circuit to prevent and/or warn against a modulator fire such as that which occurred in serial number 3 modulator during the previous quarter.

During these tests, a number of failures with the pulse forming network capacitors prompted further investigation. Most of the failures resulted in swelling of the sides of the capacitor cans with no other obvious effects, but some units failed catastrophically with bursting at the seams or bushings. X-rays of these capacitors and further testing of new capacitors revealed that their oil level was low. The supplier was alerted to the problem and remedial steps were begun.

Testing also revealed that the rectifier transformer and charging chokes were prone to develop high voltage bushing oil leaks. The defective units were repaired under warranty.

As design improvements of the modulator are made, these test vehicles are also used to prove out the design changes.

Modulators in Sectors 1, 2, 5 and 6 were tested this quarter. The tests indicated that the modulators and associated systems work well together. Most of the modulators maintained better than 0.5% pulse output amplitude stability for hours under varying repetition rate conditions.

3. De-Q'ing

The de-Q'ing system has now been perfected. Problems in the de-Q'ing switch assemblies have been solved, as several units have been life-tested for several thousand hours and many more units have lesser amounts of time. At the end of the quarter over one hundred assemblies had been received, most of which have been installed and operated.

The noise problem on the voltage dividers has been solved by putting them in an oil bath. At the end of the quarter about 140 of these oil baths had been received and installed.

4. Switch Tubes

Tung-Sol continued to deliver satisfactorily this quarter. International Telephone and Telegraph Company experienced excessive time jitter and anode time delay on their initial option tubes, but the problem is being worked out.

At the end of the quarter, there were sufficient (230) switch tubes on hand to keep up with the installation program, which is about two months ahead of schedule.

5. Pulse Transformers

Pulse transformer deliveries slowed this quarter, owing to late deliveries from the core manufacturer to the pulse transformer supplier. However, by the end of the quarter deliveries had increased, and there was a sufficient quantity of pulse transformers on hand to meet immediate requirements.

6. Pulse Cable Assembly

Problems with the pulse cable assemblies which were encountered and solved during the quarter were: (1) excessive resistance through the inner shield connections, which was solved by soldering the shield wires before making up the connections; and (2) silicon oil dissolving the silicon rubber sleeve used to cover the polyethylene layers in the male plug, which was solved by using a type of silicon rubber which is insoluble in silicon oil.

One problem as yet unresolved with this assembly concerns the receptacles which mount in the pulse transformer tank. Difficulty was experienced in molding the units; some epoxy parts cracked or did not adhere to the metal parts.

Some of the cables which had low corona starting voltage were installed in Sectors 13 through 18 in order to keep up with the test schedule. These units are satisfactory for test purposes.

7. Oil Expansion Problem

A contract for the manufacture of 250 wrap-around oil expansion tanks was let. By the end of the quarter, 30 tanks had been received and were installed on klystrons.

B. SUB-BOOSTER MODULATOR

Seventeen more sub-booster modulators were received this quarter which were more than enough to keep up with our installation schedule. In general, the modulators operated well, although a little trouble was experienced when first starting some of the modulators. The 4PR1000 modulators sometimes arc through, especially when the modulator is started cold; to combat this problem the 4PR1000's are run 24 hours a day.

C. GUN MODULATOR

The modification of one of the gun modulators for use on the machine is continuing. A new regulated heater power supply and bombarder power supply were installed in place of the old heater power supply. The grid pulse circuitry was removed for relocation in the tunnel. Contracts were let to procure special cable and bushings for transporting 100 kV dc and various services to the grid pulsers in the tunnel.

D. STORAGE RING INFLECTOR MODULATOR

This modulator was constructed and tested this quarter. The tests revealed that diodes in series with, and across, the hydrogen thyratrons are necessary in order to run at full operating voltage because of arc-back problems in the thyratrons. Satisfactory diodes are being sought.

E. MAGNET POWER SUPPLIES

The first two 0.1° pulsed magnet power supplies, the first A and B Beam quadrupole magnet power supply unit, and the A Beam Dump power supply were being tested by their respective suppliers at the end of the quarter. The A and B Beam unregulated power supply units are about 75% complete. The A and B Beam regulators and the positron source solenoid power supplies are both under construction.

Contracts were either awarded or about to be awarded for the pulsed steering magnet power supplies, the 5800 kW spark chamber power supply, the dc steering magnet power supplies, and the photon clearing magnet power supply, as well as for the End Station B beam transport power supplies.

Now out for bids are the 1590-kW power supplies, the 567-kW power supplies, and the 432-kW and 390-kW power supplies bid package. Specifications for a 3400-kW power supply were written.

VII. MECHANICAL DESIGN AND FABRICATION

A. GENERAL

Forty-nine girders were assembled and installed during the reporting period to bring the total number of installed girders to 154. In addition to these, five drift sections were assembled and installed during the period for a total of 16, and three 40-foot light-pipe girders were also put into position at the injector end of the Accelerator Housing. This meant that 6440 feet of the accelerator were installed by the end of the third quarter. The installation of the injector and its wiring were also completed during the reporting time.

B. ACCELERATOR STRUCTURES

A total of 218 ten-foot sections of disk-loaded waveguide were completed during the reporting period and readied for installation on support girders. One section was damaged and rejected during fabrication for a shrinkage loss rate of less than 0.5%. This meant that a total of 8716 feet of the accelerator structure had been completed by the end of the quarter. It is estimated that all accelerator sections will be fabricated, tuned and readied for installation by the end of the second month of the next reporting period.

C. RECTANGULAR WAVEGUIDE

A total of 68 cross bars and 141 thirty-eight-foot penetration waveguides were fabricated, tested, and either installed and tuned during the reporting period or were ready for installation and tuning. This brings the total production of these components to 167 crossbars and 362 penetration waveguides. The fabrication of all of the rectangular waveguide components associated with the injector was completed during the reporting period, and the components were installed and tested.

1. Phase Measurements and Adjustment

During the quarter, rectangular waveguide networks were phase adjusted for the following girder stations: 10-4 through 1-8, 12-4, 12-5, 13-4, 14-4, Sectors 16 through 19, except 16-7, and 30-1 through 30-7.

The phasing procedure was simplified by eliminating the coarse check of the penetrations and crossbar assemblies that had been performed before connecting to the girder assembly. A signal is fed directly, in turn, through the flange modulators (which act like highly attenuating coaxial-to-waveguide adapters) in order to make a coarse check on the network. This transmission method eliminates the half-wavelength ambiguity inherent in the final, highly accurate reflection phasing method that has been described in previous quarterly reports.

2. Rectangular Waveguide Component Status

The number of the various components completed during the quarter and the total number completed to date are as follows:

	Third Quarter	Total to Date
Waveguide Vacuum Valves	72	180
Model A Directional Couplers	69	175
RF Loads (All Types)	173	979
Power Dividers (All Types)	178	834
S-Assemblies	99	311

D. MAGNET ENGINEERING

The main concern of the magnet engineering group continued to be vendor follow-up and scheduling. As of the end of the reporting period, it appeared that all components would be delivered in time for testing and installation to meet the schedule dates for beam turn-on for all systems.

The redesign of the Brookhaven magnets was completed during the quarter, and all of the units were out for procurement before the end of the period. Delivery of the units is expected to begin by mid-February, 1966, with all on hand by the end of the first quarter of next year. The status of the other magnets in procurement or in fabrication is given below.

1. Pulse Steering Magnets

All of the pulse steering magnets will be on hand early in the next quarter. The two that were received during this period have been tested and found to perform to design specifications.

2. Emergency Bending Magnets

Because of pressures from other work, the vendor has been delayed in the fabrication of the emergency bending magnets. Delivery is now anticipated in the first quarter of 1966, which will be in time to meet installation schedules.

3. Three-Degree Bending Magnets and Reference Magnets

One of the 13 three-degree bending magnets was received before the end of September and seven more will be on hand during the next quarter. They will be processed for installation as soon as they become available. The problems, reported previously, that the vendor had experienced in working with the radiation-resistant epoxy have largely been resolved.

4. Pulse Magnets

The coils for the five pulse magnets have been delayed because of a heavy vendor workload. It is anticipated that they will be delivered in time so that the magnets can all be assembled and ready for install by the first of April of next year.

5. Quadrupole Magnets

Two of the 8-cm quadrupole magnets should be delivered during the next quarter, while the remaining magnets should be delivered early next year. The vendor had difficulty in machining the complex pole shapes for these magnets but had solved this problem by the end of the reporting period.

6. Photon Beam Stripping and Bending Magnets

Fabrication of the stripping magnets by an outside vendor was started during the reporting period, and delivery is expected by the end of the next quarter. The bids for the core and assembly of the B-28 photon beam bending magnet were unacceptable and this work will be done in house. The coil should be delivered in February of 1966.

7. Dump Magnets

The vendor solved the epoxy problem with the four "A" system beam dump magnet coils but production progress has been slow. It is expected that one magnet will be received in the next quarter and the other three in early 1966.

8. Associated Magnet Hardware

The ceramic water tubes and bellows connectors for the BSY magnets were in fabrication and the vendor was either on or ahead of schedule during the reporting period. Hardware was also coming in for the quick-disconnect couplings for the vacuum chambers.

Ceramic vacuum chambers were being fabricated for the 0.1-degree pulse magnets. It is anticipated that all ceramic blanks for the chambers will be on hand by the end of the year and machining, grinding and brazing of these will begin early next year.

E. PRECISION ALIGNMENT

The air-conditioning system for the precision alignment laboratory in the Heavy Equipment Building was completed during the reporting period and the laboratory was in use for magnet alignment. The precision alignment group was also working on second-level alignment procedures for the BSY and the several other projects reported below.

1. Second-Level Alignment Design

Second-level alignment refers to the alignment of all components and instruments in the BSY with respect to the 10-inch laser. This alignment will be performed from the upper chamber of the switchyard structure.

Procedures for this alignment were developed and written during the reporting period, and alignment was completed for several representative components in the BSY. The design concepts for the hardware necessary to perform this alignment were also resolved during the reporting period.

2. BSY Installation Controls

The controls to be used for installation of components in the BSY will be based upon monuments located at vertex points. Seen in plan view, vertex points are the intersections of principal beam drift tangents or lines. These points were initially located by ABA, and were subsequently checked and certified to a probable accuracy of 1/16 inch by the precision alignment team.

3. Tape Bench Facility

Second-level alignment in the BSY and other levels of alignment that are to be performed on the project require that precision tapes be inscribed to design dimensions. A reference tape calibrated by the National Bureau of Standards will be provided. This will be a steel tape which will be used on a tape bench located in a thermally controlled environment in Accelerator Access Structure No. 1. The initial concepts for this facility and the design of the required hardware were started during the reporting period.

Precision Invar tapes which will be used for alignment in the field will also be compared to the reference tape and inscribed as required.

4. End Station Grids

To provide for fast and reliable alignment in the End Stations, rectangular monument grids on ten-foot centers will be installed. The design of the hardware necessary for these grids and the procedures required to install the grid monuments were completed during the quarter. A microbar assembly will be the heart of the installation as well as the measuring device used to evaluate the monument locations once the grids are installed. The assembly went into fabrication during the period and will be delivered in the next quarter.

5. Coordinate Calculations

The beam geometry output was provided by the program TRANSPORT, and computations were made to convert this output to an orthogonal reference system originating at Central Monument (CM) located at Accelerator Station 105 + 08. Further computations were made to convert locations in the CM system to the conventional engineering reference system. Very precise determinations of vertex locations were computed, checked and used in the BSY.

VIII. KLYSTRON STUDIES

A. SUMMARY

During the quarter, deliveries of klystrons from Sperry and RCA have continued at a satisfactory rate, and the first three tubes of the Litton procurement were received. As a result of the continuing deliveries and taking into account the tube failures during the quarter, we had at the end of the quarter 60 tubes useable for spares, 23 tubes still in test, and 36 tubes installed in the Klystron Gallery. A graph depicting quarterly operating experience of all klystron vendors is shown in Fig. 5.

The Stanford back-up program to provide klystrons for installation in the Gallery was slowed down by permanent magnet difficulties and by a rash of window failures on Stanford tubes. A serious effort has been undertaken to understand the reasons for the Stanford window failures and to improve the coating and fabrication techniques. It is particularly discouraging to suddenly experience almost 50% window failures when six windows which are on life test have an operating time in excess of 6000 hours each with no indication of failure.

Ten klystrons were changed in the Gallery, six because of pulse transformer tank problems, three because of broken windows, and one for ceramic cathode seal puncture. One tube was changed with the sector in operation, and resulted in only 3 seconds interruption for the two adjacent tubes.

B. KLYSTRON PROCUREMENT

Our vendors are continuing to experience problems with the yield of the tubes being manufactured for Stanford.

1. RCA Subcontract

In the case of RCA, the major problems have been in fabrication and processing, with a residual problem of instabilities and "glitches." Improved tuning of the cavities and the output system have helped reduce the instabilities.

The magnet delivery problem has also continued to plague RCA; the manufacturing facilities of their magnet supplier have been relocated with considerable disruption of the magnet delivery schedules.

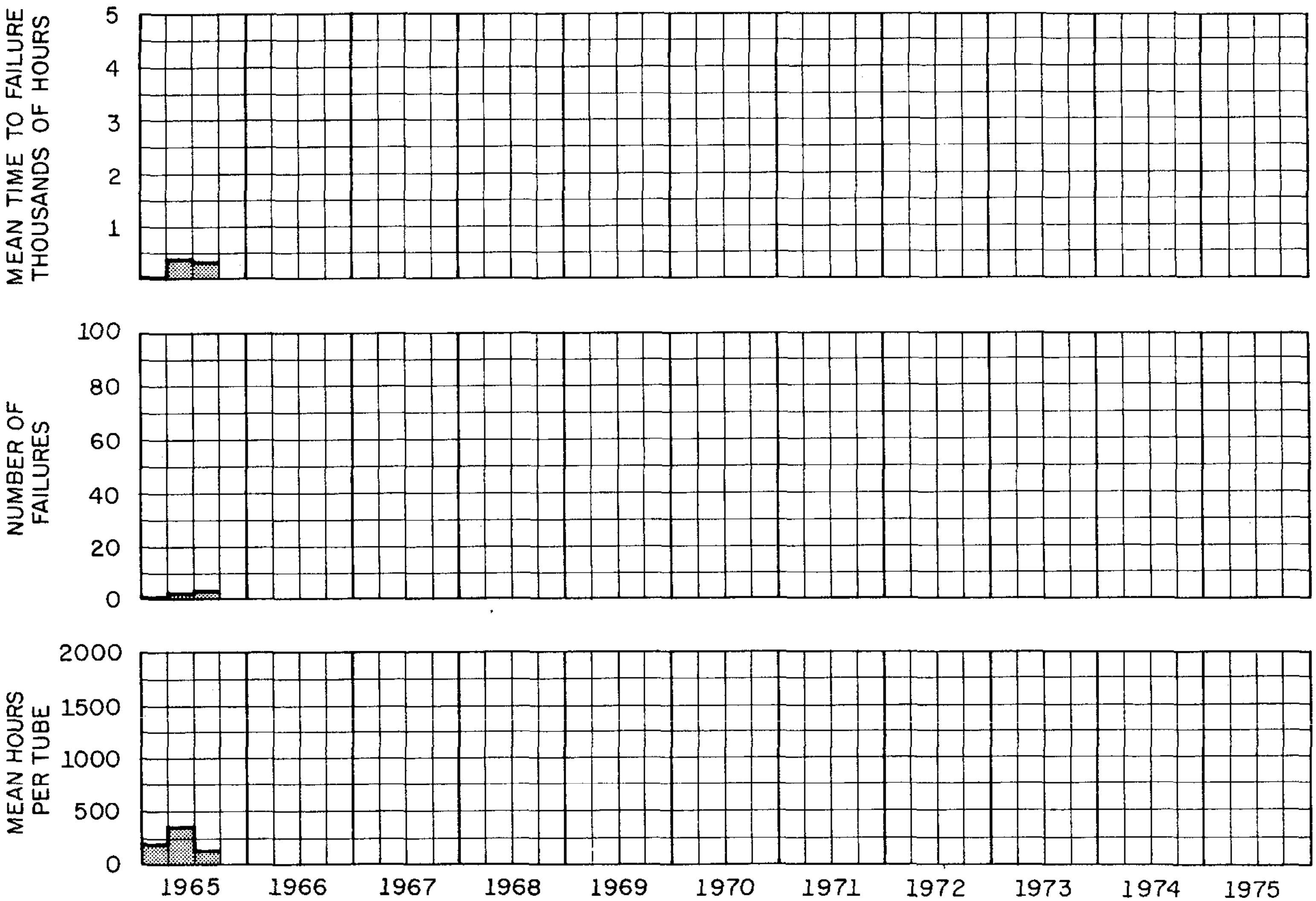

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FIG. 5 -KLYSTRON QUARTERLY OPERATING EXPERIENCE- ALL HIGH POWER KLYSTRON VENDORS

Upon resumption of sector tests, one of the RCA tubes which had been in use in Sector 2 since January was found to have suffered a broken window. The whole ceramic disk had crumbled, and the exact reason for this failure has not been discovered. Two additional RCA tubes were found to have suffered window failures, probably near the end of the acceptance test, and have been considered as shelf life failures.

RCA analyzed one of the tubes which had failed at Stanford; their conclusion is that the collector may be marginal, and they are planning to carry out some collector redesign.

2. Sperry Subcontract

As in the case of RCA, the manufacturing yield at Sperry has been less than the manufacturer's expectation, but a gradual improvement is evident, particularly in terms of sparking failures.

The problem of greatest concern with the Sperry tubes was the design of the output window. If a Sperry window should fail by thermal shock or any mechanism which can produce a crack in the window, it is possible for either water or water vapor to be admitted both in the waveguide load system and in the tube. In fact, two Sperry windows failed during the present test of the accelerator. A window redesign was undertaken by Sperry to insure that the Sperry tubes to be delivered in the future will not present this danger to the accelerator.

Sperry has also begun drop-shipping magnets directly from their magnet supplier to Stanford, since the tubes and these magnets are designed to be interchangeable. Unfortunately, the initial tests of tubes and magnets received independently have not been encouraging. Further work will be required during the next quarter to resolve the difficulties.

3. Litton Subcontract

Production problems were experienced by Litton in the initial phases of their subcontract. Several changes which they had introduced in the tubes in order to reduce production costs resulted in unstable tubes. The three tubes now received from Litton were awaiting test at the end of the quarter.

4. Stanford-Built Klystrons

The acceptance of Stanford klystrons after installation and initial tests on permanent magnets has been, in general, satisfactory from a power output standpoint. However, a high incidence of window failures developed so that the net yield of Stanford tubes has been disappointing. Nine SLAC klystron window failures occurred during the quarter (11 have been experienced since the first of the year).

C. KLYSTRON RESEARCH AND DEVELOPMENT

The emphasis during the quarter has been concentrated on testing tubes in permanent magnets for eventual use in the Gallery. Additional work has also been carried out in the areas discussed below.

1. Ion Pumps

Six ion pumps have been built for use with Stanford tubes. These pumps are designed to operate in the magnetic field provided for the beam focusing. They appear to be useful in processing the tube after pinch-off, and so far no failures have been observed with these pumps.

2. Processing

As mentioned in the previous quarterly report,* an attempt had been made to modify the processing schedule to improve the final tube vacuum. The results, unfortunately, were not satisfactory in permanent magnet because of high anode interception, and the former SLAC processing schedule is again in use.

3. Windows

The SLAC klystron tube is designed in principle so that the window can be easily removed from the tube body and replaced without any machining of the tube. Basically, the vacuum seals are made by copper gaskets between stainless steel flanges. In practice, unfortunately, copper diffusion into the stainless steel during the baking cycle makes it very difficult to remove the window without damaging the flanges. Several attempts have been made to eliminate the diffusion, but so far none have

*"Two-Mile Accelerator Project, Quarterly Status Report, 1 April to 30 June 1965," SLAC Report No. 48, Stanford Linear Accelerator Center, Stanford, California (1965); pp. 53-54.

proved satisfactory. In general, the attempts have consisted of a thin plating on the copper gasket of a material like chromium; these attempts resulted in vacuum leaks.

4. Extended Interaction Cavity

Work is continuing in an attempt to improve klystron efficiency by the use of extended interaction output cavities. At the end of the quarter a tube had been built and was being tested in which the output cavity was a two-cavity structure operating in the backward wave mode. The gap spacing was synchronous for a voltage of approximately 75% of the beam voltage. Initial tests indicate that the external Q of the cavity was not properly optimized; work will continue next quarter in improving the output of this tube.

D. KLYSTRON TESTS AND MEASUREMENTS

Since the reorganization of the test stand area which occurred July 1, 1965, the overall performance of the test and maintenance group has continued to be extremely satisfactory. Of a total of eight test stands used for high power tube tests, the average off-time for maintenance was below 100 hours for the quarter, for a test stand availability of approximately 93%. The total operating time was approximately 7500 hours. During this period four thyratron switch tubes had to be replaced, there were 12 trigger generator failures, eight sub-booster switch tube failures, and one pulse transformer failure. The maintenance crew also continued the improvements and modifications on the main modulators, including Variac modifications and pulse forming network modifications. A total of approximately 250 individual tests were run during the quarter: 130 tests for acceptance of vendor klystrons (including the measurement of the tube performance and the 20-hour high power runs, counted as separate tests), 32 final acceptance tests (of the tube mounted in pulse transformer tank ready for installation in the Gallery), and 90 tests for Stanford-built tubes (including special electromagnet and permanent magnet tests and acceptance tests).

The efforts to improve the accuracy and reliability of the test stand measurements have been continuing. Our reference capacity voltage dividers have been calibrated by the National Bureau of Standards and their measurements agree with our values to within 0.2%. In general, the power data obtained at Stanford checks very well with that reported by klystron vendors, although on occasion a run of low readings (approximately 5% low power) compared to the readings of both RCA and Sperry has occurred. Cross-calibration of the vendor equipment with our own continues.

An accurate non-inductive resistive load consisting of twelve 83.3-ohm non-inductive resistors has been purchased. A water-cooled circulating oil bath will be built around the unit, which operates satisfactorily but cannot take full power for more than a few minutes without adequate cooling. The load package will be a cylindrical aluminum tank which can be plugged directly into the pulse transformer tank.

E. GALLERY OPERATIONS

The data acquired during the tests of Sectors 1 and 2 suggested that there may be inconsistencies in the tracking between the de-Q'ing reference voltage, the variable voltage substation output, and the klystron beam voltages. In an effort to resolve this problem, it was decided to run Sectors 5 and 6 for 100 hours continuously at various reference voltages and repetition rates. All pertinent modulator, klystron, sub-booster, and variable voltage substation data were recorded during each test. The run was successfully completed near the end of the quarter with no interruptions, and the data from the run is now being reduced.

For these tests, it was decided to use a Z-head oscilloscope for the measurements of klystron beam voltages, because there still appears to be some noise pick-up or similar discrepancy in the readings of the peak reading voltmeters used during the initial shakedown of the sectors. Hopefully, the problems of the peak reading voltmeters can be resolved in the near future to enable a much easier and speedier acquisition of data in the Gallery.

F. HIGH POWER KLYSTRON WINDOWS

This quarter has been one of klystron window crisis, with a total of 17 window failures occurring or being discovered during the period. Nine SLAC klystron windows failed, bringing the total of in-house window failures to eleven since the first of this year. In addition, there are at least five windows which are in danger of thermal failure on the basis of alarmingly high operating temperature. Eight window failures were also reported on vendor klystrons during the quarter, five on Sperry tubes and three on RCA tubes.

It seems apparent at this time that most SLAC window failures can be traced to exposure to more than one tube bake cycle or to excessive coating thickness. In either case, the immediate cause of window overheating seems to be a decrease in the resistance of the coating layer during the vacuum bake cycle. The mechanism of the coating resistance change is presently being investigated, and multiple bake cycles and thick coatings are being avoided in order to decrease the likelihood of additional window failures.

Sperry window failures appear to be caused by multipactor. Multipactor has been observed on most of the recently received Sperry klystrons, particularly on the four window casualties which were observed during operation. Multipactor can be suppressed on the load side surface of Sperry tube windows by application of an evaporated film of titanium; but this remedy is at best partial because it can do nothing about the multipactor which is probably occurring on the tube-side window surface.

The three RCA window failures all occurred or were discovered during the last week of this quarter. Only one of the three failures can be tentatively explained at this time, the failure which was discovered on a klystron delivered in early November 1964. This window apparently represents a carry-over of the RCA window problems of last summer, before RCA switched to low-loss ceramic and began to use window coating.

1. <u>Resonant Ring Tests</u>

a. Klystron Window Pretesting

Routine pretests of all klystron windows are continuing to serve as a standard for tube window serviceability. Eighteen windows were pretested this quarter, one of which was disqualified for excessive coating when it exceeded the arbitrary limitation set for pretest window temperature. Two or three other windows with coatings nearly as thick, according to crystal monitor measurements, did not overheat during ring test, but one of these did fail in tube service. It therefore appears that while ring tests can be relied upon to identify windows which have not been coated sufficiently, the ill effects of excessive coating may not become apparent until the window is exposed to the tube bake. Crystal monitoring of window coating is expected to replace ring pretesting as a window acceptance criterion, but certainly will not do so before the present window failure problem is completely resolved.

b. Tests of Vendor Window Coatings

The Sperry window coating tests begun last quarter[1] were completed with the retest of the window with the standard Sperry coating after a layer of SLAC coating had been added. The slight localized multipactor which had been observed on this window previously was no longer evident, but no significant change in operating temperature was observed.

A second test sequence was performed on two Sperry coated ceramics using a test geometry roughly equivalent to the Sperry tube window structure. These window specimens were tested before and after exposure to a braze cycle intended to simulate conditions encountered during fabrication of the Sperry window assembly. The apparent effect of wet hydrogen firing was the removal of all or most of the window coating, as was indicated by visible symptoms of multipactor and window overheating (temperature gradient, 180°C at 22 MW). The appearance of the multipactor glow pattern was quite similar to that observed on recently received Sperry tube windows, including several which have failed. The effect of a dry hydrogen firing cycle was also observed due to an early misunderstanding of the Sperry brazing conditions. Dry hydrogen firing apparently results in reduction of the coating to a low resistance film which suffers excessive I^2R loss (temperature gradient, 140°C at 7 MW). Sperry coating tests are scheduled to continue in the near future with ring tests of two more coated ceramics which have been exposed to all of the actual window fabrication and tube processing conditions at Sperry. Results to date, however, strongly indicate that wet hydrogen firing is responsible for deterioration of the Sperry window coating. Corroborative evidence in support of this conclusion has been provided by the effectiveness of an evaporated titanium coating in suppressing load surface multipactor on Sperry windows.

[1] *Ibid.*, p. 64

Litton coating has also been evaluated by ring tests of a pair of SLAC windows provided with standard Litton coatings. Both of these windows performed quite well in test. Temperature data was essentially identical to that normally observed during operation of SLAC coated windows; no visible evidence of multipactor could be detected. These coatings are to be submitted to further tests, at which time the effects of vacuum bake cycle will be evaluated.

c. Window Coating Tests

The effect of exposing a coated window to the vacuum bake cycle was further investigated by ring testing. The conditions encountered by a window which has udergone prebake as well as the normal bake cycle were simulated, and the test window was exposed to two successive bake cycles. The marginal increase in window temperature gradient which followed this processing did not indicate a significant change. In another test of vacuum bake effect, the test window was taken from the vacuum bake furnace and mounted in the resonant ring in the briefest possible time in order to limit as much as possible reoxidization of the baked coating upon its exposure to air. A significant increase in temperature gradient (to $50^{\circ}C$) was observed in the ring test of the test window which followed. This result tends to support the theory that vacuum baking does decrease window coating resistance and thereby causes increased window operating temperature, and that this effect of vacuum baking is reversed by atmospheric exposure of the baked coating.

Investigation of so-called impurity film was continued with the operation of a multipactor-free uncoated ceramic first tested in the "low-vacuum" ring. After being exposed to a vacuum bake cycle, this window suffered thermal failure which was apparently due to resistive losses rather than multipactor heating. Further tests on the impurity film and its stability through various heat cycles and cleaning processes will continue as time permits.

d. Material Study Tests

The test sequence on three samples of Pyroceram 9606 begun last quarter was completed with operation to thermal failure of a titanium oxide coated sample. This specimen failed at 25 MW, 30 kW, when the center of the window melted and bubbled after the temperature gradient had exceeded 800°C. Because this failure behavior was identical to that of a previously tested uncoated sample, it is apparent that runaway dielectric loss, not multipactor heating, was the cause of both failures.

Two samples of Corning 7070 glass were tested to thermal failure at ≈ 10 kW of average power. One of the two windows was tested at 60 pps and was withstanding peak power at 60 MW at the time of its thermal failure at 10 kW. The other sample failed in a similar manner at 8 kW while operating at 360 pps. Both windows suffered runaway dielectric loss heating upon reaching temperatures of ≈ 400°C, whereupon the gradient quickly climbed to 600°C and beyond as the window became molten. No evidence of multipactor was observed in either test, but the combination of high dielectric loss and low thermal conductivity makes this material unsuitable for high average power window service. Its dielectric strength did appear to be sufficient to permit operation at relatively high peak powers.

Upon completion of the above material tests, Stanford's original resonant ring was retired from service and dismantled to make room for another tube test modulator. This ring, which had been in continuous use since its construction in 1957, is believed to be the first resonant ring built on the West Coast and one of the first to be used for high power evaluation of microwave windows. The old ring has been of limited usefulness during the past two years, especially since completion of the all-metal, high-vacuum ring which will now carry the full burden of SLAC window test work.

2. Window Life Test

An additional 900 hours of operating time during the past quarter has brought the total window life test duration to some 6500 hours. Operation for the first 500 hours was in the range of 20 - 22 MW peak power, but decreased to 18 - 20 MW during the last 400 hours following a three-week interruption for modulator modification and repair. One of the original six windows has begun to operate at temperatures significantly higher than the rest of the windows (up to 150°, some 20° to 50° higher than other windows during operation at 21 - 22 MW). There is as yet no indication that the window has failed.

3. Other Window Work

a. Window Coating Activity

Crystal monitoring was used to measure relative thicknesses coated on 24 windows during the quarter. However, because the upper and lower limits of effective coating thickness are not yet established, crystal measurements do not yet provide a reliable method of coated window acceptance. In addition to the difficulty of maintaining coating stability through bake cycles, there are other window coating problems which have to do with control and identification of the sputtering process and its end result. In order to improve our coating techniques as much as possible, a number of coating experiments are planned, including survey of coating distribution, effect of substrate temperature, calibration of the crystral monitor (by optical measurement of film thickness), and in-process temperature correction of crystal measurements.

An existing device for evaporating a titanium film onto the load side of SLAC klystron windows has been modified to adapt to the task of coating Sperry klystron windows. On-tube coatings were applied to two Sperry tube windows with resulting suppression of load side multipactor. A coating was also applied to one of the "hot" SLAC klystron windows, but, as could be expected given the apparent nature of SLAC window heating (resistive losses on the tube-side window surface), the coating had no apparent effect on operation and the window subsequently failed thermally.

Typical coatings applied to vendor tube windows have been measured by means of crystal monitors sent to each of the four tube producers. Despite the variety of coating methods and coating thickness control techniques used by the vendors, the crystal monitor measurements showed a surprising similarity in the coating thicknesses applied, all of which fell within a range of 40 to 100 Å.

b. Tube Window Failure Problem

Seven of the eleven SLAC tube windows which have failed this year and two of the five "hot" windows were among a group of fifteen which were exposed to more than one vacuum bake cycle. Of the remainder, two failures and two "hot" windows had coatings which were abnormally thick and as a result may have suffered reduction to critically low resistance during a single bake cycle.

An experiment has been devised and is now in process which is aimed at verifying the theory that window overheating is traceable to coating resistance reduction during vacuum bake. Resistance measurements are made between two points on the window surface as the coated window is being heated in an evacuated bell jar through the temperature range of a vacuum bake cycle. Preliminary results show significant decreases of coated surface resistance at bake cycle temperature. The resistance change is at least partially maintained when the window is allowed to cool, but increases abruptly upon exposure to air. Another preliminary result indicated a significantly lower resistance-versus-temperature curve for a window coated with approximately three times the normal thickness. These results do seem to support the hypothetical explanation.

G. SUB-BOOSTER KLYSTRONS

The option for the second group of 40 sub-booster klystrons has been exercised and current deliveries are against this option. Shelf life is still the major problem with the sub-booster klystron; several (four) sub-boosters manufactured during 1965 have failed shelf life tests due to pulse droop. This pulse droop is, as before, the result of gas. The latest examination of the sub-booster problem indicates that poor plating on the iron pole pieces has allowed corrosion and gas diffusion into the tube. The present remedy for this trouble is to improve pole piece plating and brazing to avoid corrosion. Several months will elapse before new tubes can be manufactured and tested for the effectiveness of this approach. Initial acceptance of sub-boosters is, however, generally good and operating life continues to be high.

IX. SECTOR TESTS

A. GENERAL

Toward the end of the previous quarter, on June 17, 1965, Sectors 1 and 2 were shut down. Operation of these sectors did not resume until late in September. During the intervening period three major programs were completed in Sectors 1 and 2.

1. Rewiring

When first installed, Sectors 1 and 2 were wired in a deliberately temporary fashion, as it had been planned that the initial period of operation was to be the prototype test period both for equipment and for overall design. Based on the experience gained during the January-to-June period of operation, design changes were made in such equipment as the modulator/klystron package, vacuum gauge controller, modulators, etc. Intra- and inter-sector wiring design was also updated during this period. To bring the design of Sectors 1 and 2 into line with that of the rest of the accelerator, the period from the middle of June to the end of September was devoted to rewiring these two sectors.

2. Injector Installation

Operation of Sectors 1 and 2 with beam during the first six months of 1965 was with the injector from Stanford's Mark IV accelerator injecting directly into the first section of Sector 1. The Mark IV injector consisted of a simple pulsed gun followed by a single cavity prebuncher and two thin lenses for focusing. During the report period, the SLAC injector was installed. Simply, this injector consists of a pulsed gun, a single cavity prebuncher, a 0.75c buncher, and a 10-foot accelerating section. A detailed description of this injector may be found elsewhere.*

3. Injector Wiring

During the report period a major portion of the injector control console and power supply area was installed and wired. Operation with beam will be possible using this new injector when Sectors 1 and 2 are

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*R. H. Miller, R. F. Koontz, and D. D. Tsang, "The SLAC Injector," to be published in the Proceedings of the IEEE Particle Accelerator Conference, Washington, D. C., March 10-12, 1965 (SLAC-PUB-91).

operating again. The final gun modulators have not been received yet; therefore, operation will commence using the Mark IV modulators.

During the report period, there were several days of operation with the injector. This was kept to a minimum because of the difficulty of maintaining adequate personnel protection. Toward the end of August, there were four days of processing and tests of the rf portion of the newly installed injector. It took very little time to get the rf power out of the klystron up to 22 megawatts; for the testing period the klystron was run at a conservative 16-17 megawatts.

Work in Sectors 1 and 2 was essentially completed by the last week of September. RF operation began, and by the end of the period both sectors had been processed up to a klystron output level of 12 megawatts at 360 pps.

B. SECTORS 5 AND 6 TESTS

Installation and wiring of the first two "final design" sectors, Sectors 5 and 6, were completed on August 30, 1965. (Certain features not necessary for rf operation, such as the beam monitoring electronics, were not ready for installation and will be completed later.) After a comprehensive operational checkout of the personnel protection system, rf power was turned on on August 31. RF processing went quite rapidly; all klystrons were operating at 15 megawatts output power on September 3. The modulator group spent several days devising and perfecting a system for adjusting transformer taps and tuning the pulse forming networks, and then tuned the pulse forming networks in all modulators. Following this, all stations were raised to full power output.

A continuous 102-hour run took place the final week of the period (September 27 through October 1). Throughout the run, either the pulse rate or the operating level was changed hourly, resulting in several cycles of minimum to maximum average power output. At each level, readings were taken of voltages, power outputs, temperatures, kick-off's, etc. The resulting data is in the process of being analyzed.

X. BEAM SWITCHYARD

A. GENERAL

The Beam Switchyard Housing was nearing completion by the end of the quarter and the Materials Handling System installation was started. A contract was awarded for installation of the BSY electrical distribution system. Mechanical and vacuum equipment installation bids were received for the BSY and the contract was awarded to the low bidder.

The design and drafting of vacuum equipment, beam transport system equipment, instruments, supports, alignment system equipment, etc., reached a peak and began to taper off during this period, while fabrication of the equipment approached its peak by the end of the quarter.

B. INSTRUMENTATION AND CONTROL

1. Beam Monitoring Instruments

The construction of the various types of beam monitors is progressing well. The completion of several monitors is dependent on the delivery of the fast-disconnect vacuum flanges which are being delayed because of design changes, as discussed below. Most of the instruments have been tested and found to operate satisfactorily on the Sector 2 test setups.

Eighty ion chambers were reworked following their receipt from the vendor and they are now ready for installation. The chambers have a gas-tight case, and it was found that the internal parts had not been lock-washered in place at the time of their manufacture.

The zinc-sulfide screen changers and the cells and mounts for the beam profile monitor were completed.

2. Electronics

a. Microwave Beam Position Monitoring System

The design for the display of the video signals was completed and all chassis are in fabrication. Design for the normalized display of the signals is 90% completed and 60% of the chassis are in fabrication.

b. Beam Current Transformer Monitoring System

The circuits for displaying the video signals were completed. The circuits for the display of average beam current are 50% developed. A precise (0.3%) beam current integrator was nearly finished. The beam current intensity monitors were completed except for their flanges and feed-throughs, and the rf shielding needed for their output leads.

c. Tune-Up Dump Spectrum Monitor

The design of the integrator and the electronic scanner was completed and construction of the equipment was started.

d. Energy Spectrum Analyzer

The design of a gated integrator detector was completed and the electronic scanner for the spectrum analyzer is under construction.

e. Secondary Emission Foil Beam Centering Device, and Secondary Emission Foil Interlock Circuits

The electronic design for the centering device was completed and construction was started. A complete engineering prototype will be tested at the injector test stand.

f. Collimator Secondary Emmission Foils

The prototype of the A-beam dump secondary emission (SEM-15) steering foils and current monitor is being fabricated. The foil design is nearly completed for collimators SEM-1, 2, 3 and 4 for the leading and trailing edges of the collimators. Slit foils SEM-12, 14, 30 and 31 are in preliminary design.

A technique was developed for chemically milling all foils integrally with the foil holder frame to achieve optimum thermal conduction. The technique, which is still in the stage of experimental refinement, consists of anodizing the foil and plating two 2- to 3-mil thicknesses of gold on narrow conducting strips. The process has been perfected sufficiently to provide greatly increased beam resolution by the foils.

g. Magnetic Measurements

The design was completed on a unit to measure the remanent field of the magnets in the BSY where this parameter is of importance. The electronics for the unit is presently in fabrication, and the mechanical design of the probe is in work.

Because of the limitations of the fixed-frequency nuclear magnetic resonance (NMR), reported earlier, the BSY group is now designing a variable-frequency NMR for use in the 3° bending magnets.

h. General Controls

The electronic chassis for the interlock system are nearing completion. Only the summary interlock system with remote control is still under construction. Installation of the system in the switchyard control room is underway.

Instrumentation for the water cooling systems was finished. Some additional equipment for a heat exchanger in beam B is being ordered.

Vacuum system instrumentation was partly finished. Amplifiers for the fast vacuum switches are still under construction.

Remote control chassis for BSY alignment were ready for installation in the control room.

The remote ON/OFF controls for all magnet power supplies were finalized and under construction.

i. Control of Slits and Collimators

A special binary-to-BCD converter was developed for Slits/Collimators position readout and is working. Presently, the following chassis are being constructed:

Two S/C position readout chassis
One S/C shaft encoder multiplexer
One S/C position feedback multiplexer.

The following chassis are still being designed:

One S/C motor and clutch selector
One S/C position controller.

3. Computer System

Delay in delivery of the computer initially ordered for BSY control forced us to terminate the contract and order a computer which could be delivered within a tolerable time. The computer finally chosen was a Scientific Data Systems Model 925, and delivery of this unit is expected on 1 November 1965. This change necessitated a redesign of certain portions of the interfacing electronic circuits. Approximately 70% of this redesign has been accomplished and some of the interface equipment is in production.

Tests have been completed on the digital-to-analog converters to be used with the computer, and the procurement cycle for the parts and fabrication of these units has been started.

The interlock fault scanner with modification to work with the SDS 925 is completely checked out and is now working. The interface electronics to the SDS 925 has been designed and parts are ordered. The complete system should be ready for checkout with the computer around mid-November.

Preliminary computer programming for the interlock fault scanner has been studied in some detail. Only very general programming for the entire BSY controls has been studied.

4. End Station Instrumentation

Work has been started to distribute adequate data to the experimenters and to provide adequate instrumentation to the switchyard operator to monitor and control the primary beams up to the target or beam dump in the End Stations. Some of the beam monitors for this purpose are on order; others need some redesign with respect to the monitors used in the Switchyard Housing. A study has been made to determine the cable requirement between the End Station and the Data Assembly Building, as well as the rack space and rack location required for remote electronics.

C. REMOTE-DISCONNECT VACUUM COUPLINGS

Several problems were encountered in the fabrication of the remote-disconnect vacuum couplings. It was found that the ring springs on the couplings were difficult to cast from the 17-4 Ph stainless steel. The casting work was let to a second vendor who used better controls and a different method of casting to solve the problem.

The Belleville washers that had been used on the disconnects were changed to Inconel 718 coil springs. This was done because the Inconel is less susceptible to stress corrosion than the 17-7 Ph stainless steel washers. (Refer to SLAC PUB-88 for a detailed description of the disconnects and associated hardware.*)

D. BEAM DUMP

The fabricator of the 2-MW dump tanks was on strike for two months. Material was ordered for the tanks, and the shell material was delivered. The heads and copper are expected early in October, and the tanks will be built in a subcontractor shop. Their welders are being certified at the present.

A model of the beam dump window was constructed during the reporting period and preliminary tests were run on it to verify that the water velocity would be adequate to prevent window burn-out. The window, which is made of 50-mil-thick copper, has a liner about its attached flange with three slots that act as high velocity nozzles to spray the inside center of the window. Preliminary tests indicate that, with a 500-gpm flow rate in the dump tank, the rate across the window is approximately 50 gpm, which is considered adequate. Additional tests on the model will be run in the next quarter.

A model was also made of the window connection flange and the remote removal mechanism was in fabrication. The flange is held together with two 2-inch diameter bolts and titanium-coated nuts that do not weld together and have a low coefficient of friction. The hexagonal lattice nature of the titanium coating provides for dry wear in the nitric acid condition that will exist in the beam dump area. The remote removal mechanism consists of a large impact wrench that is hydraulically operated from a cart. This type of wrench was chosen because it has no torque reaction. By the end of the quarter, the mechanism and cart were completed awaiting the delivery of the hydraulic pump.

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* R. Allyn, A. Eldredge, M. Heinz, A. J. Keicher, "Microwave and Fast-Acting Valves and Vacuum Couplings for Accelerators," presented at the IEEE Particle Accelerator Conference, Washington, D. C. March 10-12, 1965 (SLAC-PUB-88).

E. SLITS AND COLLIMATORS

1. High Power Slits and Collimators

The cover machining of the modules and 80% of the machining of the module bodies was completed. The contractor studied the welding problem at some length, made a proposal, and the proposal was accepted. The modules with thin walls will be hand, TIG welded, and the thick walls will be electron-beam welded. The first module will be delivered on October 15th.

The material is on hand for the strongbacks that hold the modules. The contract for their fabrication has been awarded and delivery was to have been made by the end of the quarter.

The first collimator frame will be delivered early in October, and the remaining slit and collimator frames by late October. Assembly of the first collimator will start in early October in the Electronics Assembly Building.

2. Hi-Z Slits and Collimators

The material for the tanks and heads has been received and fabrication was to start when manpower was available. The copper modules will be ready for brazing early in October. Actuating arms, cables, bearings, etc., will be ready about the same time.

3. Protection Collimators

Most of the machining work on the copper parts was completed. Protection collimators PC-10, 11 and 31 were completed and sealed off.

Protection collimator PC-31 was installed in the Accelerator Housing at the end of Sector 2 and was essentially used as a beam dump. The collimator was mounted at the end of the beam analyzer station and above, with the beam being deflected into it by a magnet. It served as a beam stopper without requiring that a special unit be built for sector test, and it also provided a means for the test of the protection collimator itself. The beam was deflected in such a fashion that it was out of the normal aperture or beam path of the collimator, so the test was not fully comprehensive, but it was successful to the extent of testing.

F. ALIGNMENT

1. Equipment Targeting

Procedures were developed for the production shop alignment of 3° bending magnets, the 8-cm and 18.6-cm quadrupole magnets, the pulsed, pulsed steering, dc emergency and dc steering magnets, as well as for the protection collimators and beam analyzing instruments. Bore target reference fixtures were fabricated for the 3° bending magnets and the quadrupole magnets to facilitate the production alignment of these magnets.

2. Alignment Targetry Procurement

The purchase orders for all the alignment targetry have been let. This includes the stainless mirror targets, tooling ball reference pads, mounting pads, lockable target shields, bulls-eye targets, etc. A severe problem arose on the heat treatment stabilization of the 440° C stainless steel mirror target and the polishing of the mirror, but these problems were worked out.

3. Alignment Room

The air conditioning unit was installed in the alignment room in the Heavy Assembly Building. Tooling bars were installed in the room and the room was occupied by the Precision Alignment Team. The calibration test stand was set up in its own room in the alignment room to facilitate the on-site calibration of instruments to maintain maximum confidence in the instruments.

4. 24-Inch Light Pipe

The change order for the four Beam Switchyard girders was negotiated with the supplier. Delivery is to be in mid-September.

5. 10-Inch Light Pipe

Design of the light pipe system was completed and purchase orders were let for all components including the target reference plate, target housing, pedestal, alunimum pipe, flanges, Fresnel lenses and actuator assemblies. Delivery of these items is scheduled from early October to late November.

A prototype alignment target station was fabricated identical to the production unit to test the position mechanism, the vacuum seal, the

Fresnel lens actuating mechanism, and the mechanical stability of the external reference targets relative to the Fresnel lens. All of these tests have been completed except the stability test on the targetry, which will be run in October.

G. SUPPORTS

1. 7-, 10-, and 12-Foot Instrument Stands

August was spent in helping the vendor line up his planer to insure that the tolerances stipulated by SLAC would be met.

The first leveling bed was delivered in September. It checked out very well. Deliveries are to continue through November.

2. Magnet Supports

The following magnet supports were delivered:

a.	3° bending magnets	16
b.	8-cm quadrupole magnets	12
c.	18.6-cm quadrupole magnets	2
d.	3° dump magnets	4

The following magnet supports will be delivered in November: B-29, B-36, PM-30 and PM-1 through PM-5.

XI. RESEARCH AREA OPERATIONS

Work continued during the quarter toward mounting the initial experimental program which is planned to meet the availability of beams from the accelerator upon its completion. Detailed layouts have been made of all the known experimental beams, and design of special items of experimental apparatus is in process. The status of the major classes of general purpose equipment is discussed below.

The buildup of personnel who will be responsible for the day-to-day operations of the Beam Switchyard and End Stations has begun, and steps are being taken to assign some of these personnel to the construction activity in these areas.

The status of the major items of general-purpose equipment follows.

A. BEAM TRANSPORT SYSTEMS

The design and initiation of procurement of magnets and power supplies for transport of secondary beams and of the primary beam within the End Stations is essentially complete. Deliveries of power supplies are expected to begin before the end of the calendar year and will be followed by magnet delivery commencing early in 1966.

Design of associated apparatus such as regulators, instrumentation, control panels, interlock summary panels and magnet stands is also complete and has entered the procurement cycle.

B. SHIELDING

Design of concrete shielding blocks for use in End Station walls, in the B-Beam target port funnel, and in the tunnel between End Station A and Beam Dump East is complete, and procurement has begun.

Some further concrete blocks will be procured for general use and will be ordered before the end of the year. Clean-up machining of steel scrap ingots for use as μ collimator shielding is well underway; about 500 tons had been completed at the end of the quarter.

Sufficient lead material is available on site for the presently envisaged program.

C. HEAVY RIGGING EQUIPMENT

An order has been placed for a 50-ton fork lift with crane jib attachment which will be used as a general-purpose rigging tool in the Research Yard and elsewhere on site. Delivery is scheduled for early in 1966. Budgetary pressures have made it necessary to delay consideration of the procurement of other heavy machinery until a later date, but such machinery is available on a rental basis.

D. LIQUID HYDROGEN TARGET SYSTEMS

An in-house design program for cyrogenic targets has begun and procurement of components of the first prototype system will be initiated during the next quarter. Progress has been sufficiently encouraging that a parallel procurement at LRL has been cancelled. Some SLAC personnel have continued to use the LRL facilities to learn technological skills and gain experience.

The SLAC cryogenic target system is a fully automatic, remote-controlled system which will not require full-time operator attendance. The first prototype is scheduled for cold tests in April 1966 and later models will be ready as required for physics.

Design work for the supporting systems — such as the liquid hydrogen storage vessel, the distribution system,the transportable dewars, and the venting and safety systems attached to the target — is 75% complete. Figure 6 shows a schematic of a typical target system with vents and transfer lines.

E. PRIMARY BEAM INSTRUMENTATION

Mechanical design of beam instrumentation packages to be used in the End Stations is 60% complete. All criteria have been established, and some parts are already in fabrication.

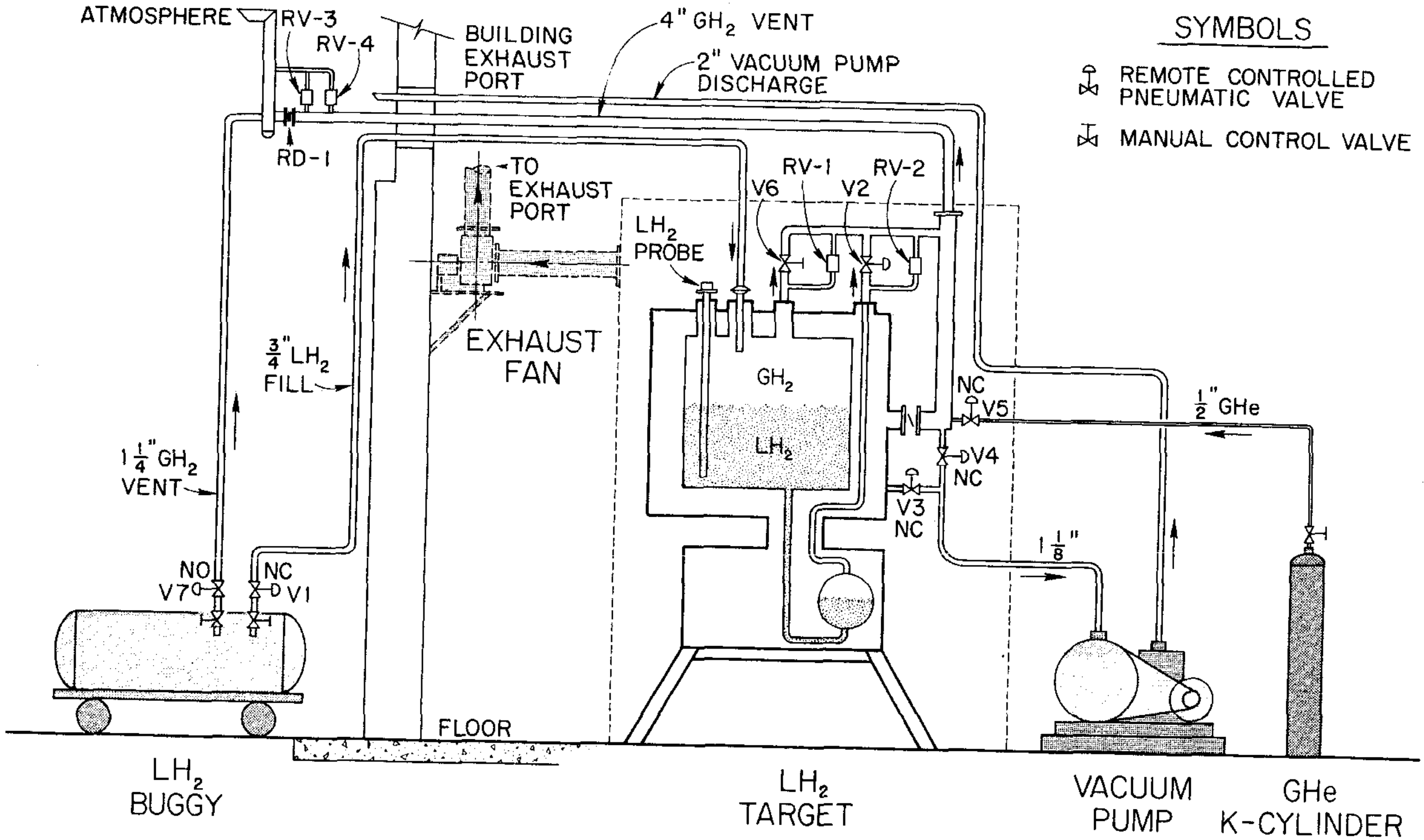

Fig. 6 - LH_2 TARGET SYSTEM END STATION B.

442-1-B

XII. PRE-OPERATIONS RESEARCH AND DEVELOPMENT

A. EXPERIMENTAL GROUP A

1. General

During the past quarter Group A has continued design effort and begun many of the major procurements necessary for the construction of the spectrometers. Engineers from Group A are also designing the magnets and supports for the 1.6-BeV system for which Group F is responsible.

2. Spectrometers

a. 8-BeV Spectrometer

All of the magnet coils and yokes have been ordered. Final assembly is to be done in-house, commencing early next year. A portion of the copper conductor has been received.

The design of the main frame of the spectrometer has been completed and the girders placed out for bid. Bids were received on the bogies and an order placed.

Design of the shielding carriage is continuing and proposals have been invited for elements of the drive system.

The design of the electrical system of the spectrometer has been started. The most serious problem is proving to be the conductors which carry the large magnet currents – typically 3000 amperes. It seems evident that we must use water-cooled cable as much as possible, and the economics of various types is being investigated.

The vacuum chamber design is continuing. Preliminary design of the central pivot, to which all three spectrometers are attached, has been done, and the bearings were ordered, in order to take advantage of a batch the vendor was running for another customer.

b. 20-BeV Spectrometer

Many of the items mentioned for the 8-BeV spectrometer apply equally to the 20-BeV device.

All of the magnets except the sextupoles have been ordered. The sextuplets will be machined in-house, commencing next quarter, and the small coils will not require a special copper procurement.

The girders of the main frame have been designed and put out for bid.

3. Power Supplies

Invitations for proposals for the power supplies have been prepared during the quarter; the largest power supplies, 1.6 megawatts, were well into procurement at the end of the quarter.

4. Detectors

Design on the detectors was firmed up during the quarter, and the associated electronics will soon be procured by the Massachusetts Institute of Technology.

Design is also proceeding at SLAC on the interface between the system being designed at MIT and the on-line computer.

The SDS 9300 processor which will be used on-line was delivered early this quarter, and acceptance tests on the system were completed in September. Preparations were begun for the large programming effort which will be required in this system.

5. End Station Preparation

Consideration of the counting house led to an expansion program in which a mezzanine was added to the counting house to considerably increase the floor space available.

Work has begun on the design of several monitors which will be required in the main beam.

6. Positron Source

Most of the design work on the positron-source system in the third girder of Sector 11 is complete, and construction is beginning.

a. Targets

The retraction mechanism and the drive system for the positron source are being designed. The radiator itself, with its support structure, has been designed, and the bearings, bellows, crank arms, and other long-lead components have been ordered.

b. Solenoids

The contract for the hollow conductor coils for the uniform-field solenoid was awarded, as was the contract for the edge-cooled coils for the tapered field solenoid. Initial progress on both contracts is satisfactory.

The frames for the hollow conductor coils were received. Some rework was necessary, but they will be ready when we start receiving the coils. It has been decided that the coils will be magnetically aligned on the frames (each is about two feet long) and the frames then will be mechanically aligned on the girders. At present it is not planned to verify the magnetic alignment with the coils in place in the tunnel.

The design for the housing for Solenoid A, the high-power coil upbeam of the target, was completed and procurement of various parts begun.

c. Instrumentation

The instrumentation and control units are the last things to be specified, and this is nearing completion.

B. EXPERIMENTAL GROUP C

1. <u>3-GeV Storage-Ring Studies</u>

a. Summer Study

A summer study on the problems of beam stability in storage rings was held at SLAC between June 28 and July 30, 1965. Representatives from most of the laboratories in the world currently engaged in high-energy storage-ring design, construction, or operation participated. Early in the summer study a general meeting was held to review the current status of our knowledge on beam instabilities. This two-day meeting was attended, in addition to the summer study participants, by physicists from SLAC, Lawrence Radiation Laboratory, MURA, and Argonne. Reviews were given of the status of various storage-ring projects around the world and of past theoretical and experimental studies of instabilities in circulating beams.

It was apparent from this review meeting that the principal area of uncertainty lay in our understanding of coherent oscillation phenomena for bunched beams for both the case of single beam and of two interacting beams. Substantial progress was made on these problems during the summer study. The results of the study are reported in detail in SLAC Technical Report 49, in the form of contributions by the authors of the works. The value of the summer study is attested to by the frequent references to this report at the International Conference on High-Energy Accelerators at Frascati during September.

The most important conclusion reached by the summer study participants was that high-energy electron-positron storage rings are feasible and that there are several modes of operation of such storage ring which would allow one to achieve the required high luminosities.

b. Colliding Beam Vacuum

During this quarter the 10-foot model of the proposed vacuum chamber was run for extensive periods under simulated operating conditions. The cryopanel was cooled with liquid nitrogen at $77^{\circ}K$ to $90^{\circ}K$ and gaseous helium at $7^{\circ}K$ to $15^{\circ}K$. Preliminary quantitative data were collected for chamber pressure, pumping speeds, electron desorption rates, and heat loads. A soldered joint in the cryopanel was damaged during one of the tests and fabrication was started on a new cryopanel. The new cryopanel will have glass-bead blasted surfaces instead of the black coating used on the present model.

2. Vacuum Measurements

a. Electron Desorption Rates

Prior to installation of the cryopanel, the electron desorption rate was 2.4×10^{-3} molecules/electron. There were some hydrocarbons present due to the supplier's initial contamination of the mass spectrometer. After installation of the cryopanel, the electron desorption rate rose 7×10^{-2} molecules/electron. This desorption rate was independent of the electron energy and electron density, and did not decay with time in a normal way. These high desorption rates are believed to be due to hydrocarbons originating with the polyester resin used to bond the black paint to the cryopanel, which had been baked at $240^{\circ}C$ prior to installation.

b. Pumping Speed Measurements

The Varian 'Q' meter was employed to establish pumping speed at both ends of the chamber and near the pumps. Measurements were made with CO, N_2 and H_2 and the following numbers obtained:

Gas	Condition	Speed (liters/second)		
		At Pump	Near Pump End	Far End
CO	Turbopumping Only	---	14	11
CO	Ion Pumping Only Conductance Limiter Closed	375	52	36
CO	Ion Pumping Only Conductance Limiter Open	375	262	103
N_2	Turbopumping Only	---	9	7.2
N_2	Ion Pumping Only Conductance Limiter Closed	360	37.5	27.4
N_2	Ion Pumping Only Conductance Limiter Open	360	260	78
H_2	Turbopumping Only	---	39	34
H_2	Ion Pumping Only 'C' Closed	1000	135	110
H_2	Ion Pumping Only 'C' Open	1000	500	244

c. Pressure Measurements

Generally, the following pressures were observed:

Prior to installation of cryopanel	2×10^{-9} torr
After installation of cryopanel	
With LN_2 in cryopanel	5×10^{-9} torr
With He in cryopanel	3×10^{-9} torr
With LN_2 and He in cryopanel and with electron bombardment (12.5 kV, 80 mA)	1.5×10^{-7} torr

3. Cryopanel Heat Loads

The liquid nitrogen and refrigerated helium cooling system were satisfactory for making the vacuum tests given above. However, the systems had too many external heat leaks, and the instrumentation was not sufficiently refined to give adequate heat-transfer data.

The crude measurements which were taken indicate that the heat load to the LN_2 system was 75 to 100 watts with no loading from the simulated electron beam. This confirms the results given by a computer program which has been written for the purpose of calculating the radiant interchange within the vacuum chamber. A soldered joint in the helium section of the cryopanel was accidentally melted out in an attempt to generate sufficient heat in order to obtain a significant increase in the helium refrigerator load.

A new cryopanel is being fabricated, and the nitrogen and helium systems are being revised to permit refined measurements of the thermal loads. Several design changes are being made in the fabrication of the new cryopanel. In particular, the support system for the helium fins is being revised since it was found that some of the stainless steel support wires had undergone a phase change and had broken.

4. Electron Desorption Studies

Total gas desorption measurements were carried out on aluminum evaporated onto copper and on solid aluminum surfaces. The results to date are summarized below:

2000 Å Al on Copper

Surface Condition	Electron Energy (eV)	Total Desorption Rate (molecules/electron)
$60^{\circ}C$		
Initial rate following pump-down to $< 10^{-9}$ torr	20 5000	5×10^{-4} 1.1×10^{-3}
$60^{\circ}C$		
Following 4h bombardment at 5 kV, 10 W/cm^2	20 5000	1.2×10^{-5} 3.4×10^{-5}
$60^{\circ}C$		
Following an air exposure and subsequent pumpdown to $< 10^{-9}$ torr	20 5000	3.4×10^{-4} 5×10^{-3}

Solid Al Surface

Surface Condition	Electron Energy (eV)	Total Desorption Rate (molecules/electron)
60°C		
Following initial pumpdown to $< 10^{-9}$ torr	20 5000	3.1×10^{-2} 1.2×10^{0}
60°C		
Following 48 h bombardment at 500 V, 10 μA/cm²	20 5000	7×10^{-4} 1.0×10^{0}
100°C		
Following 2 h bombardment at 200 V, 10 μA/cm²	20 3000	4.7×10^{-5} 1.6×10^{-4}
200°C		
Following 18 h continuous bombardment at 500 V, 10 μA/cm²	20 3000	3×10^{-6} 6×10^{-5}
60°C		
Following 20 h NO beam at 4×10^{-10} torr	20 5000	6×10^{-5} 6×10^{-5}

In almost all instances, after bombarding at high energies (> 500 volts) the highest desorption rates were observed to occur at energies near 500 eV. This is believed to be due to multiplication and scattering as the electrons reach the Al_2O_3 - Al interface. This hypothesis will be checked by measuring desorption rates on aluminum surfaces with a range of controlled oxide thicknesses.

The only exception to the above-mentioned maxima near 500 eV for these surfaces occurred when the previous bombarding maximum energy was exceeded, in which case a sharp increase in gas production was measured.

5. RF Studies – Storage Ring

Design has begun of an experimental accelerating station consisting of a cavity, a 200-kilowatt rf amplifier, and associated coupling and tuning devices. A set of technical specifications has been prepared which describes a suitable final amplifier, and the feasibility of procuring this amplifier from a commercial vendor is being investigated.

A detailed analysis of a high-efficiency rf amplifier was made to assess the feasibility for use in the storage-ring experiment. This amplifier employs a third-harmonic resonant tank in the plate circuit to flatten the plate voltage wave form, thus reducing the instantaneous plate voltage across the tube during plate current conduction.* Plate dissipation is thereby lowered and efficiency is enhanced. By suitable design, it would be possible to obtain over 90% efficiency in this mode of operation. However, the cost and inflexibility of the complicated plate circuit makes Class C operation with 70% efficiency preferred. Also, Class B operation at somewhat lower efficiencies may be employed for ease of modulation.

Preliminary rf cavity design work continues. The voltage necessary to maintain a 3-GeV beam is 870 kV (or approximately 110 kV per cavity). However, other considerations make it desirable for the cavities to present higher voltages to the beam at some level of operation of the storage ring. A conservative estimate of 160 kV per cavity has been made. With this voltage it will be possible to have most of the cavity volume in air. The gap would be in the vacuum system with a ceramic window isolating the rest of the cavity.

6. Detection

The current status of streamer-chamber development is described in a paper presented at the Frascati Conference by F. Bulos. In addition, preliminary measurements of streamer drift along the electric field in the chamber have been made. This was done by observing tracks crossing both gaps in a two-gap chamber with the central electrode pulsed. With a 25-nsec-wide high-voltage pulse, the drift is approximately 2 mm. Better measurements are in progress.

Streamers have been photographed through a three-stage image intensifier. Measurements of distortion and resolution are in progress. Also, a high-voltage pulser is being constructed to pulse the tube for elimination of the image tube noise.

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*V. J. Tyler, Marconi Review 21, 961 (1958).

7. Princeton-Stanford 500-MeV Storage Ring

A new cryogenically pumped interaction region has been constructed for the 500-MeV storage ring. This geometry of the new interaction region will allow an increase in the detector solid angle of about a factor of five. The cryogenic pumping system will provide a large reduction in the residual gas pressure at the interaction region, allowing the reaction

$$e^- + e^- \rightarrow e^- + e^- + \gamma + \gamma$$

to be used as a luminosity monitor. Installation of the new interaction region should occur next quarter.

A shower spark chamber to be used to increase the efficiency of background rejection in the electron-electron scattering experiment was tested. If the chamber is to be useful, it must have a high efficiency for electron detection, independent of the angle of the track to the plate normal, and nearly independent of energy; it must also have a high rejection efficiency for background tracks. The chamber had 8 gaps and a total of 6.5 radiation lengths in the plates. It was tested with electrons from the Stanford Mark III linear accelerator over an energy range from 150 - 650 MeV and with the beam normal and at 45° off the normal to the plates. The chamber was found to be greater than 99% efficient for detecting electrons under all conditions. Using the same acceptance criteria, less than 4% of the cosmic rays used to simulate background passed the acceptance test.

8. Experimental Physics at SLAC

The SDS9300 computer which will be used for on-line collection and processing of data from the SLAC spectrometer facility arrived in early July. Group C has been participating in conjunction with Group A in the acceptance testing of the 9300 as well as in the general design of both the hardware interfacing to experimental equipment and the programming. An analogue-to-digital converter of a standard 512 channel Nuclear Data pulse height analyzer has been successfully connected to the computer. Detailed design on the interface has begun.

9. Papers and Reports

"Stanford Linear Accelerator Center Storage Ring Summer Study, 1965, on Instabilities in Stored Particle Beams" (Edited by B. Richter, M. Sands, and A. M. Sessler), SLAC Report No. 49, Stanford Linear Accelerator Center, Stanford, California (August 1965).

F. Bulos, A. Boyarski, R. Diebold, A. Odian, B. Richter, and F. Villa, "Streamer Chamber Development," to be published in the Proceedings of V International Conference on High-Energy Accelerators, held at Frascati, Italy, September 9-16, 1965. (SLAC PUB-140)

W. C. Barber, B. Richter, B. Gittleman and G. K. O'Neill, "Wide Angle Electron-Electron Scattering on the Princeton-Stanford Storage Rings," to be published in the Proceedings of V International Conference on High-Energy Accelerators, held at Frascati, Italy, September 9-16, 1965. (HEPL Report No. 405)

C. EXPERIMENTAL GROUP D

1. Two-Meter Spark-Chamber Magnet

All major components of the magnet have been contracted. Below is the schedule for delivery.

Coils	July 1966
Iron	June 1966
Tracks	April 1966
Power Supply	April 1966

Design of the peripheral equipment, i.e., water manifolds, staging, etc., should be completed during the next quarter.

2. Marx Generator

A new Marx generator has been built suitable for driving a large streamer changer. In preliminary operation in air it delivered 300 kV, and it is hoped that in SF_6 it will go appreciably higher.

3. Image Intensifiers and Optics

The distortions of the image intensifiers are so large at the edges of the field that the useful surface area is reduced from a diameter of 88 mm to about 50 mm. This in effect decreases their resolution by a similar factor. A decision has been made to operate without intensifiers, suffering the depth of field problems required by the large aperture lens needed, namely f2. It would appear that by a large demagnification (100), a streamer of 1 mm diameter would in reprojection be enlarged to about 2 mm over a depth of field of ±30 cm.

4. Mark III Program

Preliminary tests with a wide-gap chamber will be starting during the next quarter.

A parasitic beam of electrons has been made giving about 30 electrons per second in a 1% interval in the "new end station" during operation by other groups in the "old end station." This beam should be very useful for tests of spark chambers and counters.

Data-taking is continuing in the experiment investigating $\gamma + p \rightarrow N^{*+} + \pi^{-}$.

D. EXPERIMENTAL GROUP E

1. Proton-Proton Interactions at 6 GeV/c

We have begun the analysis of the exposure of the 72-inch Lawrence Radiation Laboratory hydrogen bubble chamber to 6-GeV/c protons. This is a joint experiment with W. Chinowsky and J. Schultz of LRL.

2. Neutron-Proton Elastic Scattering at 1 to 6 GeV/c

A preliminary report on this experiment was given at the Oxford International Conference on Elementary Particles. The experiment is yielding excellent results, and the analysis continues.

3. K-Deuterium Interactions

The measurement and analysis of this bubble-chamber experiment is continuing jointly with Group B.

4. Muon-Proton Inelastic Interactions, Muon-Proton Elastic Scattering, and Muon-Electron Elastic Scattering

The construction of this experiment was begun.

5. Search for New Heavy Leptons

The design work was continued.

6. High-Energy Small-Angle Photon-Proton Elastic Scattering

M. Longo of the University of Michigan joined with us on the preliminary design work.

7. Large Spark Chamber Magnet

The detailed design of the coils was completed.

8. <u>16-GeV/c Pion Exposure in the BNL 80-Inch Hydrogen Bubble Chamber</u>

Design work on the beam was continued in collaboration with Group B.

9. <u>Electronic Development</u>

Limitations on the use of 100-Mc commercial logic modules were investigated. The results of the analysis and measurements are reported in a SLAC internal report.*

A modular dual-output limiter-clipper circuit was constructed for the shaping and fanout of photomultiplier-tube pulses. The unit is compatible with the laboratory 100-Mc commercial modular instrumentation system.

<u>Publication</u>

A. Barna and D. Horelick, "A Scaler Printout System," Nucl. Instr. and Methods <u>35</u>, 341-344 (1965).

E. EXPERIMENTAL GROUP F

Calculations correcting aberrations of the 1.6-BeV/c spectrometer were completed. Drawings for the coils and magnet have been completed and the items are in the process of being procured. Design work for a hydrogen target to be used in End Station A is in progress.

F. PHYSICAL ELECTRONICS

The following papers were presented during this quarter:

1. E. L. Garwin and J. Edgecumbe, "Electron Multiplication in Field Enhanced Secondary Emission From Low Density Dynodes," presented at the Summer Meeting of American Physical Society, Honolulu, September 1965.
2. E. L. Garwin and J. Edgecumbe, "Response of Low Density KCl Foils to Multi-MeV Electrons," presented at the Third Symposium on Photoelectronic Image Devices, London, September 1965.

Limited results have been obtained at the Mark II and Mark III accelerators from a conventional SEM tube structure with the target foils coated by the alkali-halide dynode material discussed in previous reports. These results confirm the measurements of the gain for multi-MeV primary

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*A. Barna, <u>et al.</u>, "Notes on 100 Mc Logic Modules," SLAC Internal Report, Stanford Linear Accelerator Center, Stanford, California (1965).

electrons reported in the last quarterly report. With the SEM, the measurements are free of possible error due to multiple scattering of the primary beam in the thick windows used in the earlier tube. This SEM was designed to approximate a 50-ohm line so that rise time measurements could be carried out using the beam chopper at the Mark III accelerator. The beam chopper breaks the electron pulse up into ≈ 2 nsec pulses 43 nsec apart, each pulse with a rise time less than 1 nsec. The rise time of the device was found to be 1-2 nsec, and it is believed at this time that the relatively large value is due to the construction of the SEM and is not inherent in the emission process from the low-density dynodes. The gain of the one foil (two coated surfaces) was sufficient to produce a 6-volt signal into 50 ohms and was easily seen directly on a Tektronix 519 oscilloscope (vertical sensitivity = 9.8 volts/cm, rise time = 0.3 nsec).

Work has started on the techniques required for the fabrication of multi-dynode structures for single-particle detection. An experiment is also being planned to study the single electron counting statistics of the low-density dynodes. The latter experiment will give information on whether possible internal multiplication, as discussed in previous reports, will limit the usefulness of these detectors in direct particle detection.

G. MAGNET RESEARCH

1. Water-Cooled Magnets

a. Positron-Source Solenoids

A prototype double pancake for the homogeneous field solenoid was manufactured using the SLAC alumina-loaded epoxy formulation. The impregnation of this coil was performed under vacuum for the first time. The double pancake was immersed in water for a period of 10 days and tested repeatedly at 4 kV ground. The corona threshold of the coil was approximately 1.3 kV.

The high-field upstream solenoids (edge-cooled coils) with alumina-loaded glass fiber cloth had experienced manufacturing difficulties which were solved by using a new impregnation technique. The inter-turn insulation and the insulation between pancakes is a B-staged alumina-loaded glass epoxy matrix. The coil is wound dry and then impregnated with a low-viscosity, unfilled, high-radiation epoxy system. The coil was tested successfully.

b. Muon Trap Project Magnets

For the muon trap project now being studied a set of bending magnets and quadrupoles is foreseen. The tentative parameters for these magnets are given in Tables I - III. The specific properties of the bending magnets are a field of 20 kG at the median plane with a homogeneity of better than 10^{-3} over approximately ±5 cm. The elliptical quadrupole (Table III) makes full use of the iron designed around the coil and will cut down the power requirements compared to an equivalent Panofsky quadrupole by a factor of 3.8. The rectangular aperture is reduced to an elliptical form which is adequate for the beam pipe.

2. Superconducting Magnet Research

A new winding technique has been introduced in superconducting magnets which gives a high packing factor of 0.2 to 0.25 and can be operated close to the H-I characteristic of the short sample. The coils are fully stabilized, and, in order to allow the helium to be in close contact with the superconductor, a high resistivity wire is either wrapped around the superconducting cable or wound bifilar with the superconductor in each layer. Glass fiber cloth with axial copper strips is used as interlayer insulation. The coils built with this system have been tested repeatedly to their quenching. The coil mentioned* previously with the effective bore diameter of 2.5-inches i.d., a conductor i.d. of 2.88 inches and o.d. of 7.5 inches, 6 inches long, has been built and tested as follows:

Outer coil section of Nb(25%)Zr, with an i.d. of 4.4 inches and a packing factor of 0.29, when energized alone, produced a field of 46.5 kG and carried a current of 29 amps per strand (seven-stranded copper-clad cable).

The inner coil was made of Nb(48%)Ti; energized separately, it produced a field of 29.5 kG and carried a current of 30 amps per strand (seven strands). Some of the Nb(48%)Ti cable obtained by SLAC was found to be unstable; at low fields it did not meet the specifications. In the meantime, better materials have become available, and it is believed that the above values can be increased considerably.

*"Two-Mile Accelerator Project, Quarterly Status Report, 1 April to 30 June, 1965," SLAC Report No. 48, Stanford Linear Accelerator Center, Stanford, California (1965), p. 101.

TABLE I

MUON TRAP STUDY - 7.5-CM BENDING MAGNET

Field in the gap center	20 kG = 2 Wb/meter^2
Effective length	1 meter
Gap height	7.5 cm
Gap width	15 cm
Ampere-turns per pole	1.014×10^5 amps
Pole tip field	2.2 Wb/meter^2
Turns per pole	78
Number of pancakes per pole	6
Maximum operating current	1300 amps
Conductor cross section (0.56 inch $\times$ 0.56 inch)	1.69 cm^2
Cooling hole (0.25 inch)	0.317 cm^2
Coil resistance ($\Delta\theta = 30^\circ$C)	7.7×10^{-2} ohms
Maximum rated voltage	100 volts
Power at 1300 amps	130 kW
Water flow ($\Delta\theta = 30^\circ$C)	62.11 liters/minute
Water passage per double pancake	2
Pressure drop	8 kg/cm^2
Copper weight	850 kg
Iron weight	4000 kg
Total weight	5400 kg
Magnet overall dimensions:	
Length	1.35 meters
Height	0.64 meter
Width	1 meter

TABLE II

MUON TRAP STUDY - 13-CM QUADRUPOLE

Maximum gradient	1.6 kG cm^{-2} = 16 $Wb/meter^3$
Effective length	1 meter
Aperture diameter	13 cm
Pole tip field	10.4 kG
Ampere-turns per pole	3×10^4 amps
Maximum current density	11.72×10^2 amp/cm^2
Conductor cross section (0.5 inch × 0.5 inch)	1.28 cm^2
Cooling hole (0.25-inch diameter)	0.317 cm^2
Number of turns per pole	20
Maximum rated current	1500 amps
Coil resistance ($\Delta\theta$ = 30°C)	0.042 ohms
Maximum rated voltage	63 volts
Power at 1500 amps	94.5 kW
Water flow for 30°C temperature rise	43.8 liters/minute
Pressure drop (two water passages parallel per double pancake)	5.5 kg cm^{-2}
Copper weight	380 kg
Iron weight	1250 kg
Total weight	1800 kg

TABLE III

MUON TRAP STUDY — ELLIPTICAL QUADRUPOLE

Aperture dimensions	15 cm/60 cm
Maximum gradient	0.48 kG/cm
Effective length	2 meters
Pole tip field	10.34 kG
Ampere-turns per pole	6.5×10^4 amps
Peak rated current	1300 amps
Turns per pole	50
Conductor cross section (0.56 inch × 0.56 inch)	1.69 cm^2
Cooling hole (0.25 inch)	0.31 cm^2
Coil resistance ($\Delta\theta = 30^\circ C$)	0.1538/ohms
Maximum rated voltage	200 volts
Power at 1300 amps	260 kW
Water flow ($\Delta\theta = 30^\circ C$)	126 liters/minute
Pressure drop	8 kg/cm^2
Water passages per coil section	2
Coil section per pole	3
Copper weight	1700 kg
Iron weight	≈ 18,000 kg
Total weight	≈ 21,000 kg

By running both sections from two power supplies, a maximum field of 72 kG was achieved repeatedly at a maximum current of 25 amps per strand in the outer section [Nb(25%)Zr], and 26 amps per strand in the inner section [Nb(48%)Ti].

This magnet is used for testing short-sample characteristics of superconducting type II materials, magnetoresistance probes, and stability studies for the prototype magnet with 12-inch bore.

3. Publications

The following papers have been presented since the last report:

H. Brechna and W. Haldemann, "Physical Properties of Filament-Wound Glass Epoxy Structures as Applied to Possible Use in Liquid Hydrogen Bubble Chambers," presented at the 1965 Cryogenic Engineering Conference, Rice University, Houston, Texas, August 23-25, 1965.

H. Brechna, "Electromagnets for High-Energy Physics Applications," presented at the International Symposium on Magnet Technology, Stanford Linear Accelerator Center, September 8-10, 1965.

H. Brechna and E. Oster, "Insulation Structure and Coil Reliability," presented at the International Symposium on Magnet Technology, Stanford Linear Accelerator Center, September 8-10, 1965.

H. THEORETICAL PHYSICS

Publications

1. H. P. Noyes, "New Nonsingular Integral Equation for Two-Particle Scattering," Phys. Rev. Letters 15, 538 (1965). (SLAC-PUB-124)
2. S. D. Drell, "Special Models and Predictions for Photoproduction Above 1 GeV," (to be published in Springer Tracts in Modern Physics, Vol. 39).
3. S. D. Drell, H. M. Foley and M. A. Ruderman, "Drag and Propulsion of Large Satellites in the Ionosphere: An Alfven Propulsion Engine in Space," Geophys. 70, No. 13 (July 1965).
4. M. Bander and C. Itzykson, "Group Theory and the Hydrogen Atom," (submitted to Rev. Mod. Phys.). (SLAC-PUB-120)
5. S. D. Drell, "Theoretical Expectations for Electron and Photon Physics," Report at SLAC Users Conference, Stanford Linear Accelerator Center, October 1-2, 1965.
6. J. D. Sullivan, "W Meson Production in $\pi^- + p \rightarrow W^- + p$ Interactions," (to be submitted to Phys. Rev.). (SLAC-PUB-144)
7. S. D. Drell and J. D. Sullivan, "Axial Meson Exchange and the Relation of Hydrogen Hyperfine Splitting to Electron Scattering," (to be submitted to Phys. Letters). (SLAC-PUB-145)

8. W. I. Weisberger, "Unsubtracted Dispersion Relations and the Renormalization of the Weak Axial-Vector Coupling Constants," (submitted to Phys. Rev.). (SLAC-PUB-143)

9. H. P. Noyes, "Analysis and Interpretation of the New Nucleon-Nucleon Experiments near 25 MeV," Report at the International Conference on Polarization Phenomena of Nucleons, Karlsruhe, Germany, September 1965.

10. J. S. Ball, A. Scotti and D. Y. Wong, "One-Boson Exchange Model of the NN and $N\bar{N}$ Interaction," (submitted to Phys. Rev.). (SLAC-PUB-130)

11. B. Barrett, M. Jacob, T. Truong and M. Nauenberg, "Consequences of C-Violating Interactions in η^0 and X^0 Decays," (submitted to Phys. Rev.). (SLAC-PUB-123)

12. C. Itzykson and M. Nauenberg, "Unitary Groups: Representations and Decompositions," (submitted to Rev. Mod. Phys.). (SLAC-PUB-106)

Items 1 through 4 have been discussed in previous reports.

The observed exponential decrease of form factors at large momentum transfer is being studied. In a non-relativistic potential model, the maximum allowable fall-off, $e^{-a\sqrt{q^2}}$, of the form factor is obtained when the charge density is an analytic function of r^2 near the origin. A less rapid fall-off of $e^{-a(q^2)^{\alpha}}$ with $0 < \alpha < 1/2$ is obtained when the charge density has an essential singularity at the origin (corresponding to a potential more singular than $1/r^2$). All other cases lead to power fall-off. The proton and deuteron form factors are consistent with a behavior $e^{-a(q^2)^{\frac{1}{4}}}$ which corresponds to a $1/r^4$ potential. Three-body nuclei and the relativistic-field-theory situation are being studied.[5]

Calculations of the production cross section of W bosons in $\pi^- + p \rightarrow W^- + p$ have been made using the single-particle exchange model with initial-state absorption corrections.[6]

A recent suggestion of Nambu and collaborators that axial vector meson exchange might remove much or all of the discrepancy between theory and experiment for the hyperfine splitting in hydrogen has been investigated and shown to be very difficult, if not impossible, to reconcile with existing data on the cross section ratio of positron-proton to electron-proton elastic scattering.[7]

From the assumptions that the equal-time commutation rules for the vector and axial-vector current octets proposed by Gell-Mann are valid and that the divergence of the $\Delta Y = 0$, $\Delta I = 1$ axial current is a strongly convergent operator obeying unsubtracted dispersion relations and dominated by low-frequency contributions, a sum rule is derived for the renormalization of the neutron axial β-decay constant, G_A, by the strong interactions. The result agrees with that previously obtained from the assumption that the axial-current divergence is proportional to the pion field. The results are generalized to the strangeness-changing leptonic decays in the context of Cabibbo theory and generalized Goldberger-Treiman relations, and are used to compute the d/f ratio for the weak baryon-axial current coupling and an independent value of G_A.[8]

The Saclay group has recently completed two polarized-beam, polarized-target experiments (A_{xx} and A_{yy}) on p-p scattering at three energies (10, 18.6, 25.7 MeV). Analysis of the 25.7-MeV results confirms the suspicion that one of the R measurements near this energy is inconsistent with the rest of the data and moves the phase shifts into closer accord with theoretical expectations. The new results confirm the theoretical prediction made in 1959 that one-pion-exchange will make the $^1S_0$ phase shift larger at 25 MeV than the prediction of the shape-independent approximation. Combining these results with phase shifts up to 330 MeV, it is possible to show that the corresponding static, local model for the interaction gives unique predictions for the $^1D_2$ and $^1G_4$ phase shifts at high energy. Since these predictions are 50% larger than experiment, there is no doubt that the singlet interaction is in fact non-local and/or velocity-dependent, an effect expected theoretically because of the importance of vector meson exchanges. Preliminary measurements of C_{nn}(23 MeV) for n-p scattering by the Los Alamos group also show significant sensitivity to ϵ_1, the phase parameter most needed to resolve discrepancies between our current understanding of two-nucleon forces and calculations of multinucleon systems. In both cases it is clear that important new information has been obtained by polarized-beam, polarized-target experiments and that this new technique should be pushed.[9]

The relativistic model for the two-nucleon interaction due to single boson exchanges has been put in a form suitable for crossing by removing the subtraction constants and using ratios of coupling constants predicted by SU_3. The resulting four-parameter model is still reasonably close to nucleon-nucleon experiments, and when used to calculate bound states of the nucleon-antinucleon system, predicts those, and only those, bosons which were used in the original channel. Although still not quantitatively successful, this qualitative success of the "bootstrap" assumption is striking; additional physical effects which should be included in the n-$\bar{n}$ channel will clearly act in a direction to improve the self-consistency.[10]

The consequences of a possible violation of charge-conjugation invariance in the decay of the η and the X^0 have been investigated in some detail. Various recent speculations concerning the strength, symmetry and electromagnetic properties of a C-violating interaction have been considered, and the corresponding effects in η and X^0 decays have been compared with available experimental data.[11] In view of the great interest in the application of higher symmetries to elementary particles, a review article on unitary groups, with special emphasis on the use of Young tableaux to study the representation, has been written. General tables for decomposition of unitary groups have also been calculated.[12]

Recent interesting speculations (Nature, May 29, 1965), suggesting that a meteor which fell in Tunguska, Siberia, in 1800 may have been composed of antimatter, have led to the study of the behavior of bulk antimatter incident on the earth's atmosphere. The fate of an antimeteorite depends critically on the atom-antiatom annihilation cross section, which is estimated to be of the same order as for atomic collision. This is due to the formation of positronium leaving the residual system (called a Nullecule) in a bound state. On the basis of these calculations it is found that an antimeteorite of reasonable size ($\approx$ 10 - 100 meters radius) evaporates high up ($\approx$ 300 km) in the atmosphere, ruling out such an explanation for the Tunguska crater.

An investigation on the domain of validity of the semiclassical or JWKB approximation to the Schrodinger function in three dimensions, which is very useful in understanding the scattering of high-energy electrons and positrons from heavy nuclei, has been carried out. Classical trajectories of a parallel beam of particles incident on a potential generally cross, leading to envelopes along which the density of particles is infinite. The JWKB approximation in three dimensions breaks down along these envelopes (analogous to the turning points in one dimension). The connection among the multiple solutions obtained from the Hamilton-Jacob equation and their usefulness in obtaining scattering cross sections for large momentum transfers for singular as well as nonsingular potentials is being investigated.

Since the preliminary investigation of secondary beam production from the SLAC machine five years ago by Drell and Ballam, some additional experimental and theoretical work has been done by various people. For incorporation in the SLAC User's Handbook, a new analysis of these results has been undertaken. In particular the following items are being considered.

(a) The experimental results at both CEA and DESY show the copious ρ photoproduction cross section. They also show the characteristic of the cross section to be diffraction type. This implies that the pions from the decay of ρ will completely overshadow the pions produced through the Drell mechanism at high energies. Detailed investigation of π energy-angle distribution from γ-ρ production is being carried out.

(b) No useful data on photo-K production exist. However, if ρ is produced so copiously through the diffraction mechanism, one would expect K^* to be also copiously produced. If so, $K^\pm$ pairs from the decay of K^* will become important as a source of K mesons at SLAC.

(c) One would like to make a more reliable calculation on the photo-antiproton cross section.

(d) The original Drell processes are all non-gauge invariant. This must be corrected.

(e) Spectral distribution of bremmstrahlung from a thick target, say 0.5 radiation length, is not well investigated. There is some work to be done here.

Studies of models of strong interactions involving a small number of fundamental two-component, spin-$\frac{1}{2}$ fields are in progress. The general connection between existence of a parity operator and an algebra of symmetry operators has been explored.

I. COMPUTATION GROUP

1. Projects

The Computation Group has concerned itself largely with (1) the development of programs and facilities for general laboratory needs, (2) the analysis of computer needs (both hardware and software) for the various scientific groups in the laboratory, and (3) the development of and experimentation with programming techniques for real-time data analysis and control. Explicitly, the group has undertaken the following projects:

a. Development of Library of Mathematical and Utility (Printing, Plotting, Data-Handling) Programs for the IBM 7090 and the Burroughs B5500

Several codes have been generated that are included in the Program Library. The effort has largely been concentrated on programs for integration of systems of ordinary differential equations, eigenvalue and eigenvectors for large matrices, codes for generation of random variables for a variety of specified distributions, and codes for minimization of functions of several variables.

b. Development of IBM 7090 System for Analysis of Bubble Chamber Data

This system is based on the TVGP, SQUAW, and ARROW Codes developed at LRL-Berkeley. This system of codes has been adapted to the Stanford IBM 7090 and its particular equipment configuration.

c. Development of Magnet Design Codes and Ray Tracing Codes

The TRANSPORT Beam Optics code was developed at SLAC and has been in use for many months as a first-order and second-order approximation. Recent work has been aimed at calculating more precisely the matrix elements that are relevant to calculation of fringe fields; also, matrix elements have been added to enable one to simulate multiple scattering in absorbers. Recent work has been directed toward development of a second-order code. Special-purpose magnet-design codes have been developed for use in the design of the bubble-chamber magnets, spark-chamber magnets, and the positron source. A particle-tracing code for tracing particles through the field of the spark-chamber magnet has been written. Modifications of these programs are being made to adapt them to particular design problems.

d. Chebyshev Approximation

The work on Chebyshev approximations is directed to finding the best rational approximations for functions representing attenuation in coaxial cables. The functional motivation for the problem is to calculate certain parameters used in the design of attenuation equalizers. The first program of this kind was completed in March 1965. A larger program using more sophisticated techniques is under construction.

e. 20-BeV/c Magnetic Spectrometer Real-Time Analysis System

The SPECTRE System is a real-time data analysis system utilizing an SDS 9300 Computer on-line to the 20-BeV/c spectrometer. The control system is being designed, including the modifications to the SDS real-time monitor. Also being studied are the problems of handling concurrently data from the 8-BeV and the 1.6-BeV spectrometers.

f. Beam Switchyard Control Programs

The Beam Switchyard control system has been developed around an SDS 925 Computer which is to be delivered in early November 1965. The control program for this system is being designed.

g. Research on Real-Time Control Programming

Studies are being made on the structure of priority-controlled on-line programs. Present efforts are concentrated on the development of data structures and scheduling algorithms for dynamic assignment of interrupt priorities. Also work is being done on languages for micro-programming of the kind needed in machine design and control-program design. A joint effort with the Stanford Computation Center is the development of the scheduling algorithm for the SLAC central computer facility.

h. Research on Graphic Data Processing

A joint effort with the Stanford Computation Center is being carried out on the use of graphical display methods as an aid in magnet design, structural design, and hypothesis testing. A long-term project on automatic film data processing has been initiated. Several aspects of the project are in the initial phases. An IBM 7090 version of the Argonne programs AROMA-AIRWICK for spark film analysis has been developed and tests are being conducted on film digitized by the HUMMINGBIRD digitizer developed at SLAC. Programs are also being developed for scanning and examination of streamer (wide-gap) chamber film.

In addition to the above explicit projects, the Computation Group conducted classes on ALGOL programming, FORTRAN programming, and Statistical Methods. Also members of the group devoted a great deal of time to consultation with other SLAC staff members on programming, numerical analysis, and statistical methods.

2. Facilities

SLAC is currently using the facilities of the Stanford Computation Center for general scientific computing. These facilities include:

(1) a Burroughs B5500

(2) an IBM 7090 - IBM 1401 combination

(3) a PDP-1 with display scopes and time-sharing access to the IBM 7090.

In April 1965 the Computation Center installed a data link consisting of a card reader and printer combination at the SLAC site. This data link is connected to the B5500 over a leased phone line. It provides ready access to the B5500 on a scheduled basis and permits the Stanford Computation Center to do some multiprogramming (card-to-tape, and tape-to-printer) while SLAC is using the B5500 via the data link. The data link has worked almost trouble-free since its installation.

The laboratory is planning the acquisition of a large general facility to be located at the SLAC site in the first quarter of 1967. An analysis of the laboratory's requirements and the specification of needs has been submitted for approval prior to requesting proposals from computer manufacturers. It is expected that proposals will be submitted and a selection made in the fourth quarter of 1965. The development of a command and control language, the file-processing algorithm, and the scheduling algorithm for the real-time, time-sharing monitor is being carried out jointly by the SLAC Computation Group and Stanford Computation Center personnel.

3. Publications and Reports

1. J. C. Butcher, "Some Recent Developments in the Theory of Runge-Kutta Methods," Proceedings of IFIP (International Federation for Information Processing) Congress 65, New York City, May 24-29, 1965.

2. J. C. Butcher, "A Modified Multistep Method for the Numerical Integration of Ordinary Differential Equations," Journal of ACM 12, 124 (January 1965).

3. J. C. Butcher, "On the Attainable Order of Runge-Kutta Methods," Mathematics of Computation 19, 408 (July 1965).

4. W. F. Miller, "Computation and Control in Complex Experiments," Proceedings of IBM Symposium on Man-Machine Communications, Thomas J. Watson, Jr., Research Center, Yorktown Heights, N.Y., May 3-5 (1965).

5. W. F. Miller (with Robert Clark), "Computer Based Data Analysis Systems," Methods in Computational Physics, Vol. V (in press) Academic Press.

J. HEALTH PHYSICS

Three more peripheral monitors, which are being constructed by the Light Electronics Group, are nearly finished. Background data for one station for most of a year and for four stations for the wet season will be accumulated before machine start-up.

A workable calibrated ozone detector is now in use based on the chemiluminescence of ethylene gas. An ozone concentration of 0.02 ppm doubles the noise signal. Preparations are made to measure ozone, NO_2, and total nitrate production during the beam tests with the 660-foot accelerator.

A shower experiment was performed at the Mark III accelerator using thermoluminescent dosimeters. Measurements were made at one energy (1 GeV) and for two materials (copper and lead). The data is mostly read out and analyzed. A paper on the preliminary shower experiment will be published.*

Two versions of the water monitor are being tested. The final version will be ready about the first of next year. The air monitors are being procured now. The survey meters are being readied for procurement by Light Electronics.

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*T. M. Jenkins, J. K. Cobb, W. R. Nelson and R. McCall, "Measurement of Electron-Induced Showers with Thermoluminescent Dosimeters," to be published in Nucl. Instr. and Methods (SLAC-PUB-122).

Design of the End Station area monitors has been started. Several commercial detector candidates are either on order or are being tested. Electronics work will not start until detector selection is complete.

Among the new equipment received were the neutron REM counters and the 45 manway monitors. Tests of these have been started and they will be used during the current beam tests.

Assistance was provided to other groups in shielding problems, radioactive source procurement, radiation damage problems, and instrument calibration.

A closed truck has been assigned to the group and is being fitted as a mobile laboratory. It will be equipped to carry laboratory instrumentation for measuring neutron fluxes and γ-ray doses. A small multichannel analyzer is being procured for spectral measurements in the field.

K. CONVENTIONAL DATA ANALYSIS

The Conventional Data Analysis program was organized with several major projects to be completed this fiscal year:

1. Two new measuring projectors of one-micron accuracy were ordered from NRI in Berkeley. These will be delivered in the spring. The electronic control system for these machines will be designed and built at SLAC.
2. Two spark-chamber measuring projectors for Group E were completely assembled and are now being debugged.
3. A computer system for collecting the data from the various projectors was proposed. This system would eliminate the card punches and perform logical checks and controls on the measuring of events.
4. Four scanning tables were assembled; two of these will have image-plane digitizers. They are now being wired and debugged.

L. HYDROGEN BUBBLE CHAMBER

Since the last report (December 31, 1964), the SLAC 40-inch hydrogen bubble chamber group has made considerable progress.

Recruitment of the engineering group is complete, and the technical staff for testing, assembly and operation is being assembled. The design parameters were reported to the first SLAC Users meeting, October 1 and 2, 1965. That description, with slight revision, is reproduced here.

1. Magnet

The chamber has a magnetic field with an average value of 20 kilogauss. The design goal is a two-percent overall variation in this field within the visible region. The magnet weighs some 240 tons.

2. Magnet Transport

The magnet is to be designed without a transport system; gross movements will be accomplished by use of rollers. The magnet is provided with jacks; nine inches of upward or downward motion from the normal beam height are available. Slight horizontal adjustments will be possible with auxiliary jacks.

3. Beam Windows

An early experiment that will be proposed for the chamber is photoproduction of strongly interacting particles. The present design calls for a chamber beam window of beryllium 28 inches × 7 inches by 1/8 inch thick.

4. Optics

Ninety-four percent of the 400-liter chamber volume will be visible to at least two camera lenses. The lens axis is horizontal, perpendicular to the main window. Bright-field illumination with three ring-light flash tubes and Scotchlite retrodirector will be used. The camera has three lenses equally spaced on a 31.5-inch circle photographing at 17:1 reduction on a single strip of 70 mm perforated (Type II) film. The nominal image size on the film is 60 mm, but only 57 mm of the film width is usable. The spacing between views in the triad is approximately 41 inches between views 1 and 2, and 26 inches between views 2 and 3.

A databoard containing alpha numeric and binary chamber and experiment information is associated with each triad. It is adjacent to, and preceding, view 1.

5. Operation

Operation will be at 1 or 2 pulses per second. Initial operation will be with hydrogen; deuterium operation is to be provided for.

Engineering activity has concentrated on procurement of major portions, and the following components of the chamber are in the procurement cycle:

1. Main optics windows have been cast by the vendor.
2. Inflatable gaskets are on hand.
3. Four expansion bellows have been received.
4. Copper for the magnet has been ordered.
5. A development contract has resulted in the delivery of eight beryllium beam windows, 7 inches × 28 inches × 1/8-inch thick.

Design work has progressed so that next quarter should see the procurement of almost all of the major components of the chamber. These include the magnet coil fabrication, magnet core, magnet power supply, castings for the chamber body, the bulk liquid hydrogen tank and small transportable dewars, and the portable enclosure to cover the chamber. In addition, work is proceeding on the bellows test fixture and the expansion system prototype test fixture. The chamber control schematic is nearly complete and ready for review. A major departure from bubble chamber practice is the use of purchased bulk liquid hydrogen for refrigeration rather than self-contained refrigeration systems. This change (back to the techniques of the smallest chamber) is made possible by the availability of inexpensive bulk liquid hydrogen. Work is also continuing on the properties of beryllium at cryogenic temperatures and techniques for sealing the window to the chamber.

The work to date is essentially on schedule.