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TWO-MILE ACCELERATOR PROJECT

Quarterly Status Report

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April 1965

Technical Report

Prepared Under

Contract AT(04-3)-400
Contract AT(04-3)-515

for the USAEC

San Francisco Operations Office

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I. INTRODUCTION

This is the ninth Quarterly Status Report of work under AEC Contract AT(04-3)-400 and the third 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.

II. PLANT ENGINEERING

A. GENERAL

The conventional facilities program was continued throughout the quarter, design emphasis being placed on the building and utilities of the Target Area. At year's end the major part of the overall design effort had been completed. Construction of the beam switchyard and Data Assembly Building was begun, and work continued on the Klystron Gallery, Control Building, and Central Laboratory. Field construction for the project is now scheduled for completion in February 1966. The present status of a number of the facilities in the construction phase is shown graphically in Figs. 1 through 5.

Design of the 220-kV power feeder line to the Sand Hill site is being performed under contract to the U. S. Atomic Energy Commission. The Title I work has been reviewed by SLAC and agreement reached on details of pole location and hardware proposed for installation on Stanford lands. Consideration is being given to relocating the oil circuit breaker from the Skyline tap point to the SLAC Master Substation.

The California State Division of Highways continued construction of the overpass bridge at Accelerator Station 83 as part of the Junipero Serra Freeway. A view of this activity is shown in Fig. 5. The necessary waveguides, vacuum fingers, and service piping have already been installed in the Accelerator Housing penetrations at this location.

B. DESIGN STATUS

The remaining detailed design effort relates principally to (a) Target Area utilities and site improvements, (b) the Cryogenics Building, and (c) any necessary changes to facilities under construction. The status of the major items is discussed below.

The bid package for End Stations A and B was mailed out in December and will be followed by an addendum to modify the floor and foundations of End Station A to accommodate the spectrometer facility. Bid opening is scheduled for January 22, 1965.

Bids on the Cafeteria-Auditorium were opened on December 15th and are being evaluated. Initial site and service road work for this facility was completed earlier in order to shorten the contract construction period.

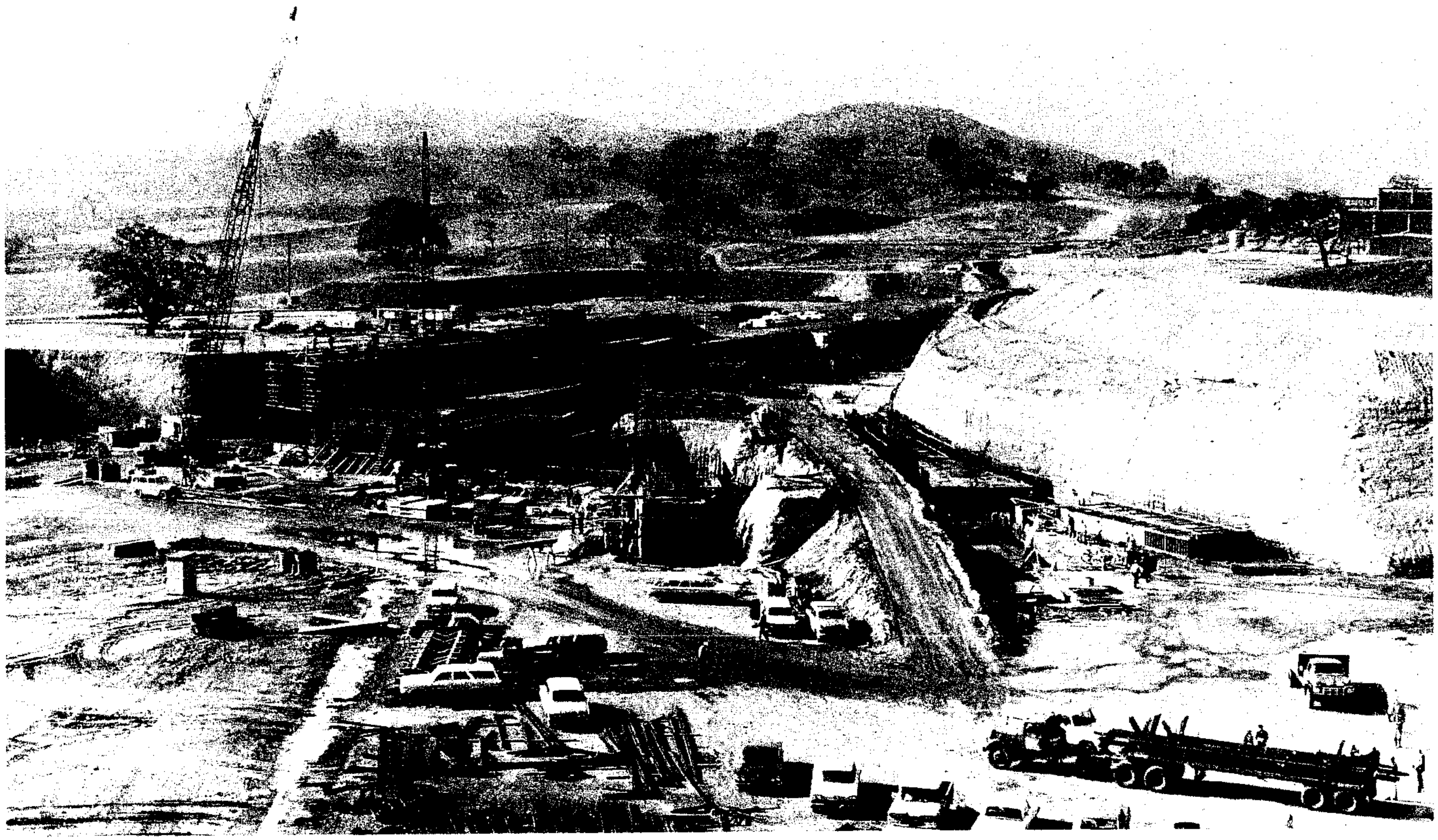

FIG. 1--Beam Switchyard construction in progress.

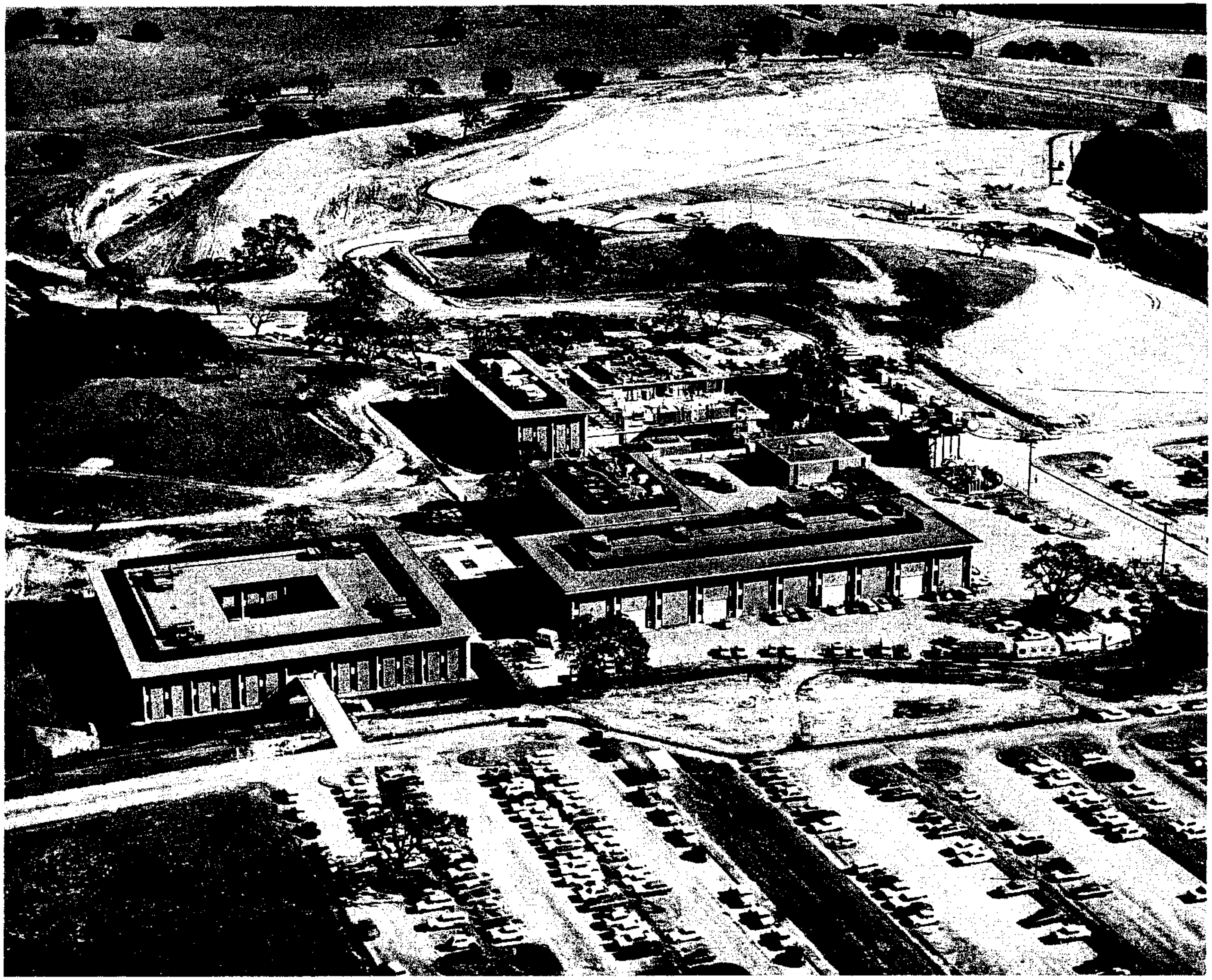

FIG. 2--Aerial view of SLAC laboratory area.

FIG. 3--Construction status of Control Building.

FIG. 4--Aerial view of project; target area in foreground.

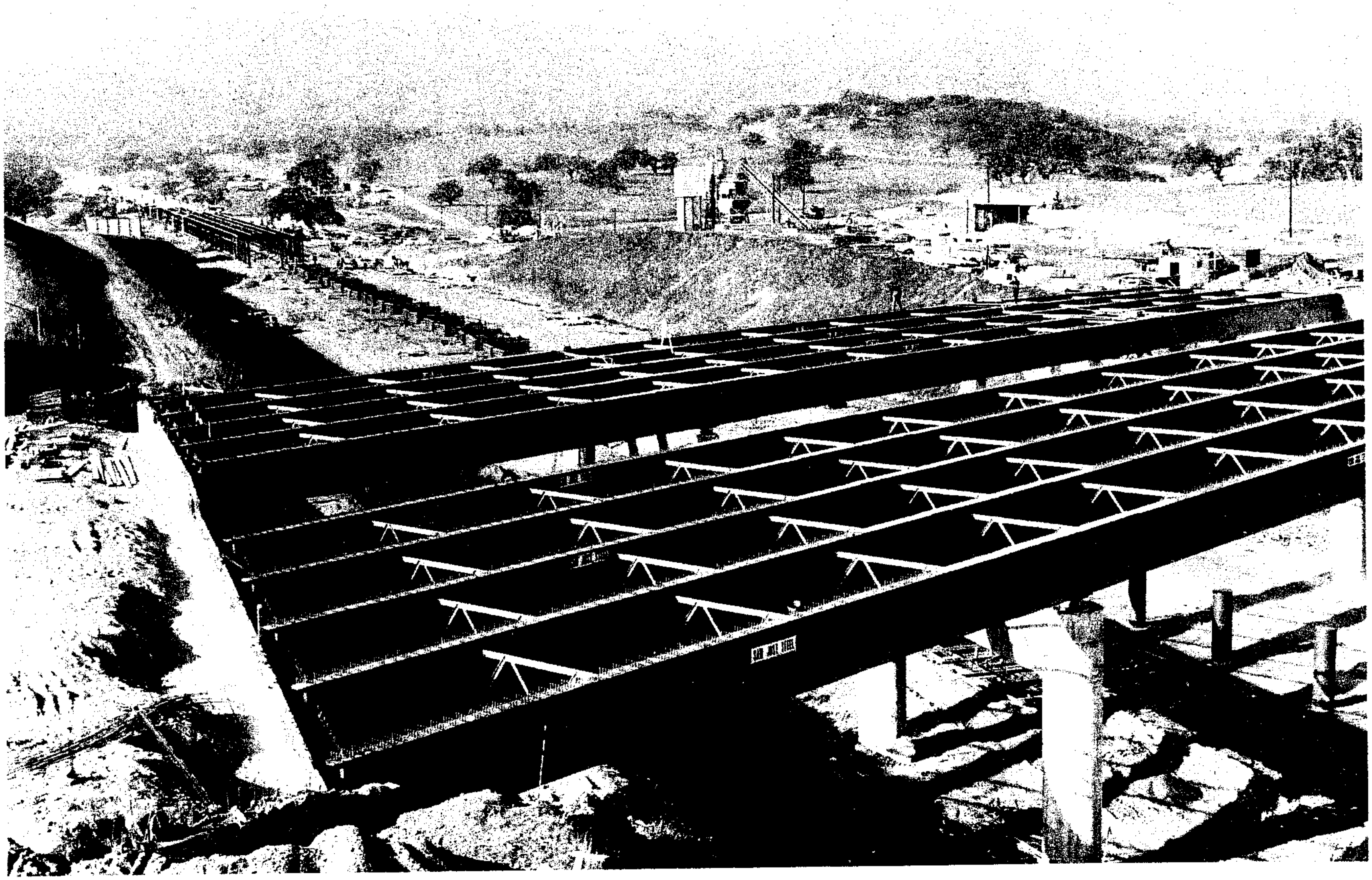

FIG. 5--Klystron Gallery viewed west; overpass bridge for Junipero Serra freeway in foreground.

The Title II design for site improvements and utilities in the Target Area is 85% complete for the beam switchyard and 30% for the End Stations. The two packages will be handled as separate contracts.

The 100% design for the materials handling system in the Beam Switchyard was submitted and is being evaluated.

Bids for the equipment in the two target area unit substations will be opened January 13, 1965.

Title II work on the Cryogenics Building is 5% along. Some recent changes in criteria have been incorporated, relating largely to hydrogen safety considerations. In principle these assume that the equipment and operating procedures are the primary safeguards, and that safety features built into the conventional facilities should be designed to minimize damage rather than prevent accidents.

The remaining work on cranes is being handled as several packages, as follows. The Target Area cranes, (one in End Station A, two in End Station B, and one in Beam Dump East), will be procured as a group. Proposals from bidders will be solicited in January. Final design for modifying three surplus 20-ton bridge cranes (two for use in the Heavy Assembly Building and one in the Cryogenics Building) was received and a procurement contract will be negotiated. The contract bid package for a 50-ton crane to be used in the Heavy Assembly Building was mailed in December. Bids will be opened January 12, 1965.

The structural part of a second-story addition to the one-story wing of the Central Laboratory is under construction by the Central Laboratory contractor. Design of the mechanical and electrical portion is essentially complete; it is planned to obtain bids for the construction work on this portion of the job.

C. CONSTRUCTION STATUS

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

Facility	Percentage of Completion
Central Laboratory	93
Landscaping (Increment No. 1)	85
Control Building	69
Klystron Gallery	65
Klystron Gallery Utilities	
Piping and Site Improvements (600-Y-1)	57
Electrical (600-Y-2)	4
Cooling Towers (600-Y-3)	96
Switch House (for Master Substation)	25
Data Assembly Building	18
Beam Switchyard	12
Central Laboratory (second-story addition)	35

All items of work associated with Sectors 1 through 8 of the Klystron Gallery contract have been completed and these sectors have been turned over to SLAC. Prolonged rain during December seriously affected overall progress. Considerable additional grading will be required as a result of rain damage. Beneficial occupancy has been taken of Sectors 9 through 12; this schedule of beneficial occupancy is continuing at the rate of one sector per week.

During the quarter, the Accelerator Housing, Heavy Assembly Building, and Shop Dining Room were made available for SLAC occupancy or use.

A contract was awarded in December for the Master Substation equipment. Data submittals are expected early next month for SLAC and ABA review.

D. PLANT ENGINEERING SERVICES

Planning is underway for the move-in of equipment and the extension of utilities at the Central Laboratory. Occupancy of the three-story wing of the building is scheduled for mid-January.

A description of the design basis, operating characteristics, and special features of the LCW system (Target Area) was issued for the benefit of potential users.

Plant Engineering continued its activities relating to space occupancy planning, facility alterations, and the provision of craft support for all SLAC groups. The National Labor Relations Board conducted a hearing on December 2nd in connection with a petition by IBEW to represent the SLAC Craft Shop group. The matter is still under consideration.

III. SYSTEMS ENGINEERING AND INSTALLATIONS

A. ACCELERATOR ENGINEERING, DESIGN AND INSPECTION

1. General Accelerator Design

Definitive drawings of a proposed outdoor vacuum pumping station for the alignment system at the west end of the Klystron Gallery were begun.

The positron source cooling requirements were revised and definitive drawings were updated accordingly.

A revised equipment numbering system was developed for testing, operation and maintenance of the two-mile accelerator. This system is based on the 40-foot support girder as the basic unit instead of the 10-foot accelerator section. Existing definitive drawings are being revised to incorporate the new numbers.

A view of Sector 1 in the Klystron Gallery prior to installation of klystrons is shown in Fig. 6 . Figure 7 is a photograph of the prototype cryosorption pumped vacuum roughing system.

2. Standards and Specifications

The following standards were revised: soft solder for electronic usage, dimensioning and tolerancing, electronic symbols, abbreviations for document use, engineering document and parts identification system, receptacles and plugs.

Revisions to the following standards are in process: Quality Control and Workmanship Standard, General Drafting Instructions and Inert Gas Arc Welding of Aluminum for Vacuum Systems.

Thirty-three specifications were written or revised during the quarter in collaboration with requesting groups. The first draft for a simultaneous language interpreting system for the auditorium-cafeteria area was in process.

Assistance, on a continuing basis, was provided for responsible engineers on various portions of the support and alignment systems.

3. Model Shop

Activity this quarter included revisions of the A-beam dump area, models of two types of magnet disconnect devices, fabrication of a glove

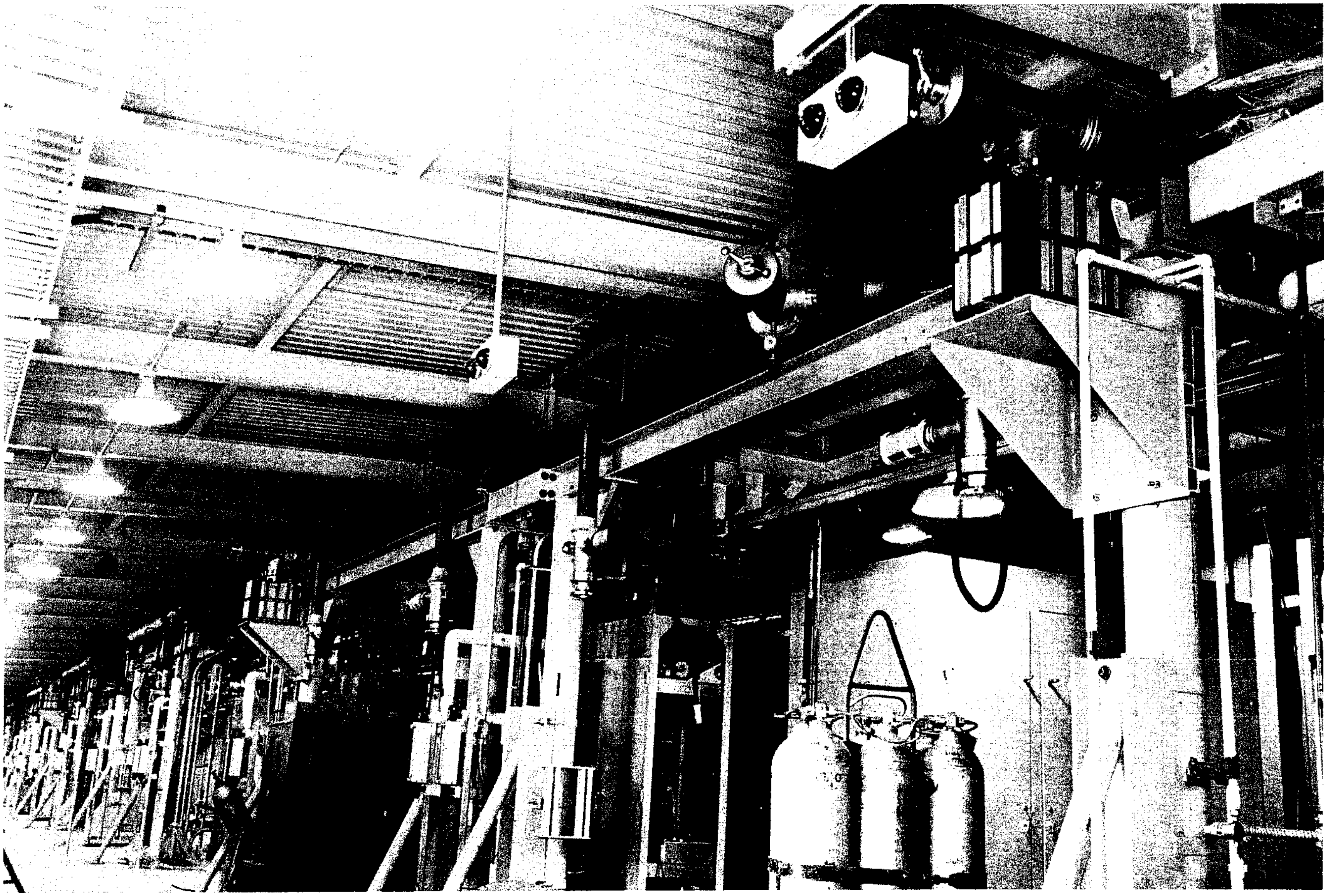

FIG. 6--View of Sector 1 in the Klystron Gallery prior to installation of klystrons (looking east).

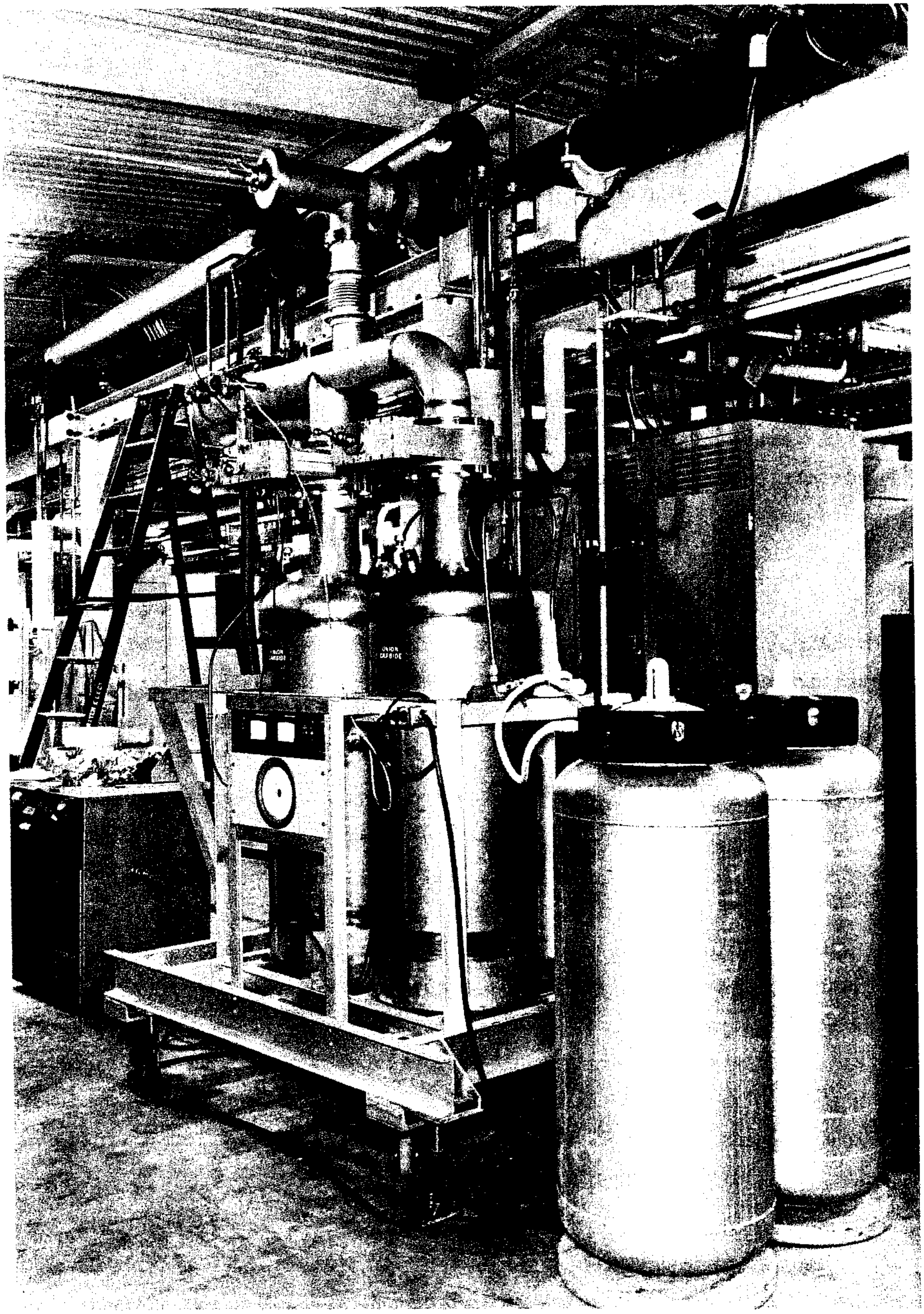

FIG. 7--Prototype of cryosorption vacuum roughing system.

box and pistol-grip heliarc welding gun, and the addition of a breech block and rails to the 155-mm gun barrels for the Research Division, to facilitate its further study of shielding methods.

4. Installation Drawings

The drawings were updated to reflect modification requests to the cooling water and electrical systems. Electrical modification work included beam analyzer station and various accelerator controls. Off-axis deletion and positron source addition were in process on the cooling water system drawings. Rack layouts and installation drawings for sectors 3-30 were completed. Drift Section vacuum connection drawings have begun.

5. Vacuum

The drift section connections design was approved and issued for bidding. Specification modifications were being prepared to change the torque to 10 and 20 ft-lbs (from 5 and 10 ft-lbs) for the 3-inch and 6-inch valves, respectively. The "O" ring problem is under study.

The resubmitted getter-ion pump with 24 elements and shortened anodes was tested and accepted. Pre-production tests are complete except for power supplies which are under test by the Light Electronics Group.

Problems still exist with control units of cold cathode gauges. Silicon diodes are being replaced with ceramic units to meet temperature requirements. Seven units received were rejected due to high voltage power supply failure.

Calculations are underway for pumpdown time on the alignment vacuum system. The system will consist of two 500-cfm mechanical pumps for roughing and a 2000-liter/second, refrigerated, baffled diffusion ejector pump backed by a 150-cfm mechanical pump.

6. Cooling Water

New definition of cooling water requirements for the positron source were established and drawings are proceeding. A circulating nitrogen gas system has been added. Heat exchanger specifications were modified and resubmitted. Preliminary instrument specifications were prepared. A corrosion test unit is in operation on the third test run.

7. Electrical Services

Acceptance testing and operating modifications to variable voltage substations continue as new units are installed.

8. Electronics

Fiat racks were reworked to include the new modulator-klystron protection system and the remainder of the Instrumentation and Control cable and rack installations were in process for Sectors 1-2 beam turn-on.

A second rack fabrication package was approved and sent out for bids; bids were received from eight concerns. A recommendation is being prepared. A package for Instrumentation and Control installation for Sectors 3-30 was prepared and issued for review.

Two major cable procurements--multipair and main trigger line--were bid during the quarter.

Service channels for personnel communications in Sectors 1 and 2 have been checked out and are in service. The proposed audio-visual systems for the auditorium were reviewed and approved. A detailed schedule for design, procurement, installation and checkout is being processed.

A study was made and recommendations issued concerning equipment for a radio alerting system for the SLAC fire brigade. It has been recommended that an additional government frequency assignment be obtained for SLAC radio systems.

B. BEAM SWITCHYARD

The coordinated program for updating definitive drawings continued during the quarter.

A design change to the materials handling system was prepared. Additional track will be installed (a) to provide crane access to the downstream equipment pit of the parasitic beam and, (b) to provide facilities to transfer loads onto the floor between beam channels. Additional changes included, (a) relocation of vacuum penetrations, (b) enlargement of cooling water penetrations, (c) provision of anchor bolts for equipment and (d) addition of channel inserts at wall service chases.

1. Vacuum

Vacuum pumping systems procurement was prepared, approved and sent out for bids.

Drawings and specifications are being completed for vacuum fingers, drift sections, central divergent chamber and tune-up dump.

Fast valve closing time was established at 12-14 milliseconds by two methods--scan frequency of the oscillator and a photo-electric method. The valve has been assembled and the mechanical actuation test was satisfactory.

The 530-cycle closure test on lead seal material for 6-inch and 10-inch isolation valves was completed. Design of a 10-inch isolation valve has started.

2. Electronics

A series of sound level measurements was made at the new Mark III end station to obtain background data for the accoustical study underway on the beam switchyard end station areas.

3. Cooling Water

Work continued on the final flow diagrams and layout drawings. Specifications for heat exchangers were issued for project review and are being revised. The pump specification is being prepared.

4. Electrical

Power system redesign is progressing satisfactorily and drawings are being revised to agree with magnet and pulse magnet data as it becomes available.

A modified prototype of the remotely-operable power disconnect was received and is being tested. Alternate designs for power disconnections to magnets are being considered, one of which may replace the remotely-operable disconnect.

The drive line package is being redesigned as a result of temperature control problems in the Klystron Gallery.

The trigger line couplings have been clearly defined. The equipment needing trigger signals is being identified and located.

Radiation resistant coaxial and twinaxial connector specifications are underway.

Specifications are being prepared for several special-function radiation-resistant cables. The concept of using hermetically sealed radiation resistant cables is under review. These cables were visualized as consisting of glass fiber insulated cables in a flexible corrugated jacket. The assembly would be baked out and evacuated.

IV. ACCELERATOR PHYSICS

A. INJECTION

1. Main Injection System

a. Wiring and Electronic Assembly

The general wiring and electronic assembly of components of the injector system are being done on a time-and-materials contract which is now half complete and progressing satisfactorily. All racks and most controls for the injector are scheduled to be delivered and installed by April 1965.

Wiring of the control console is 95% complete; the console is scheduled for delivery in March 1965. The racks for the high current power supply system, which include the main auto-transformers, controllers and all associated wiring, are complete and in place at the site. The high current power supply subcontract has been awarded and the first unit is scheduled for delivery in April 1965, with the complete order of 24 units to be received by May 1965.

The racks for the medium current power supplies are in place at the site. The power supplies are the same as those used for steering dipoles on the rest of the machine and will be delivered as part of that subcontract. Fabrication of the remote controllers is in progress.

The power supplies for the vacuum system are wired and in place. The design of the vacuum interlocks and console readouts is in progress.

Space has been reserved for two gun modulators; the interconnecting wiring has been designed as part of the overall injector wiring system.

b. Waveguide Components

The design of the standard strongback to support the disk-loaded waveguide for the injector has been changed to a concentric stainless steel round tube inside of which the disk-loaded waveguide is housed and aligned prior to tuning. The focus coils are supported by the outside diameter of the tube. The whole structure is then mounted on the girder and supported at three points. This change of design minimizes the danger of damaging the completed waveguide when mounting the focus coils around it.

Parts for the disk-loaded waveguide are being fabricated. The 0.75c buncher has been tuned and is ready to be brazed onto the waveguide. The components and supports for the rectangular waveguide will be fabricated and tested during the coming quarter.

Components for the injector drift section are in the final design stage; fabrication will take place during the next two quarters.

2. Electron Guns and Modulators

Parts and subassemblies for the SLAC electron gun were completed during this quarter, and bell jar testing of the inner gun (bombarder-cathode-grid) will begin. The initial testing will check the performance of the filament and bombarder diode in the proposed thermal environment. When the thermal tests are complete, emission tests will be made. Production of parts necessary to assemble and test the vacuum envelope are about 50% complete.

Gun Model 1-1 was installed in the beginning of Sector 1 of the machine for Sectors 1 and 2 tests starting in December and is performing satisfactorily. Gun Model 1-2 has been converted and is available for backup use in sector tests. Gun 2-2 is still operating on the Injector Test Stand.

The second modulator, Model 4-2, was accepted this quarter and arrangements are being made to rework the first modulator, Model 4-1, so that it will be acceptable.

3. Injection Test Stand

The Injection Test Stand operated during most of the quarter and was utilized for a variety of experiments. In particular, measurements were carried out to verify the operation of the rf sweeper and the beam position monitors of both the microwave and video types. The stand was also used in radiation studies.

B. DRIVE SYSTEM

1. Main and Sub-Drive Lines

Installation of the main and sub-drive lines has continued on schedule with Sector 6 installed by the end of the quarter. Sectors 7 through 15 are on hand and are being inspected and tested. Deliveries are far ahead of the installation schedule and completion of the procurement contract is expected to be on schedule.

Power from the main booster amplifier has been transmitted through the first three sectors of the main drive line into a water load. Power from temporary sub-booster modulators has been transmitted and distributed by the sub-drive lines in Sectors 1 and 2. Two problems were discovered during the quarter. The method of anchoring the drive lines to the ground to assure phase stability with respect to the beam has been found unreliable, the anchors being too weak to hold the lines in place under stress. A method to improve their stability is being studied. The other problem is that the temperature stabilizing system for the drive lines is insufficient, causing the temperature to vary by more than 10°F over a 24-hour period. Methods for improving the heat transfer and temperature stability are being investigated.

2. Varactor Frequency Multipliers

Efforts are still being made to locate a suitable substitute diode to replace the original which is no longer available. The manufacturer who supplied the original units is working with SLAC in an effort to reproduce the desired and necessary characteristics. Two other manufacturers are also providing diodes for evaluation and it is believed that a diode capable of producing 350 mW from the multiplier will be found.

Step-recovery diodes are also being examined in the hope of building a multiplier with greater phase stability over drive power variations. At this time no step-recovery diode capable of producing adequate output power levels for our purposes exists but higher power diodes may become available from industry in the next few months.

3. Main Booster Amplifiers

The output power regulation of the main booster amplifiers has been improved and is now about ± 0.05 dB per week. This result should improve the phase stability of the frequency multipliers, which depends on the input drive power from the amplifiers.

A prototype switching system has been built, installed, and tested. This switching system provides local, remote and automatic switching of the two main boosters in the event of a failure. At this time, one amplifier has 3,000 hours of beam operating time, the other 2,000 hours. Aside from occasional trip-outs of the main high voltage breaker, no failures have occurred and there is no deterioration of performance.

4. Master Oscillators

Three master oscillators and one frequency synchronizer have been delivered and all units meet specifications. Minor trouble has been experienced with meter relay contacts which provide status and switching information. This will be corrected by repair of the present meters or by replacement with a different type of meter. Two of the oscillators are presently in operation and are being tested in the main drive system for Sectors 1 and 2. A switching system for the master oscillators and sub-booster klystrons in Sector 1 is also under design.

5. Sub-Booster Modulators

Both pre-production sub-booster modulators have been tested and delivered to SLAC. Originally, the modulators were built with only two switch tubes, but it was subsequently decided that improved operation and longer life would be obtained with three tubes. For this reason, SLAC authorized the addition of an extra switch tube per unit. Both units appear to be meeting all rf specifications. A number of electronic malfunctions have been detected and are being studied by personnel from the Heavy Electronics Group. Some shipping damage was sustained by one of the auxiliary power supplies, which had to be returned to the vendor for repair. The first modulator is now installed in Sector 1 of the machine.

6. Drop-Out Cables

The pre-production drop-out cables were tested and found to meet specifications. The sizes of the production quantity were established and the vendor was notified to proceed with the production units.

7. Positron Phase Shifters

The positron phase shifter (a ferrite circulator) has been tested. The prototype driver which switches the circulator utilizes a resonant charging technique which permits the transmitted pulses to rise from 10% to 90% amplitude in less than 500 nsec. The mechanical design to incorporate the driver and the circulator into the isolator-phase shifter-attenuator units is being completed. Cables to obtain the proper triggering control have been included in the installation contracts.

8. RF Drive Power to the End Stations

Plans for the extension of the main drive line into the end station area are progressing satisfactorily.

9. Present Status of the Overall Drive System

Tests of the drive system in Sectors 1 and 2 indicated successful use of the master oscillators, the main booster amplifiers, the main drive line transfer switch, the drop-out cables, the varactor multipliers, and the temporary sub-booster modulators; and for each klystron, the individual isolator-phase shifter-attenuator assembly. Aside from minor adjustments, this system has operated without any problems.

C. PHASING SYSTEM

1. Isolator-Phase Shifter-Attenuator Units

The subcontractor has agreed to fit the length of phase compensating cable specified by SLAC. Quantity production and delivery are proceeding satisfactorily. One hundred fifteen units have been delivered, complete with dual directional couplers; 59 have been tested and approved for accelerator installation; eight units have been rejected. Of these, three will be returned to the subcontractor and the remainder will be repaired by substitution of components at SLAC. No serious fault has been found.

Fourteen control phase shifter units have been delivered and are awaiting acceptance testing.

The first special isolator-phase shifter-attenuator unit having a dc motor and potentiometer coupled to the phase shifter has also been received.

2. RF Detector Panels

A subcontract for the panels was awarded on November 25, 1964. Three preproduction units are scheduled for delivery in January 1965.

3. Programmers and Electronics Units

Fabrication of the pre-production units is proceeding, with delivery scheduled for January 1965.

4. Linear Detectors

Six prototypes were manufactured from the new drawings and will be tested before the bid package is completed.

5. Permanent Beam Analyzing Station

The station has been completed and is ready for installation in the accelerator housing. All the protective interlocks mentioned in the previous status report have been incorporated.* An electronic scanner for sampling the integrated charge built up on the foils by passage of the electron beam has been designed and built. All major components, viz., beam position, intensity and profile monitors, spectrometer magnet, steering and focusing magnets, have been aligned. The spectrometer magnet has been calibrated by means of a floating wire.

6. Temporary Beam Analyzing Station

The spectrometer magnet has been delivered, tested, and found to be satisfactory. Fabrication of the strongback, vacuum envelope, foil box and dump is completed. It is expected that the station will be assembled at the end of Sector 2 in January 1965.

7. Beam Position Monitors for Drift Sections

The first set of rf cavities was assembled from components machined at SLAC. Redesigned coupling probes were welded into the cavities after the frequency and loaded Q had been adjusted. The complete assembly was incorporated into the test injector vacuum system so that beam tests could be made. A prototype rf panel and an electronics unit were available, allowing the complete system to be checked. All components performed satisfactorily, and have now been installed in the permanent beam analyzing station.

Two of the three sets of parts machined by a subcontractor have been brazed together, and the coupling probes have been adjusted and welded in position. These assemblies will be installed in Drift Sections 1 and 2. Two rf panels are nearing completion.

After the performance of these monitors has been evaluated by Sectors 1 and 2 tests, procurement for remaining units will be initiated.

8. Beam Position Monitors for the Beam Switchyard

Approximate cavity dimensions have been established and detailed drawings are being made. A prototype assembly will be built from these drawings and

*"Two-mile accelerator project, Quarterly Status Report, 1 July to 30 September 1964," SLAC Report No. 34, Stanford Linear Accelerator Center, Stanford University, Stanford, California (1965); p. 25.

tested before construction of the nine sets required in the switchyard is begun. Preliminary design of the rf detection and video transmitter panel is completed, and components for a prototype are being procured.

Particular attention is being given to the requirement for radiation resistance in all materials used. For example, the coaxial cables connected to the cavities will have to operate in a high-radiation environment. It is probable that only ceramic dielectrics will be used close to the machine. RF connectors will be designed to be remotely disconnected from the servicing trolley passing overhead. Water will be used for stabilizing cavity temperature. Shielding will be used to reduce the radiation level in the upper tunnel where the rf detection and video transmitter panels will be located. Two rf phase discriminator circuits will be used for each position monitor. One will use thermionic diodes for large signal detection; the other will employ tunnel diodes and will be switched in when the beam current is low.

D. GENERAL MICROWAVE STUDIES

1. RF Separators

Measurements of the efficiency of the LOLA III deflector ($v_g/c \approx -0.007$) were completed. Similar measurements on the LOLA II deflector ($v_g/c \approx -0.029$) will be taken during the next quarter.

2. Coupler Asymmetry

After numerous measurements, the attempt to use a double iris coupler for improving phase symmetry was abandoned because none of the techniques were successful and those using two input couplers complicated the matching and tuning of the first cavity without solving the problem.

E. OPTICAL ALIGNMENT SYSTEM

1. Alignment Targets and Frames

Targets and frames are being received from the manufacturer on an accelerated production schedule which will permit early installation of targets in the Fabrication Building as one of the last operations in the girder assembly procedure. Acceptance testing consists almost entirely of optical comparative measurements which detect gross errors of mounting or ruling. All the targets examined, with the exception of the two copies of one model which were mounted out of tolerance, have been accepted.

2. Target Installation

As part of the retrofit program to install targets in the early sectors of the machine, a device is being built to determine the actual installed position of each target. The error in mounting as well as errors in assembly of the hinge system will be combined in this measurement, which will yield a correction factor for both the horizontal and vertical position of the target.

F. MAGNETIC SHIELDING AND DEGAUSSING

Continued delivery of the magnetic shielding has been well ahead of the amounts requirements for the production of accelerator elements. The samples which were evaluated gave shielding factors ranging from 18 to 30 at 1 cps. The low value is within the experimental error of the required value. The highest value represents an exceptionally good performance for an 0.006-inch single layer of shielding. The first tests of the complete magnetic shielding system were made as part of the Sectors 1-2 tests.

V. INSTRUMENTATION

A. GENERAL

The work reported in this report was performed by the Instrumentation and Control and Light Electronics groups.

B. DATA HANDLING

1. Status Monitoring

Binary status information at each sector will be transmitted to Central Control on a time-shared multiplex system. A contract for this equipment has been awarded with delivery of the preproduction unit scheduled for January 1965.

2. Analog System

Slowly changing analog signals will be transmitted to Central Control by means of individual hardwire pairs and will be read on standard panel meters.

An Engineering Design report for this system has been prepared and is under review. In general, the readouts will be available on switched panels in Central Control. Two data racks will contain the analog switching relays for the switched sector panels. The principal sector equipment is the analog metering panel, which makes each analog signal available for readout at the Instrumentation and Control alcove. The mechanical design of this panel is now complete and prototypes have been installed for Sectors 1 and 2 beam test.

3. Beam Monitoring

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

a) An FM signal which gives an accurate representation of the charge per pulse (Q) at each sector, and

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

Prototype transmitter and receivers have been built for Sectors 1 and 2 tests.

A contract has been awarded for FM transmission equipment which will be used to transmit the output of the accurate intensity monitor from each sector to Central Control; it will also be used at several locations in the beam switchyard. Delivery of a pre-production system is scheduled for March 1965.

4. Remote Control

The Remote Control System consists of a transmitter which transmits binary codes and a receiver in each sector which translates the codes into a signal to actuate a relay or motor. Remote control signals are sent to each sector as binary coded signals which may operate one control relay or motor at a time. A few controls are transmitted directly on hardwire transmission line-pairs.

Two remote control receivers, each equipped for 32-channel operation, and one 30-channel transmitter-encoder have been built and tested. These prototype units will be used for Sectors 1 and 2 beam tests. A bid package consisting of all drawings for the remote control transmitter and receiver is being prepared and will be completed in January 1965.

C. BEAM GUIDANCE

Beam steering power supplies were received and prototype controllers for the supplies have been built and will be installed for beam tests. Satisfactory tests of the electronics of the beam position monitoring system were carried out on the injector test stand. A complete unit, giving $\ln Q$ (beam charge) and x- and y-position information, to be used with the girder 1-1 spectrum analyzer, was installed and additional units of this type to be used for the Sectors 1 and 2 beam tests were completed. The procurement specification for this equipment is being prepared.

The electronics to provide a signal linearly proportional to the charge in each beam pulse was improved, and preliminary measurements indicated that an accuracy of 1% over a 60-dB range of beam charge can be obtained.

Development of display modules to be used at Central Control has continued.

D. TRIGGER SYSTEM

The trigger system for Sectors 1 and 2 tests is installed and operating satisfactorily, and includes an injector trigger generator for the temporary injector. Procurement specifications for the sector trigger generator have been written. Design criteria on the comparator for the master trigger generator have been issued and design has started. Preliminary design criteria on the pattern generator have been issued.

The following components of the trigger system are presently under construction: sector take-off transformers, master trigger generator, rate selector, sequence generators, and portable rate generator.

E. MODULATOR-KLYSTRON PROTECTION SYSTEM

Modulator-klystron protection units and associated equipment - the rf distribution panel, forward and reflected rf output detectors, and the rf drive sampler and detector - have been installed and tested in Sectors 1 and 2 of the Klystron Gallery.

Interim reference voltage supplies for controlling the variable voltage substations in Sectors 1 and 2 and for supplying a reference voltage to the modulator de-Q'ing circuit have been installed and tested. Interim monitor-rectifier units used in conjunction with the reference voltage power supplies have also been incorporated and tested in the Klystron Gallery.

F. PERSONNEL PROTECTION SYSTEM

A temporary personnel protection system has been installed to permit beam tests in Sectors 1 and 2. It contains most of the elements of the final system. Keys for the access doors to the Accelerator Housing must be returned to a key bank before the machine may be turned on. The hatchcovers for the accessways to the housing are interlocked with the substations supplying high voltage to the modulators. Emergency shut-off buttons in the housing turn off the machine. A warning is sounded in the housing (and in the Klystron Gallery) at the start of lock-up procedure and before the modulators can be turned on. Warning lights in the gallery indicate when the modulators are on and when radiation exists in the housing.

Additional special measures for beam tests in Sectors 1 and 2 include a main shielded wall below the Sector 2 beam analyzing station, a lighter shielded wall behind the injector, and locked gates at the west end of the housing and at a suitable distance downstream of the shielding wall.

The final circuit design for the permanent Sectors 1 and 2 equipment has been completed and will be installed during the next quarter.

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 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. A contract for the tone generator and receiver has been awarded. Tests have been completed on the tone interrupt unit and packaging is beginning.

For the 50-microsecond network, a pulse train generated in the beam switchyard allows the gun to be turned on once for each pulse. Interlock circuits, acting on a pulse-to-pulse basis, interlock the pulse train when it is determined that the switchyard cannot accept the beam for the next pulse. Specifications of the amplitude and pulse shape for the pulse generator in the switchyard are now being studied. Design has started on a circuit which permits the gun to operate only on receipt of these pulses.

A coaxial cable installed in the housing will be used as a continuous ionization chamber to indicate quantity and location of radiation produced by the beam along the accelerator. A back-up set of discrete ion chambers to detect radiation at each sector has been constructed and is ready for tests. Following tests in Sectors 1 and 2, a decision will be made as to which system will be used for the two-mile machine.

H. CENTRAL CONTROL

Mock-up control panels are being replaced with functional prototypes as designs are finalized. This will continue until console installation, now scheduled for June 1965.

The detailed design of panels continues to change as new lists are written of signal and control requirements for the injector and the beam switchyard. The concept of using a computer to control the accelerator has influenced design of the control system since its beginning. More detailed studies have begun this quarter.

I. RADIO FREQUENCY INTERFERENCE STUDIES

Tests have recently been made to determine experimentally the level of interference that can be expected in instrumentation systems due to the leaking of the high power modulator pulses into the main Klystron Gallery environment.

Measurements of modulator leakage in the Klystron Gallery indicate that it is considerably smaller than that of the earlier version of the modulator installed in the Test Laboratory. After filters were added to some of the instrumentation lines coming out of the modulator, the maximum video level on conductors leaving the modulator was about 0.2 amperes. This was measured by means of a magnetic induction loop added to a battery operated portable oscilloscope. The largest component of this interference appears to be a five-megacycle damped sine wave with a decay period of about five microseconds. Such currents were measured on ground busses, the outside of electric conduits, and instrumentation cables leaving the modulator box. One hundred feet away from the modulator all of these currents were reduced by at least a factor of 10.

Tests were also made to determine what level of pickup might be expected on a well shielded video signal originating in the Accelerator Housing and transmitted at low level up a penetration to an amplifier in the Klystron Gallery one hundred feet from the source of the signal. The toroid beam intensity monitors are perhaps the instruments most vulnerable to this kind of video interference.

This test was made by constructing a video system with a well shielded beam toroid at one end and a well shielded low noise transistor amplifier thirty feet away. The two boxes were connected by a twinax cable contained in a 1/2-inch-diameter copper tube with 0.060-inch wall thickness. This system was purposely placed in a noisy modulator environment where approximately one ampere of video signal as described above was present on the outside of the copper tube. Under these conditions the differential pickup on the twinax cable amounted to only seven microvolts across the 100-ohm input to the amplifier. This low level of video interference permits the toroids to measure beam currents of one milliampere with a sensitivity of 0.1%, i.e., a beam pick-up sensitivity of 10^{-6} amperes.

The shielding techniques developed in these experiments are being incorporated in the design of the electronics for the beam toroids.

VI. HEAVY ELECTRONICS

A. MAIN MODULATOR

1. Modulator Procurement

Tests and improvements on the 20 pre-production modulators continued during this period. The main high voltage rectifiers which had caused difficulty during the previous quarter were reworked and now appear to operate satisfactorily. The end-of-line clipper fault interlock circuitry was improved so that if, for example, one of the switch tubes in the dual tube system should fail, the modulator would shut down after one fault pulse instead of 10 fault pulses. Weaknesses in some small components were also corrected.

The testing also revealed that the modulator could be improved with respect to interlock chain operation, shock mounting of the main ac contactors, airflow switch flutter, keep-alive power supply for the thyratrons, and in other ways. These changes were written into the modulator contract, and in November the supplier was given authorization to begin construction of production modulators. At the end of the quarter the supplier had five cabinets in-house, had ordered almost all the necessary parts, and had made up many of the wiring harnesses.

Two pre-production modulators, Serial Nos. 2 and 3, are on life tests in the Test Laboratory and have 4298 and 3727 hours, respectively, of high voltage operating time. Most of this operation has been at full power into a water load for serial number 3 and a diode load for serial number 2.

Of the ten modulators in Sector 1, seven have been equipped with klystrons and have operated simultaneously for Sector test purposes. Most of these modulators have operated on the order of 100 hours at high voltage.

Most of the rest of the pre-production modulators, which are in Sector 2, have been operated a few hours into water loads.

2. De-Q'ing

During the quarter specifications were written and procurement was initiated for the de-Q'ing switching devices.

Samples obtained from two companies will undergo 1000-hour life testing, as provided for in the Request for Proposal. These samples should be on test about the middle of January. Following these tests, a decision will be made as to the type of de-Q'ing circuit to be installed in the production modulators. Life tests on other switching devices also continued during the quarter. Five of the 20 "package circuits" to be used in the pre-production modulators failed under tests and were returned to the supplier to be reworked.

Silicon controlled rectifiers continued to be tested in Serial Nos. 2 and 3 modulators on a 25:1 turn charging inductor ratio. A single SCR in Serial No. 2 modulator ran about 2500 hours before failure. Two SCR's in series in Serial No. 3 modulator had run about 2500 hours when one SCR was removed because the use of a single SCR looked so promising at that time. However, a few hundred hours later the remaining unit failed. It appears, in view of all our testing, that the use of two SCR's in series is to be preferred over a single one because the additional voltage margin is necessary under certain, rare, fault conditions. The safety factor in the specifications for de-Q'ing switching devices makes it necessary to use at least two SCR's in series.

Another de-Q'ing system using a 50:1 turn ratio in the charging inductor and a single 800-volt SCR has over 2500 hours life in prototype No. 1 modulator. This system does not regulate as well as the one using a 25:1 turn ratio; therefore, no further work is being done on it, although it does appear to be a good back-up measure.

3. Switch Tubes

As mentioned in the previous Quarterly Status Report,* the contract for ZT7004 hydrogen thyratrons was modified to allow the substitution of a pair of GL 7890 tubes for each ZT 7004 tube. The substitute tubes came in very quickly; at the end of December some 85 tubes were in-house. These tubes have allowed us to move ahead on sector testing.

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*"Two-mile accelerator project, Quarterly Status Report, 1 July to 30 September 1964," SLAC Report No. 34, Stanford Linear Accelerator Center, Stanford University, Stanford, California (1965); p. 36.

The KU 275A tubes received appeared to improve in their operating characteristics during this quarter. X-rays of the tubes revealed that interelectrode spacings were slipping as much as 47% during construction. We have correlated this defect with excessive kickouts and anode time delay. The X-rays were made at SLAC with a cobalt-60 source.

Life tests on these tubes indicate that they are long-lived; five of the tubes have been run for 4578, 2619, 1662, 1549, and 1203 hours. The first in the above series has run 90% of its life at full power. The others have been running in the Test Stand modulators used for klystron aging. All the tubes are still operating.

The third switch tube supplier has delivered several tubes. Two problems, both connected with interelectrode spacing, were initially experienced with these tubes: experimentation with different interelectrode spacings and drifting of element spacings during manufacture (again discovered with the SLAC X-ray technique described above) appeared to cause excessive anode delay time and kickouts. However, at the end of the quarter these problems were solved, and the tubes delivered were satisfactory. One tube on life test has run 960 hours and is still working well.

The "keep-alive" voltage on the pre-trigger electrode* continued to stabilize all tubes to about 10 nanoseconds. This system is being incorporated in all production modulators.

4. Pulse Transformer Tank Assembly

The preproduction run of 20 transformers (plus an additional ten) was essentially complete at the end of the quarter. Six transformers in the early deliveries will be reworked to correct core problems.

The core problem** excessive core loss and excessive droop on the top of the pulses is a result of deformation of the lower half of the two-section

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*Ibid., p. 37

**Ibid., p. 38

cores, with a resultant widening of the air gap between cores. This occurs during the first 1000 hours of operating at full power. At first it was thought that this was due to the high oil temperature in which the transformer operates, and methods of additional cooling for the pulse transformer tanks were explored. An additional water jacket welded to the side of the tank reduced the oil temperature 20°C. Strapping a commercially available plate coil water jacket to the side of the tank yielded an oil temperature drop of 15°C. Either method can be utilized if it becomes necessary to reduce the oil temperature. However, it is not yet clear whether the oil temperature should be lowered. Tests with two essentially identical transformers were run, one in hot oil and the other in cool oil. The results, after 1000 hours of full power operation, indicate deformation of the transformer that was operated in cool oil. The same test is being continued under the opposite oil temperature conditions.

Pulse transformer tanks have been coming in on schedule with some 70 tanks in-house as of the end of the quarter. There have been a few leaks in the welds but these can easily be repaired by the manufacturer.

As of the end of this quarter, there were 14 completed klystron tank assemblies, three tanks ready for klystrons, six tank assemblies with water loads, and two tank assemblies with diode loads. In addition, there were six pulse transformers, 48 tank bodies, seven oil expansion tubes, 232 capacity voltage dividers, 35 klystron filament transformers, 103 triaxial sockets, 124 klystron socket assemblies, 121 klystron socket support sets, and 230 safety heads in stock. This is an adequate supply of parts at this time.

B. SUB-BOOSTER MODULATOR

SLAC received the first pre-production modulator at the end of this quarter, and a second was enroute to the site. They were extensively tested at the manufacturer's in a 168-hour heat run and life test, and performed quite satisfactorily. Upon arrival at SLAC, the first one was installed in Sector 1 for further tests. These modulators were built with three switch tubes instead of two in order to improve the operation and life of the unit.*

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*Ibid.

VII. MECHANICAL DESIGN AND FABRICATION

A. GENERAL

The fabrication and assembly of all components for the first two sectors, or 660 feet, of the accelerator structure had been completed and sixteen 40-foot support girders with a total of 640 feet of disk-loaded waveguide had been installed. The assembled and/or installed components also included two 10-foot drift sections, one at the end of each sector, and the special equipment required for those sections. The permanent beam analyzer station for Sector 1 and the temporary beam analyzer station for Sector 2 were also completed during the period. (The design of these two stations was only about 60% complete at the end of the previous reporting period.) A view of the installed equipment in the two sectors is shown in Fig. 8.

The rectangular waveguide crossbars and the penetration waveguides for the first two sectors were also installed and tuned by the end of the year together with the necessary waveguide vacuum valves and Model A couplers for the klystron tubes. With the installation of the fast-acting vacuum valves on the drift sections, all equipment was either in place or ready to be installed for the turn-on of the test injector for sector testing immediately after the first of the year. Other components being fabricated by the department were also being produced in sufficient quantities to keep up with assembly and installation requirements of the new year.

B. ACCELERATOR STRUCTURES

A total of 144 ten-foot sections of disk-loaded waveguide were completed during the reporting period. This included the fabrication, low power rf testing and tuning, high power testing and all other steps required to make the sections ready for installation on support girders. (An additional seven sections were fabricated but rejected during testing. This meant a shrinkage loss rate of 4.6%.) This meant that a total of 219 sections were completed by the end of 1964 as compared with 32 sections that had been completed by the end of 1963. By the end of the

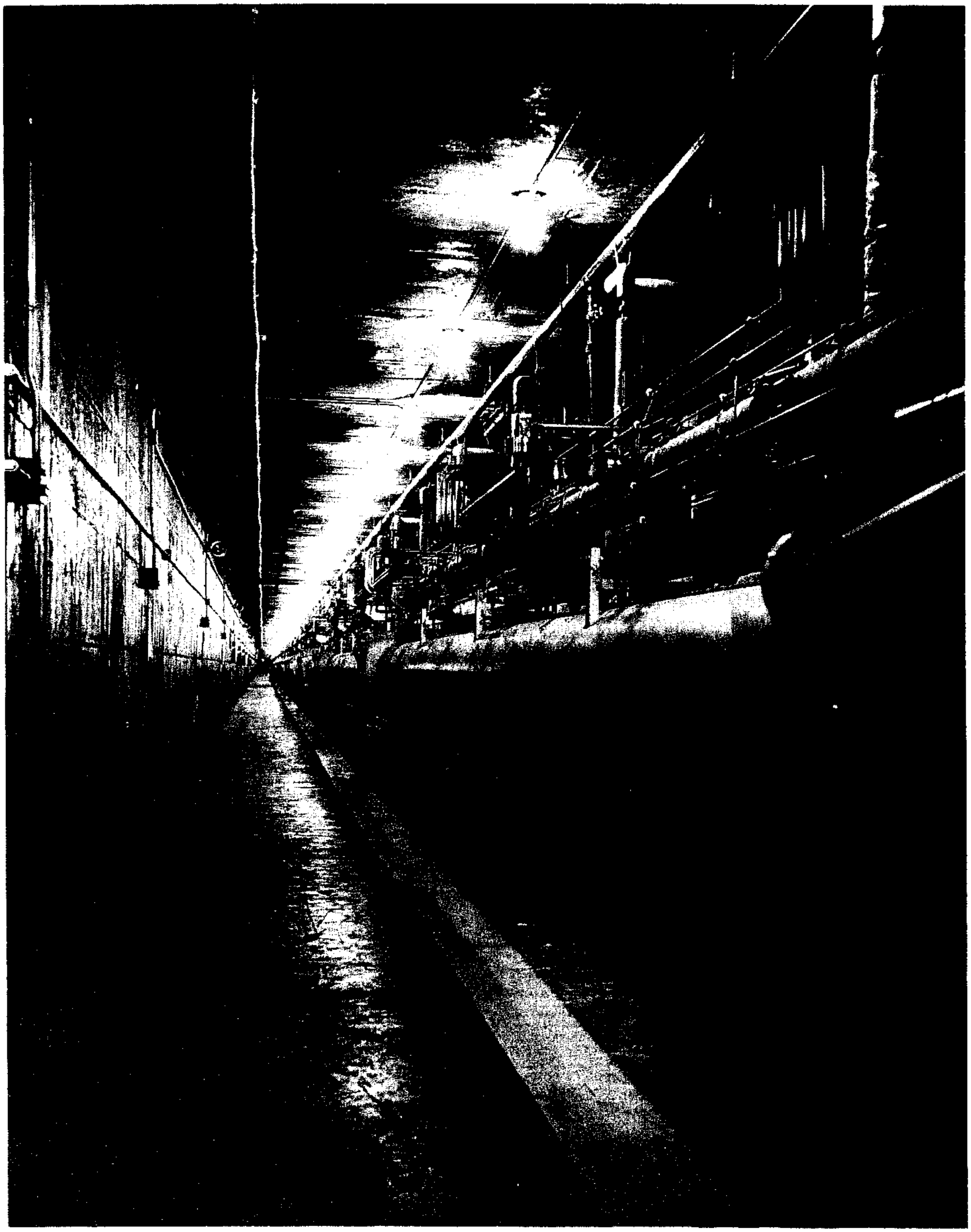

FIG. 8--Partial view of Sectors 1 and 2 in accelerator housing.

reporting period, an average of 17 sections were being completed each week. The design requirements for the special seven-foot sections of disk-loaded waveguide were also completed during the quarter.

1. Low Power RF Tests

Modifications to the tuning station were completed during the reporting period. These included the interlock circuits to provide for automatic monitoring of the temperature, pressure, and rf input frequences at the accelerator section together with the water and vacuum systems. The hydraulic system is monitored through the phase meter on the tuning console. The interlock arrangement and the tie-in between the phase meter and the hydraulic system help protect a section from damage or improper tuning if there is a variation from a specified tolerance in any one system.

By the end of the period, an average of three and one-half sections were being tuned and quality-control checked in a two-shift day.

2. High Power RF Tests

A total of 170 ten-foot sections of disk-loaded waveguide were processed through the rf test area during the reporting period. This compares to 47 sections that were processed during the previous quarter and the number differs from the 144 completed sections because of a backlog that had existed in the high-power test area.

C. FORTY-FOOT SUPPORT GIRDERS

A total of 16 40-foot support girders were assembled and installed in the Accelerator Housing during the reporting period. A completed 40-foot segment ready for transport to the housing is shown in Fig. 9. Accelerometer checks on girder loading during transport are made for each segment. The maximum loading of 0.3 g's that was measured at the time the prototype segment was transported was not exceeded with the later girders and the average was reduced to 0.15 g's. This reduction was due, in part, to the use of an aircraft tug for towing and a subsequent reduction in vibration which occurred.

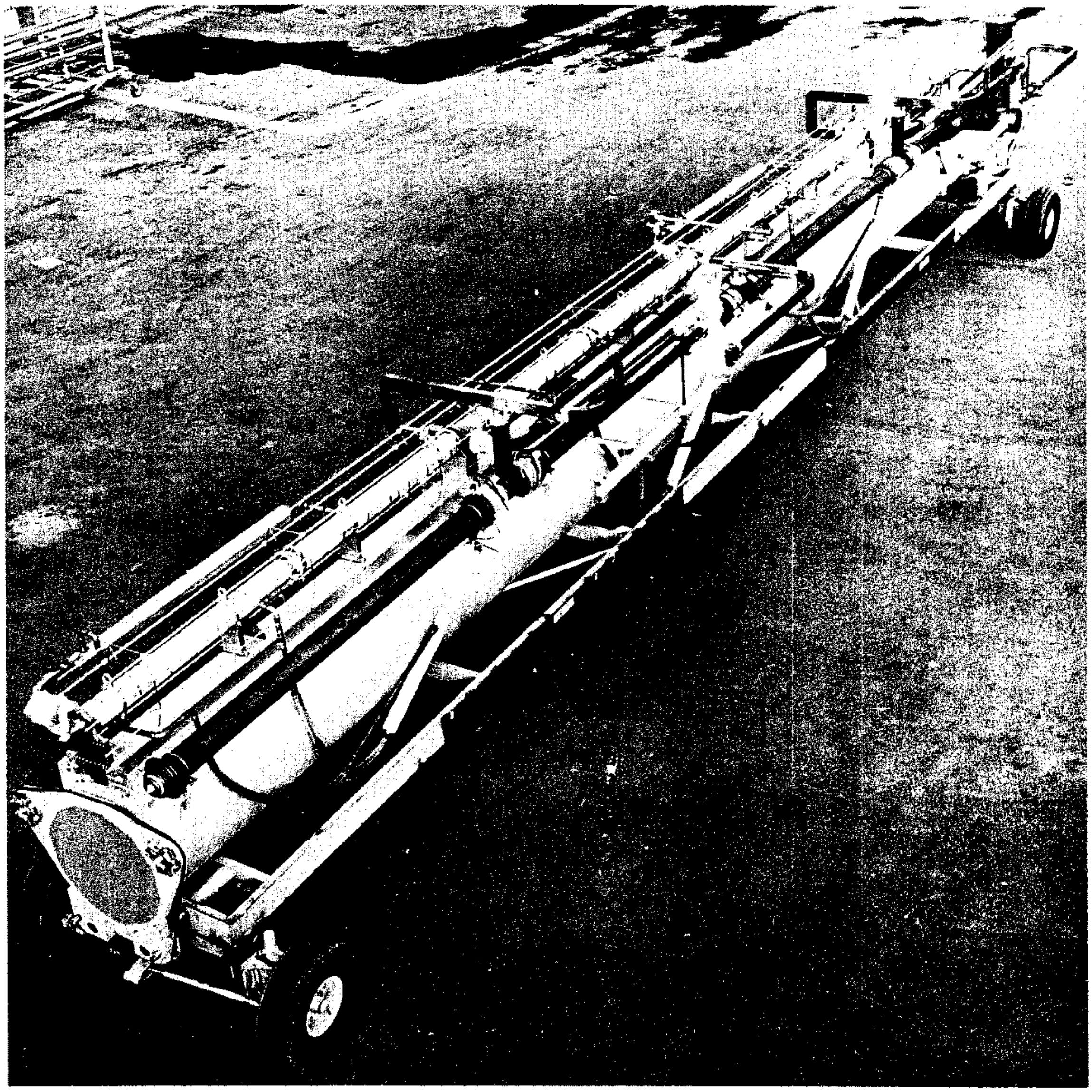

FIG. 9 - COMPLETED 40 - FOOT ACCELERATOR SEGMENT READY FOR TRANSPORT.

After a 40-foot segment is towed into the housing, two Hovair craft* lift the segment from the wheels of the transporter. The segment is then slid into its installed position in the housing on the craft as is shown in Fig. 10. By the end of the reporting period, a 40-foot segment was being installed on an average of one each day and a half.

D. RECTANGULAR WAVEGUIDE

A total of 20 crossbar assemblies and 40 thirty-eight-foot penetration waveguides were fabricated, tested, installed and tuned during the reporting period. These were sufficient to meet the requirements for the first two sectors plus one-half of Sector 3. Phase measurement and tuning, as discussed below, was performed successfully using the modulated-reflection phase tuning and measurement system previously described.**

The transporter for the crossbars is shown in Fig. 11. The first penetration waveguides had been put in place using a helicopter to lower them through the roof of the Klystron Gallery. An Army-surplus missile transporter and a cherry-picker crane were obtained (Fig. 12) for the placement of subsequent waveguides.

1. Phase Measurements, General

Uniformity in the fabrication of rectangular waveguide assemblies continued to improve to the extent that it became practical to eliminate all pre-installation electrical length measurements. Post-installation measurements and adjustments are made in two stages as was described in the previous quarterly status report.***

The crossbar-plus-penetrations assembly is seldom unasymmetrical by more than 30 electrical degrees following installation. Phase measurement of the complete rectangular waveguide feed system, using the

*"A Manual for the Application of Hovair to the Stanford Linear Accelerator," (Sept. 1964), Vehicle Dept., GM Defense Res. Lab., OM64-04, Santa Barbara, Calif.

**"Two-mile accelerator project, Quarterly Status Report, 1 July to 30 September 1964," SLAC Report No. 34, Stanford Linear Accelerator Center, Stanford University, Stanford, California, (January 1965); pp. 53-59.

***Ibid, pp. 52-55.

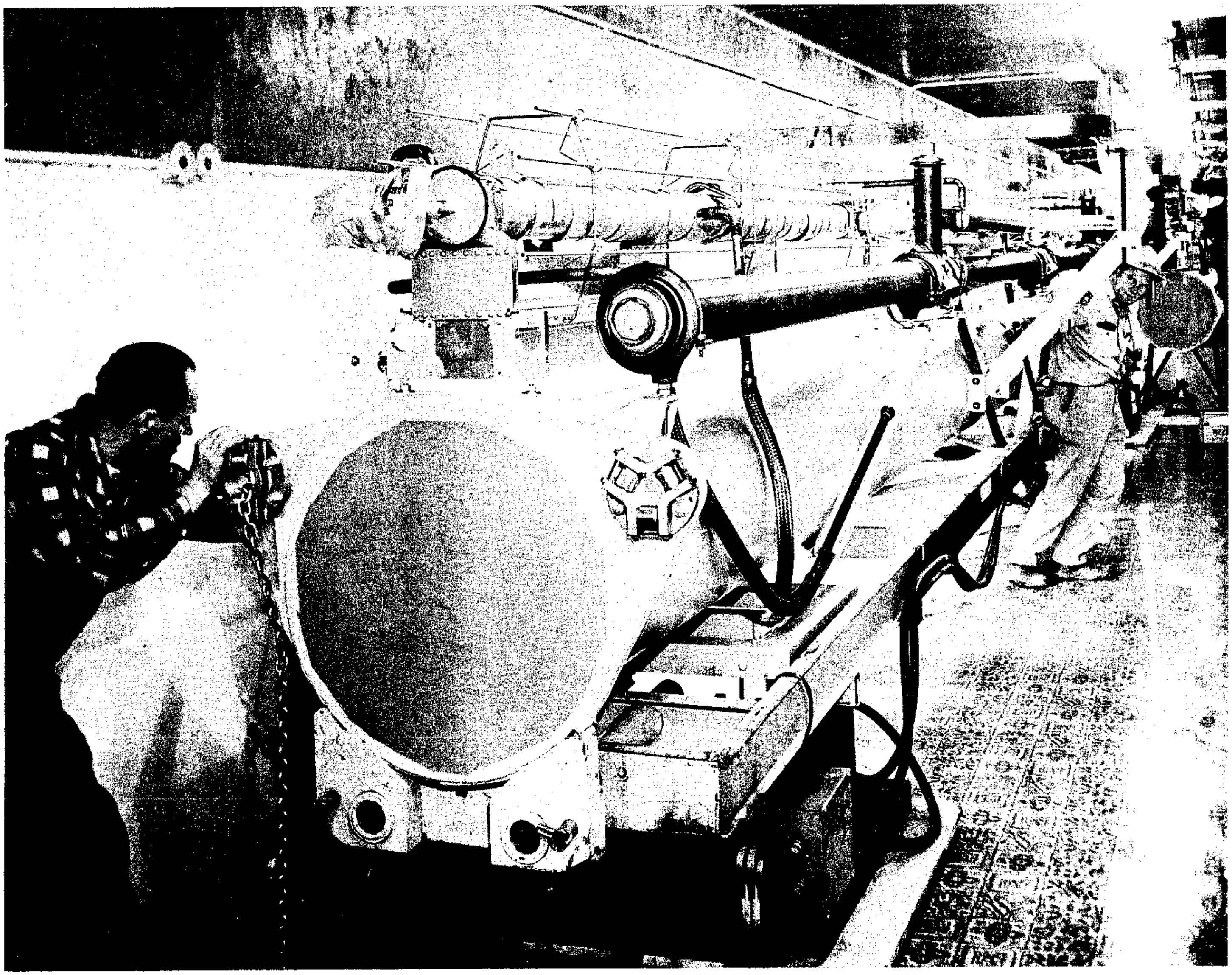

FIG. 10 - POSITIONING 40-FOOT SEGMENT IN HOUSING.

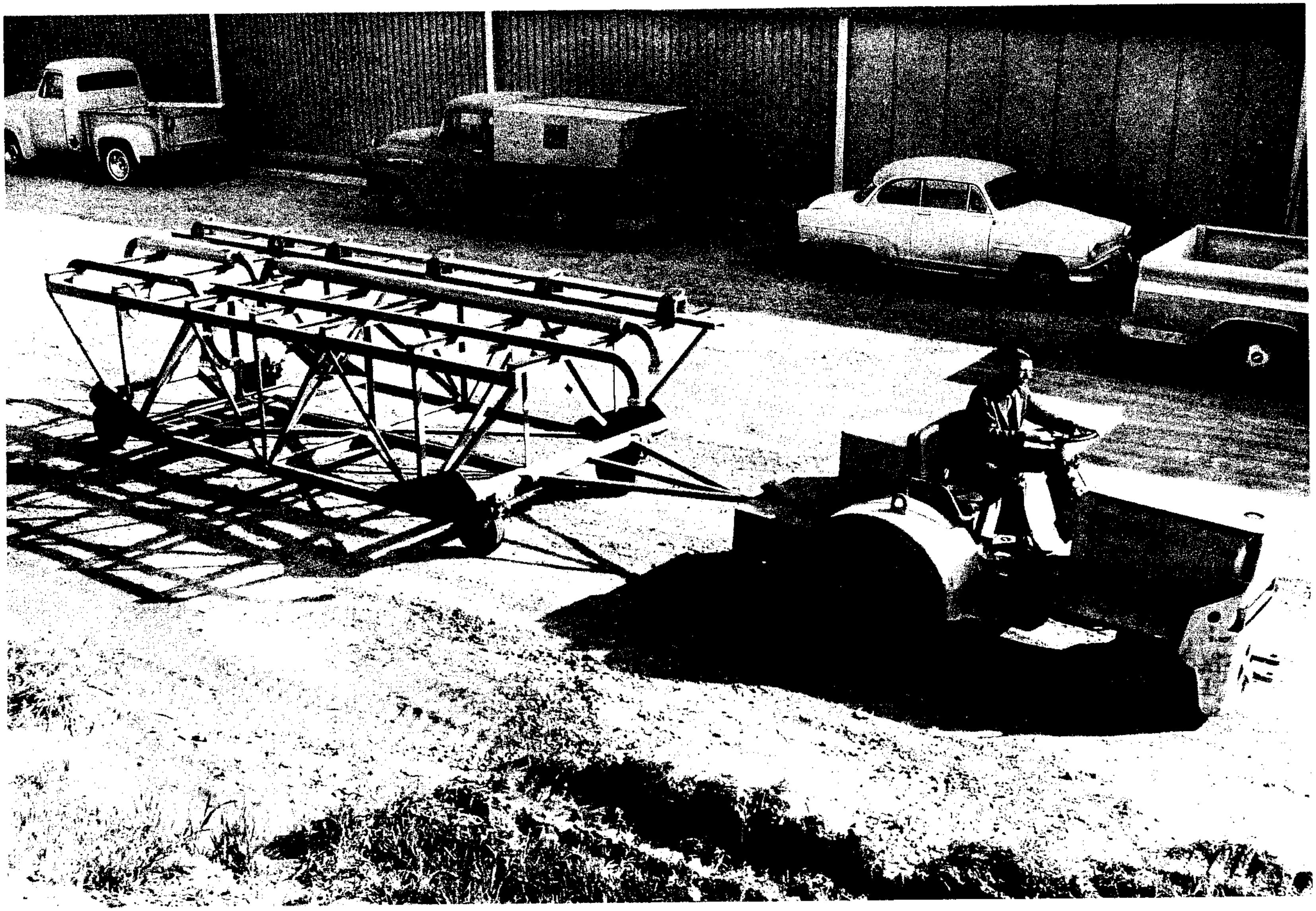

FIG. 11 - TRANSPORTER FOR RECTANGULAR WAVEGUIDE CROSSBARS

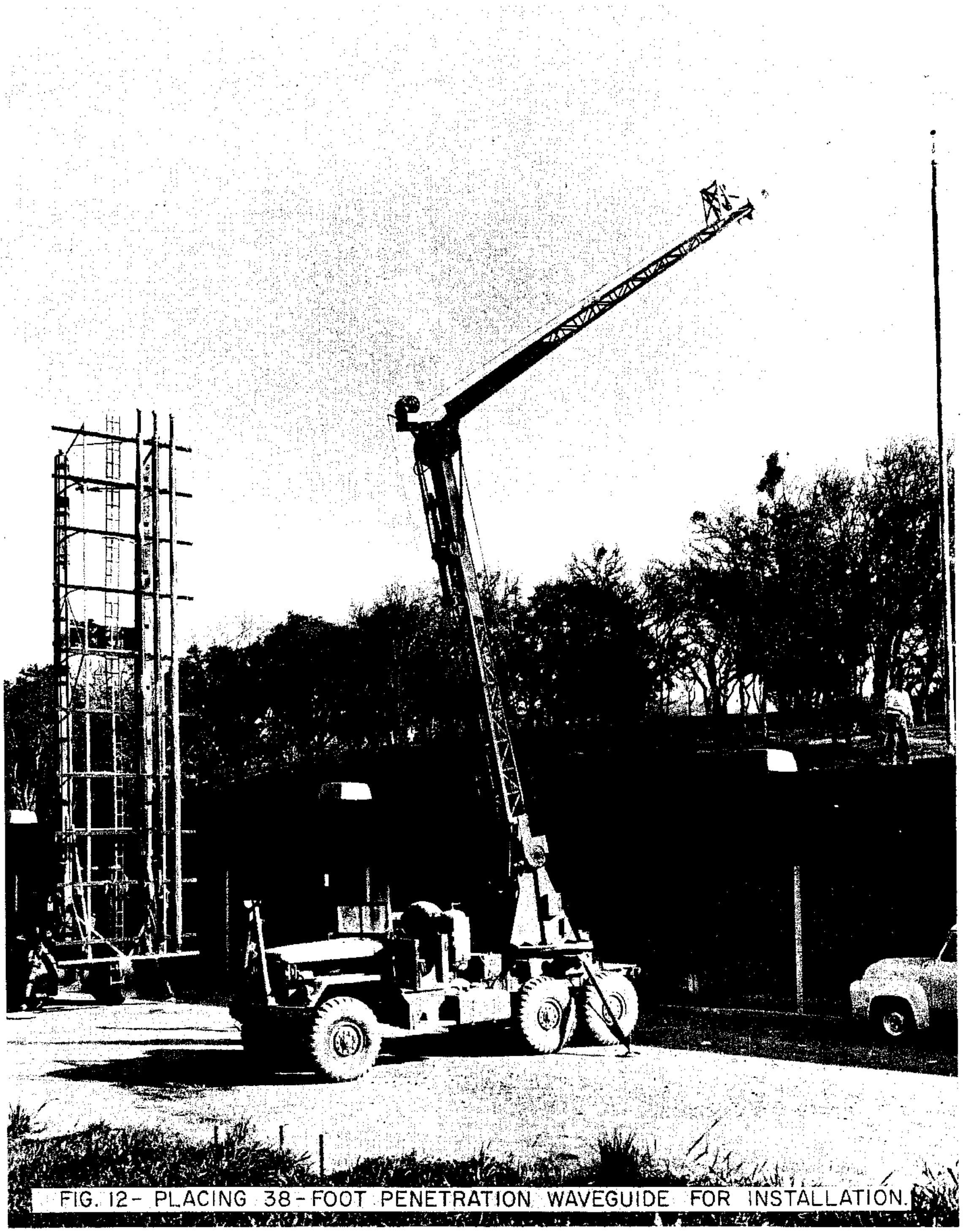

FIG. 12- PLACING 38-FOOT PENETRATION WAVEGUIDE FOR INSTALLATION.

modulated-reflection system, seldom shows a range of phase-length greater than 30 degrees before final tuning. All coarse phase adjustments made on the penetration waveguides are made by squeezing the walls in a two-foot long region near the top of each waveguide. Final phase adjustments are made by squeezing the walls of the waveguide S-assemblies on the installed 40-foot support girder.

All waveguide squeezing is done with C-clamps that are fitted with special jaws about 15 inches long. The jaws are shaped to produce a smooth transition between the squeezed and unsqueezed regions, with provisions for smooth overlapping of squeezed regions. This has appeared to be more practical than using a remotely-operated squeezing tool as it allows one operator to devote his full attention to the phase measurement instruments while another operator, in telephone communication with the first, (Fig. 13) operates the squeezing tool. One-man operation is impractical as it would be difficult to have the instrumentation and controls close to the waveguide being squeezed. The two-man operation and the instrument setup has proved quite efficient.

The reflection-modulation circuitry was improved both mechanically and electrically. A new version of the circuitry was being designed and it will consist of one portable cabinet containing both the instruments and the waveguide components. Provision has been made for a precision waveguide line stretcher to replace the presently used dielectric slab phase-changer. This will improve both the accuracy and ease of operation of the equipment.

Twenty-two modulator flanges (Fig. 19, SLAC 34) had been built by the end of the quarter. Teflon* O-rings were used for the vacuum seals around the tuning screws on the modulators, and the modulators are recalibrated to determine the phase of the reflected wave after each use. The measured phase of the reflection seldom changes by more than 0.1°. Calibrations will be required less frequently as conditions warrant.

The portable temperature-regulated water system, which maintains the temperature of the accelerator disk-loaded waveguide and rectangular waveguide S-assemblies during the final phase-adjusting operation, was

*Registered trademark.

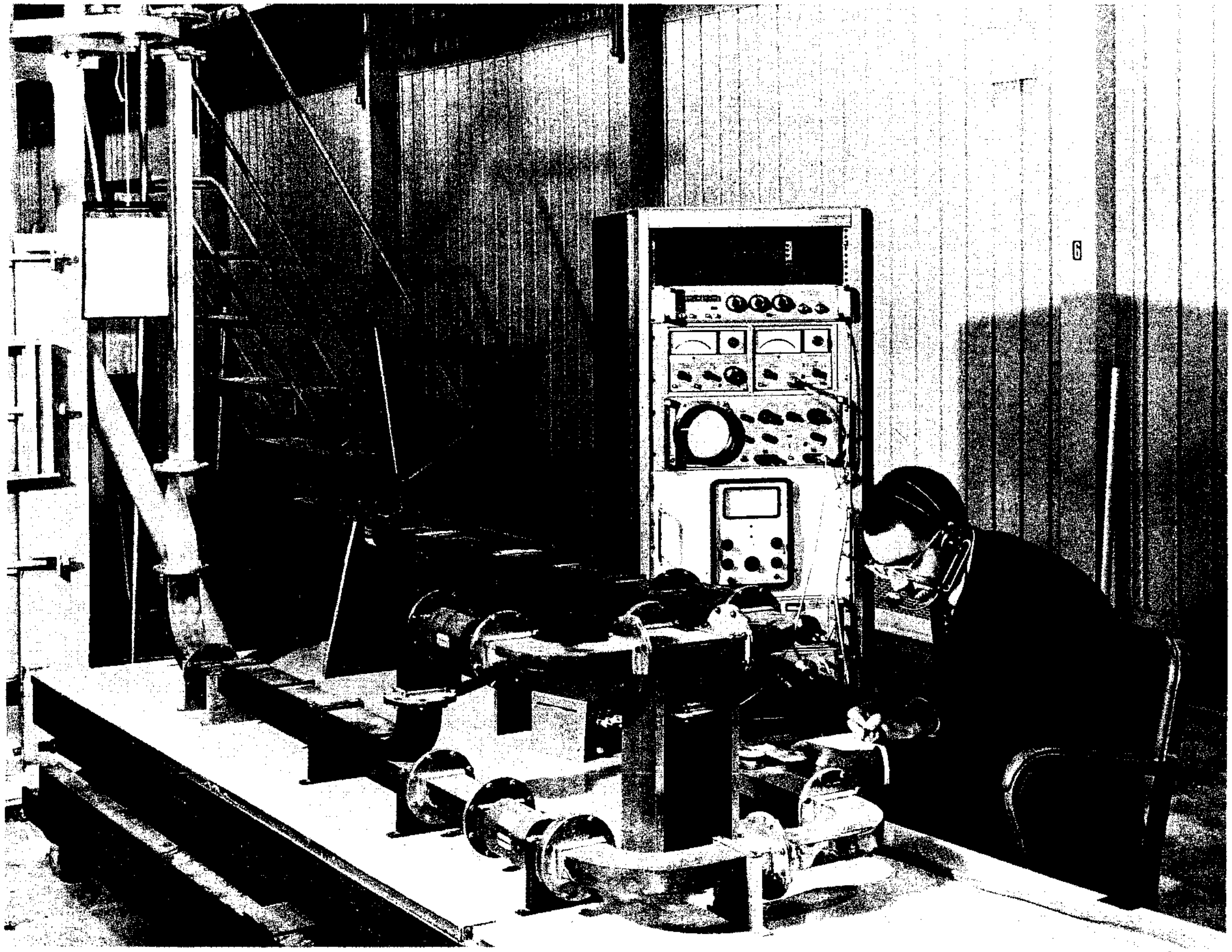

FIG. 13 – PROTOTYPE TESTS CONSOLE AND WAVEGUIDE FOR MODULATED REFLECTION SYSTEM.

analyzed in detail. It was modified slightly and found to be satisfactory. A new thermometry system with a provision for remote indication is under investigation. The effect of the water flow rate was investigated and, under normal conditions, the electrical length of a waveguide branch, including the 10-foot accelerator section, was found to vary by about 0.15 degrees of phase-per-gallon-per-minute change in flow rate. The flow rate can be held within 0.2 gpm of its specified value quite easily.

More modulators were being constructed at the end of the period and the modulated-reflection phase measurement system appeared to be working well and to be capable of meeting the full production schedule.

2. Rectangular Waveguide High Power Tests

During the reporting period, 99 rf loads, 19 Model A directional couplers, six pre-production waveguide vacuum valves and 14 production valves were processed through the high power test area. A fourth test stand was being installed for processing couplers and waveguide valves during the last of the reporting period. When it is completed, test stand No. 3 will be used for the testing of rf loads.

3. Model A Directional Coupler

Eighteen Model A couplers were fabricated and tested during the reporting period. A tabulation of the forward coupling ratio at low and high rf power is given in Table I. The low power measurements were made using a precision attenuation setup that had a precision of 0.1 dB to levels of approximately 100 dBm. The high power measurement was made using a calorimeter system that has an accuracy of better than ± 0.1 dB. The measurements were made at an rf input power level of 10 kW average. The table also includes the difference between the two independent measurements using the low power measurement as the reference. Agreement between these measurements is good and within the error factor of the measurements themselves.

A schematic diagram showing the main steps in the fabrication of the Model A couplers is shown in Fig. 14.

TABLE I

Model A Coupler - Tabulation of Data

Unit	Forward Coupling Level		Δ Coupling[c] Between A&B	VSWR (input)
	A[a]	B[b]		
A	51.83 dB	51.47 dB	- 0.36 dB	1.035
B	52.11 dB	52.16 dB	+ 0.05	1.06
C	51.82 dB	51.51 dB	- 0.31	1.055
D	51.95 dB	51.60 dB	- 0.35	1.075
E	51.60 dB	51.65 dB	+ 0.05	1.04
F	52.65 dB	52.54 dB	- 0.11	1.035
G	52.35 dB	52.19 dB	- 0.16	1.06
H	51.71 dB	51.36 dB	- 0.35	1.07
I	52.0 dB	51.99 dB	- 0.01	1.07
J	51.81 dB	51.88 dB	+ 0.07	1.08
K	51.99 dB	52.04 dB	+ 0.05	1.04
L	51.21 dB	Not Calibrated		1.04
M	51.76 dB	51.72 dB	- 0.04	1.06
N	51.19 dB	50.97 dB	- 0.22	1.04
O	52.06 dB	51.96 dB	- 0.10	1.04
P	51.54 dB	Not Calibrated		1.03
Q	51.34 dB	51.13 dB	- 0.21	1.04
R	52.07 dB	51.88 dB	- 0.19	1.04

[a]Low power insertion loss measurement

[b]Calorimetric measurement at 10 kW average power

[c]Using low power value as reference

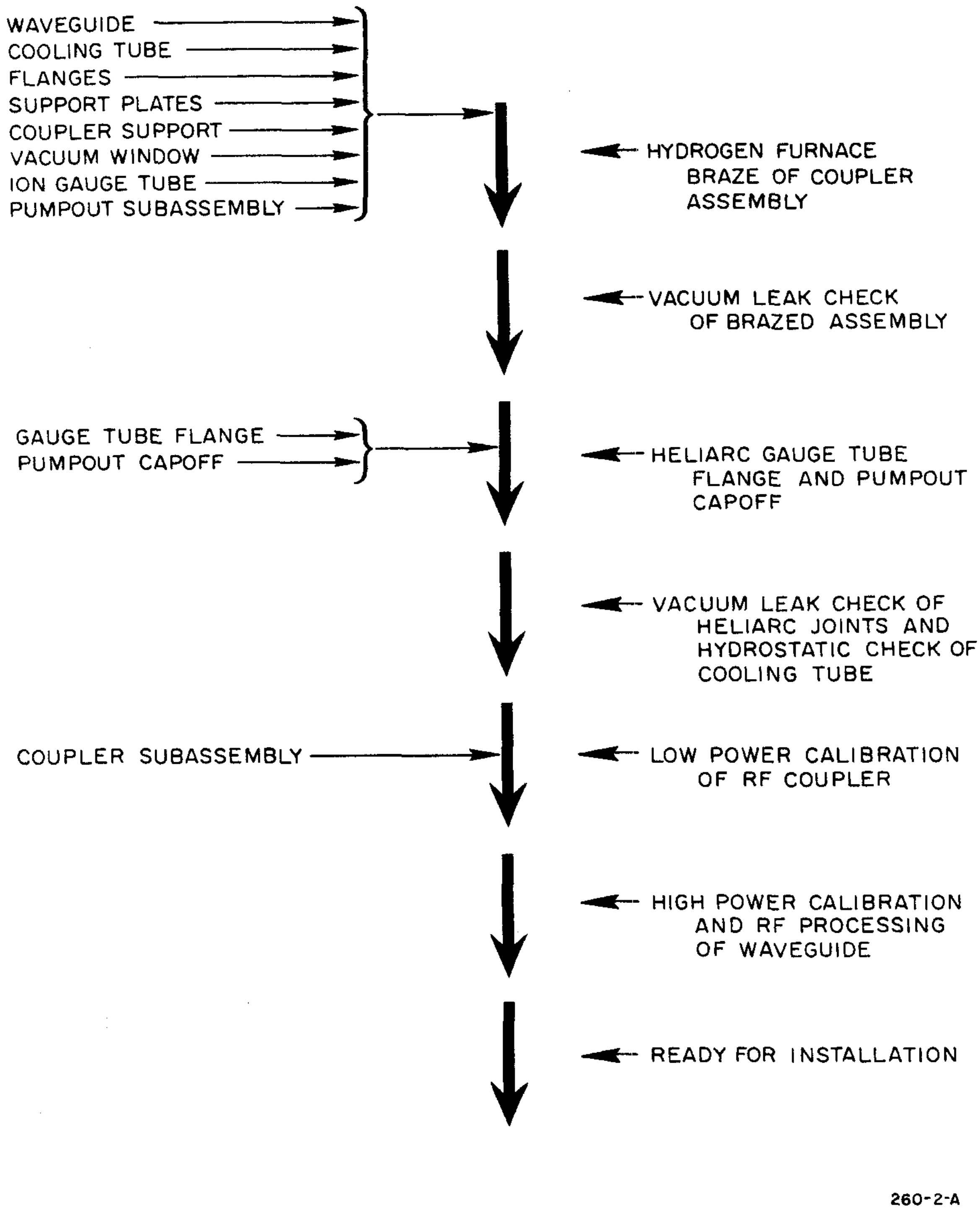

FIG. 14 - SCHEMATIC DIAGRAM OF MODEL A COUPLER FABRICATION

4. RF Waveguide Vacuum Valves

Production of the vacuum valves was started during the period and 19 valves were completed and tested by the end of the quarter. No difficulties of any significance were encountered in the fabrication or testing. All units met the established vacuum specification and also high and low power rf requirements. The valves were tested to 24 kW average power and to levels in excess of 60 MW peak power in the resonant ring. A typical low power VSWR versus frequency curve is shown in Fig. 15. The data on the curve is an average of eight valves that were selected at random. Valve fabrication is expected to increase during the quarter so that one completed valve will be ready each day.

5. RF Loads

Of the three types of rf loads being produced, 59 of the Type A were fabricated, tested and installed during the reporting period; 18 of the Type B loads and their associated Model B directional couplers were installed; and 55 of the Type C were produced. Evaluations continued regarding the corrosion rate of the 304 stainless steel that was being used for the loads as previously reported.* Results of the tests should be available by the end of the next reporting period.

E. FAST-ACTING VACUUM VALVES

The design of the fast-acting vacuum valves for beam axis application in the accelerator was completed during the period, and five of the valves (Fig. 16) were constructed, tested and installed in Sectors 1 and 2. The primary function of the valves is to isolate a sector of the accelerator when vacuum deteriorates within that sector. When this occurs, a sensing device turns the electron beam off and automatically trips the valve at either end of the sector to isolate the sector from the rest of the accelerator. Since each valve is required to close in nine milliseconds, they function to minimize the portions of the accelerator that are exposed to pressure rise and thus reduce contamination and damage to other sectors of the accelerator. This also will reduce the down-time for repair of the accelerator.

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*Ibid, p. 62.

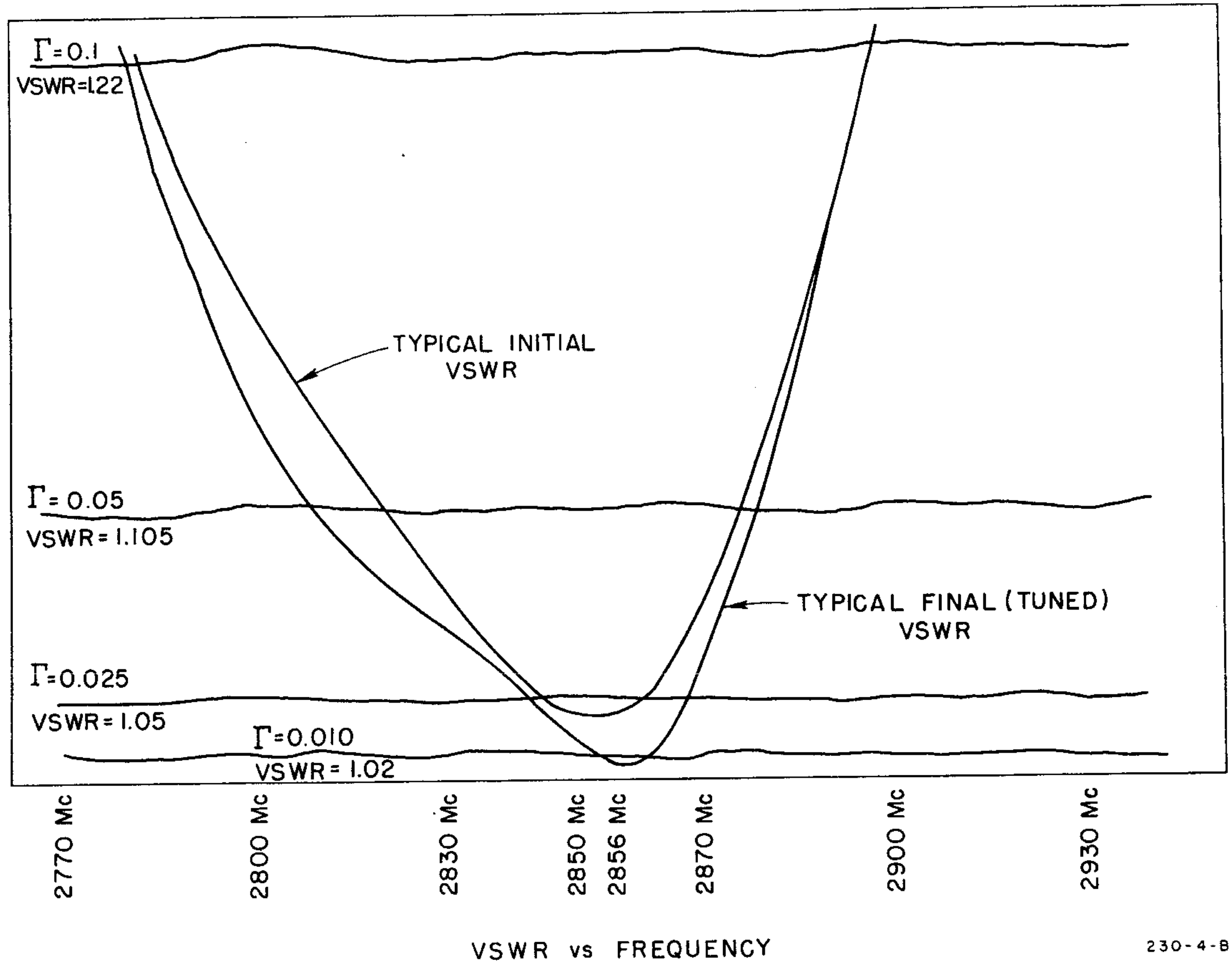

FIG. 15 - TYPICAL LOW POWER VSWR VERSUS FREQUENCY CURVE.

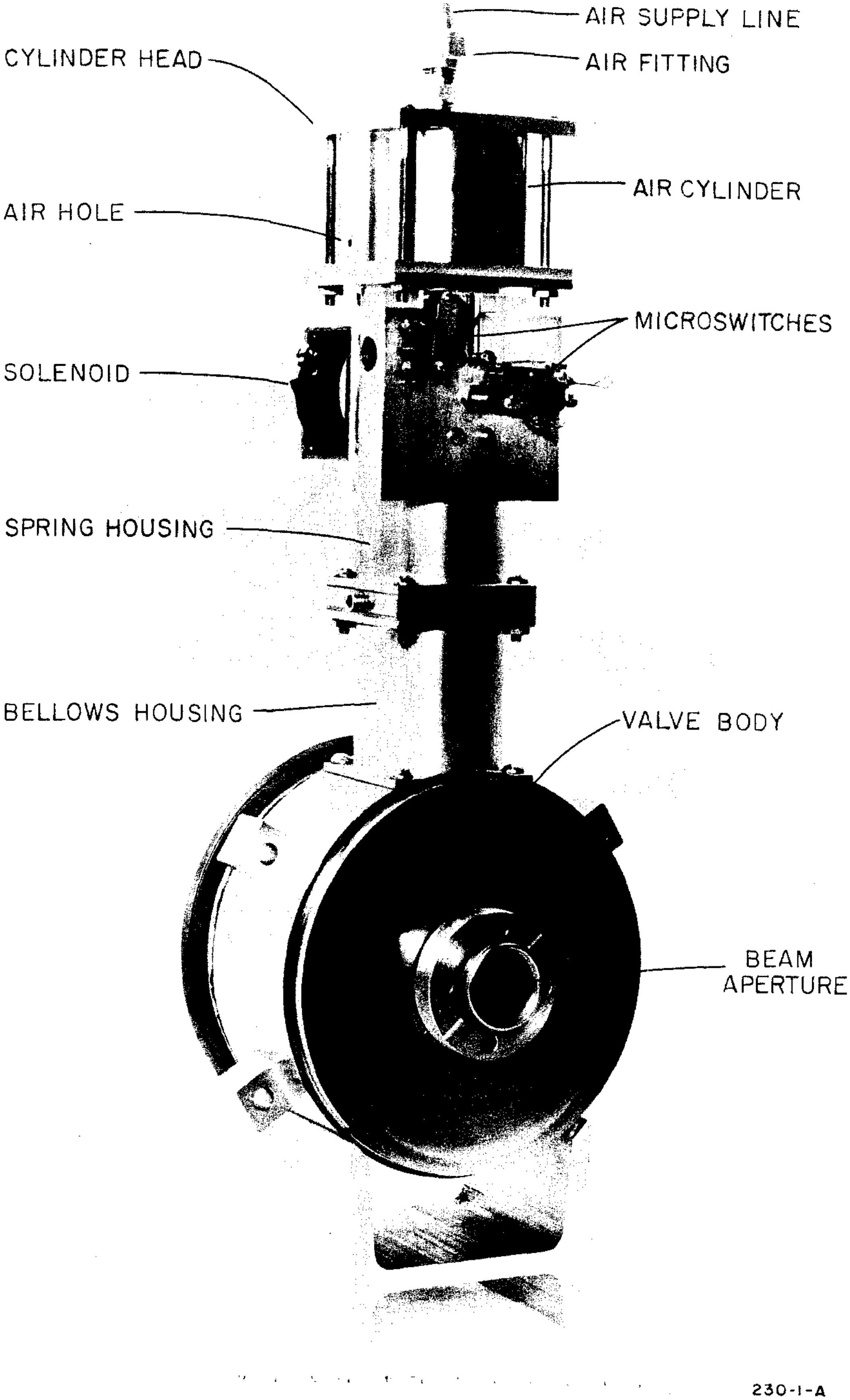

FIG. 16 - ASSEMBLED FAST-ACTING VACUUM VALVE.

As can be seen in Fig. 17, the valve has a 13/16-inch aperture through which the electron beam passes under normal accelerator operation. The oval disk of the valve has a groove in which a remeltable indium seal is located. When the valve is closed, the knife-edge ring on the tube that forms the aperture indents into the indium to affect the low leak rate seal. With each cycle, the knife-edge ring bites more deeply into the indium. When the valve is in its open position, with the oval disk down, a heater in the heater-can will be energized remotely, when necessary, to remelt the indium and re-new its sealing effect. The valve can be cycled open and closed approximately 20 to 30 times before it is necessary to remelt the seal. (Under normal circumstances, this is estimated to be well in excess of one year of accelerator operation.) The heater is energized approximately 10 minutes to melt the indium and approximately one hour is required to return the valve to operating temperature.

Tests on the valves by the end of the reporting period showed that the sealing effect was such that the leak rate was less than 10^{-6} std cc He/sec as measured with a mass spectrometer leak detector. In most instances, the rate was less than 1/100th of that rate, and a reliable valve life of more than 1000 cycles had been obtained. In actual operation, the valve will close when its solenoid is actuated through a control circuit in the Klystron Gallery. When vacuum deterioration is detected by a sensing device, it will energize a tripping circuit which will cause a charged capacitor to send an actuating pulse to the solenoid. When the causes of vacuum deterioration in a sector have been determined and corrected, the sector is again pumped down to $< 10^{-6}$ torr and the valve is opened by the application of 90 psi of air pressure to the cylinder of the valve. (For additional information on the valves see the reference listed below.*)

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

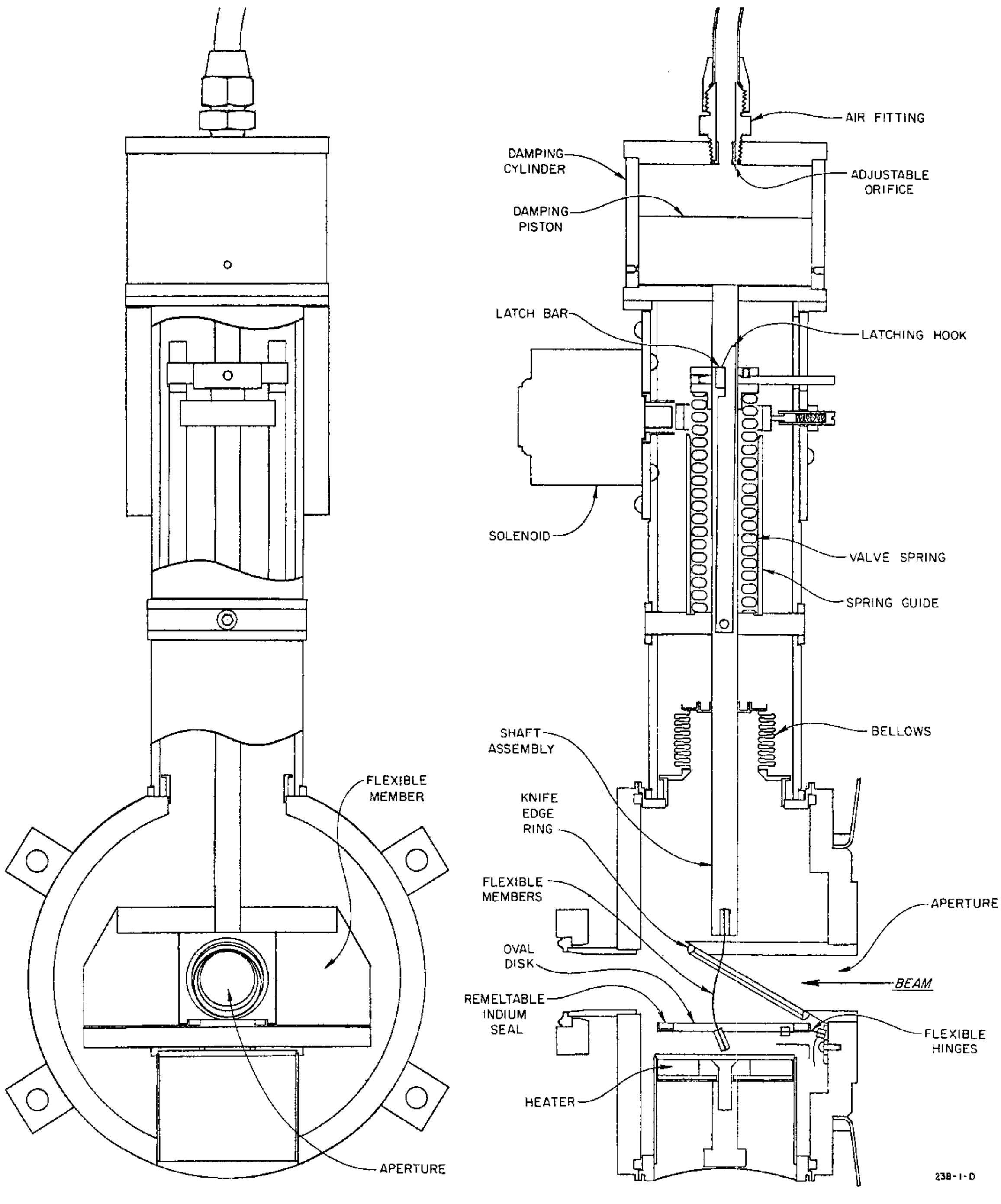

FIG. 17 - CROSS-SECTIONAL VIEW OF FAST-ACTING VALVE.

VIII. KLYSTRON STUDIES

A. SUMMARY

Fifteen klystron tubes were received during the quarter, ten of which were acceptable. RCA is continuing a gradual engineering improvement program to achieve full specifications; one of their tubes has been accepted as a full specification tube. Sperry has undertaken a major engineering effort to achieve full specification tubes; its first full specification tube is scheduled for shipment during the next quarter.

Litton and Eimac are continuing their efforts to deliver the tubes under their subcontracts during the next quarter. Both companies have been delayed by accidental failures of either tubes or test equipment.

Stanford is continuing its engineering improvement program. A program for fabrication of Stanford tubes for back-up has been initiated, as well as the procurement of permanent magnets to use with these tubes on the accelerator should the need arise. The Sperry klystron, which had started life test last quarter, has failed after 890 hours. By the end of the quarter all ten klystrons needed in the first sector of the Klystron Gallery were installed. In addition, seven klystrons were in storage mounted on pulse transformer tanks and eight additional klystrons were available for installation on tanks.

Thirteen sub-booster klystrons were received and eleven accepted during the quarter. Shelf life on sub-boosters is still a potential problem; on the other hand, four tubes had logged 10,800, 6,500, 5,700, and 4,300 hours of operation without failure.

B. KLYSTRON PROCUREMENTS

Many discussions have been held during the quarter with our main subcontractors, RCA and Sperry, to insure an adequate supply of klystrons for installation on the machine. Because of delivery delay, the following decisions have been made:

1. Stanford is proposing to build 36 klystrons for installation on the machine to reduce or eliminate the gap between the planned installation date and the availability of klystrons.

2. An Invitation for Bid has been forwarded to permanent magnet manufacturers to build magnets for use with the Stanford-built klystrons. A small change has been introduced in the mechanical outline of the magnet so that it should be possible to use these magnets interchangeably with tubes from other manufacturers.

In addition, general problems of delivery schedules of permanent magnets have been reviewed and a back-up program involving the use of electromagnets is being considered in the event that permanent magnets would not become available on schedule.

1. RCA Subcontract

During the quarter RCA has delivered 12 tubes for a total of 26 tubes by the end of December; eight tubes were accepted during the quarter (including two received last quarter), for a total of 18 tubes accepted as of December 31; three tubes are still under test. Of these tubes, one has been accepted as a full specification tube, the others as end-of-life tubes.

In general, the problems at RCA have been of two types: the first is low yield, the second is achievement of full specification tubes. At least a good portion of the low yield trouble was caused by vacuum leaks which can be traced directly to the learning processes of the factory. It is believed that engineering and quality control will improve the technique so that a much better yield of shippable tubes should be expected during the coming months.

During the fabrication of presumably shippable tubes, RCA is continuing a parallel effort of improving electrical performance to achieve full specification tubes. The main approach is an increase in gun perveance; since many of their tubes are at present between 20 and 21 MW, an increase in perveance from 1.9 to 2.05 should result in full specification tubes. In addition, they are making minor changes in drift distances between cavities and are also planning to increase the range of tuning of the output coupler to insure optimum performance of each individual tube.

2. Sperry Subcontract

During the quarter Sperry has shipped three tubes for a total of 11 received at Stanford by the end of the year; we accepted one for a total of two tubes accepted as of December 31. Both of these tubes were the end-of-life specification type.

During the quarter Sperry has built several experimental tubes which have shown a definite improvement in power output, and it appears that they should be in a position to begin the delivery of full specification tubes early in 1965. Their program consisted of adjustments of drift tube diameters (which yielded no improvement except with extremely high focusing fields), of modifications of drift distances, and of optimization of output cavity coupling. By a combination of the latter changes they have built several tubes in which 21 MW output has been measured at 250 kV in the existing magnets. They have also ordered a higher field magnet as an additional safety measure to achieve the full specifications.

In general, the yield at Sperry has been remarkably good during the past quarter and they seem to have solved most of the problems which they had previously experienced with temperature-limited cathodes and sparking tubes.

We have accepted a schedule which they submitted and which will be included in the latest subcontract amendment. Again, the schedule does not give us as many klystrons as early as we need from the installation schedule standpoint, but the equipment and facility limitations dictated the maximum number of tubes which can be expected.

3. Eimac Subcontract

The initial plans at Eimac to produce high efficiency tubes involved the design, building, and testing of a modified gun which would operate in partially confined flow and be focused in a one-inch-diameter drift tube. After initial tests of this gun in the standard body tube, the output cavity was to be replaced by an extended interaction cavity in the hopes of achieving efficiencies in excess of 50%.

The first test vehicle was built early in October, but the tube had to be rebuilt because of a cathode seal failure, and testing was delayed until the first week of November. Unfortunately, what appeared to be very strong gun oscillations were observed in the tube. Even when it was used in an electromagnet, the beam transmission was not as high as had been measured in the beam tester. As a result, Eimac decided to abandon this design and to concentrate on building a copy of the Stanford designed tube. The first of these tubes was tested in electromagnet in the middle of December with substantially the same results as those measured on the average Stanford-built tube of the same design. The cathode seal was punctured a few days later and no permanent magnet tests have been conducted yet.

4. Litton Subcontract

By a mechanical redesign of the cathode to more closely approximate the Stanford design, Litton was able to eliminate the gun oscillations observed in their first test vehicle. Early in November they demonstrated a tube in their plant which apparently exceeded the full specification power requirements. Because of instability in their drive system and generally poor wave shape, accurate measurements of neither power nor phase and amplitude jitter could be taken at Litton. They submitted the tube to Stanford for test and evaluation purposes. Unfortunately, the window had failed during tests at Litton so the tube was not operable in the calibrated test set.

In December Litton built a second test vehicle which was brought to Stanford for test and evaluation purposes on December 15 after repairs of the cathode seal puncture. Our measurements indicate that the power output meets our specifications, but the gain is low by 7 to 10 dB. Phase and amplitude jitter probably exceeded our final specifications on this tube.

A modification of the cavity losses and of the tuning schedule of the cavities is being introduced in the next tube to be built by Litton which they hope to deliver in January as a full specification tube.

5. Stanford-Built Klystrons

During the past quarter the deliveries of six experimental magnets were completed, allowing us to verify the performance of Stanford design tubes in permanent magnets. Further details on this performance are given later in this report.

A careful review of the schedule proposed by RCA and Sperry indicates the possibility of an insufficient number of tubes being available during the installation period. Hence, as a precautionary measure Stanford has decided to build additional experimental tubes which can be used on the gallery to fill the gaps which might be caused by further delivery delays. This build-up is in accordance with the previously established SLAC policy of maintaining a tube fabrication facility as a back-up program to maintain an adequate supply of klystrons on the accelerator line. Enough starts have been made to enable us to build, process, and install a minimum of 36 klystrons during the coming year.

6. Magnets

The question of procurement and availability of permanent magnets has been very carefully reviewed during the quarter. Visits to and discussions with magnet manufacturers indicate that a requirement for ten magnets per month should present no difficulty for any of at least three magnet manufacturers and that with sufficient lead time each of these three could build up to 20 or more magnets per month. Definite statements were obtained from the various manufacturers indicating that there are no basic material availability limitations which could in any way cause problems in permanent magnet fabrication. These statements appear to be in contradiction with the experience of one of our klystron suppliers, which has had difficulty obtaining delivery of more than four magnets per month, and which may not be able to obtain magnets at a sufficient rate to satisfy our requirements.

One other potential magnet problem, magnet and tube interchangeability, has been carefully reviewed during the quarter. From a technical standpoint there appear to be no basic problems in interchanging tubes in magnets. In fact, Stanford's experience indicates that the same magnets can be used to focus tubes using the Picquendar gun (initially used at Stanford) and the Merdinian gun (MS-2 gun now used as the standard Stanford gun). It would be advantageous to have on the accelerator only one kind of magnet since the total number of magnet spares could be reduced. It is obviously impossible at this stage to achieve complete standardization since we have received several Sperry and RCA tubes which use magnets of completely different field shapes. In addition, the mechanical details of the magnets used by RCA and those used by Stanford are quite different, although the field shapes are substantially the same. In view of the possible advantage of standardization, discussions will be held in this area during the coming quarter.

In the event that permanent magnets could not be obtained to complete the procurement and installation of klystrons on schedule, some studies have been undertaken to determine the feasibility of utilizing electromagnets over a portion of the machine. The first part of the study is to determine the difference in performance of tubes in electromagnets and permanent magnets. As evidenced by the results obtained from Stanford-built tubes, there is a slight but minimal deterioration of performance in operation in permanent magnets rather than in electromagnets (averaging less than 1 kW at full repetition rate over the range of voltages considered). Since it is expected that the electromagnets will require between 2 and 2-1/2 kW of focusing power, no net gain in power can be anticipated from the use of electromagnets. The possibility of obtaining focusing power and water cooling for the electromagnets has been investigated, and appears to result in minimal cost if it is possible to design the electromagnets to utilize and be connected in series with the klystron cooling water. Requests for engineering estimates and comments have been mailed to potential electromagnet manufacturers. A working decision will be made next quarter, but in any case, all information will be available so that replacement of permanent magnets by electromagnets could be made within a few months of the discovery that permanent magnet manufacturers are falling behind schedule.

C. FACILITIES

A program of improvement of our tube fabrication facilities is continuing. We have received a high temperature ceramic metalizing furnace. Because of unexpected delays in delivery and installation, and the necessity of high temperature test runs to familiarize ourselves with the equipment, no metalizing has yet been achieved with this furnace.

In order to improve the cathode fabrication and assembly cleanliness, it was decided to install a heliarc spot welding system in the cathode assembly area. With this system it should be possible to do all spot welding required on the gun structure in an inert atmosphere and hence decrease the possibility of cathode gassing and poor activation characteristics. The glove box and welding table are completed, with fixtures and jigs being designed for use with this system.

Minor modifications are still being introduced in the window coating equipment to increase the reliability and reproducibility of the results. In addition, various means are being considered to allow us to measure the thickness of the titanium coating on the windows during sputtering or at the end of the operation.

The X-ray facilities have been used extensively for examination of welds. The low voltage X-ray unit has been received and is operating satisfactorily. The equipment has also been used extensively in studying the problems concerning the high power hydrogen thyratrons procured by Heavy Electronics. We believe significant results have been achieved in improvement of thyratrons as a result of these studies. Good progress has been made in the acquisition of klystron handling and storage equipment. The klystron handling truck, received at the end of the previous quarter, is being fitted with a special body to facilitate moving the klystrons to the gallery. The scheduled delivery date is early January.

A check-out cart containing electronic equipment has been completed to facilitate the analysis of klystron performance in the gallery. Work is progressing on two trailers, one carrying all equipment necessary for mechanical installation of the klystrons and pumping down the waveguide volume between the klystron window, the waveguide valve and the 3-inch valve; the other carrying powerstat and auxiliary equipment to allow checking of klystrons independently of the variable voltage sub-stations installed in the gallery.

The initial quantity of modified klystron support yokes was received in December and appears to be entirely satisfactory. All klystron stabilizing brackets have been received during the quarter.

D. KLYSTRON OPERATION AND PROTECTION

Work has continued on the mock-up test stand on the analysis of the performance of the modulator-klystron protection unit. Comparisons have been made of the behavior of klystrons in acceptance tests on the mock-up test stand and in the first sector of the accelerator. Of particular concern was the possibility of harmonic reflections in the sector tests which might impair the operation of the reflected energy protection unit or introduce phase instability at the fundamental frequency. The evidence thus far indicates that there is a slight increase in phase jitter with the waveguide valve in the circuit but that the total phase jitter is well within acceptance specifications. Also, an increase in the rejection of harmonics in the stripline low pass filter has resulted in satisfactory operation of the M-K protection unit.

On the other hand, a careful study of the requirements of reflected energy protection indicated the need for a modification in the initial design of the circuit from an integrating to a peak reading circuit. With this modification, the circuit responds effectively to reflected power rather than to reflected energy and it appears possible to set each protection unit at a fixed level of reflected power, which should prove satisfactory to give adequate protection to the klystron window and insure its long life. Since it is difficult to test the reflected energy circuit under actual operating conditions, a special piece of waveguide has been designed in which the electric field should be enhanced by a factor of approximately 50. With this field enhancement arcing in the waveguide at approximately 10 MW is expected. It is hoped that this unit can be used to demonstrate under actual waveguide breakdown conditions the operation of the M-K package.

E. KLYSTRON FABRICATION AND DEVELOPMENT

Fifteen klystrons and eight diodes were processed and tested and the testing of 12 tubes and four diodes was completed. In addition, a filament short and a punctured high voltage seal (resulting from low oil level) reduced the yield to approximately 60%. This is obviously not satisfactory and serious investigations into the reasons for the low yield have begun. In general, the electrical performance of the tubes built and tested is highly satisfactory, but additional improvements need to be made in heater hum and oscillations. Approximately 40% of the tubes show a small amplitude 5-cm oscillation which does not result in undue phase or amplitude jitter in the output pulse. Additional work is being conducted to eliminate this oscillation completely. In addition, amplitude modulation resulting from heater hum has still been observed in over 50% of the tubes in spite of a redesigned heater package which should have eliminated the heater hum completely. It is suspected that the heater hum comes from very minute misalignments in the cathode structure which results in scraping off some of the rf signal on the beam, particularly at low drive. The building of tubes with adjustable cathodes during the next quarter to confirm the source of the heater hum is planned.

Regardless of the difficulties mentioned above, at the end of December eight Stanford tubes were mounted in permanent magnets and pulse transformer tanks as spares for the gallery, and five additional tubes were available, but lack of permanent magnets prevented their final installation. Two of these spare tubes meet all specifications of power and jitter at all voltages and drive levels.

The basic performance of the tubes continues to be as reported in the last quarterly status report.* However, it was discovered that the adjustments performed on the permanent magnets can result in irreversible changes in the magnetic field and the degradation of the permanent magnet. Hence, the average performance of tubes in permanent magnets is not as good as it had been during the previous quarter by approximately 1 MW. We have initiated procurement for magnetizing coils with which we expect to bring the permanent magnets back to their initial field strength. In addition, our personnel are learning to handle the magnets more carefully so that we can expect that the degradation in performance will be limited by the careful handling. The graph of Fig. 18, showing power output as a function of voltage in electromagnets, gives an idea of the improvement in Stanford klystron performance observed over the last year.

Further development work is continuing for additional improvements of both the yield and the performance of the present Stanford design tube.

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*"Two-mile accelerator project, Quarterly Status Report, 1 July to 30 September 1964," SLAC Report No. 34, Stanford Linear Accelerator Center, Stanford University, Stanford, California (1965); pp. 75-79.

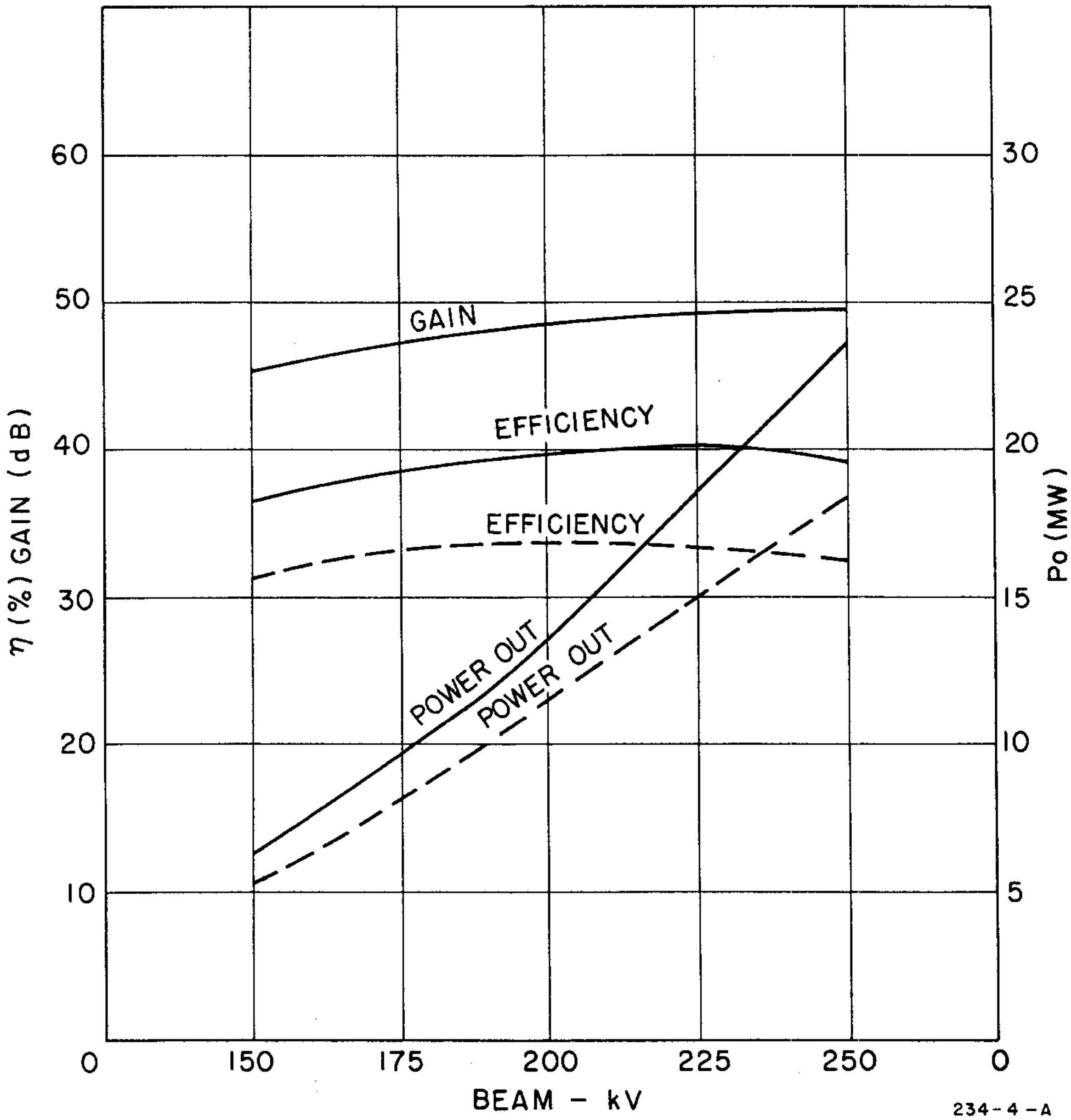

FIG. 18--Comparison of klystron average performance (electromagnet focusing).

——— Stanford 2422 klystron, XM3 Body, Merdinian gun, tested between October 1, 1964 and January 1, 1965. Average of 10 tubes.

— — — Stanford 2422 klystron tested between September 27 and December 31, 1963. Average 9 tubes.

Many factors may contribute to the possible tube gassiness. A systematic analysis of the materials used in the tube has been initiated. We hope to be able to correlate the results of this study with the incidence of soft tubes which have been observed during the quarter. In addition, it has been decided to build a few tubes incorporating ion pumps which can be operated after the tube is pinched off from the bake station. It is hoped that the indications from this will also contribute to understanding of tube gassiness. Finally, the handling of the cathode parts is being improved and the bake and activation cycles are being carefully reviewed for further clues.

The work on further improvement of klystron performance is following two main approaches: minor gradual improvements in the present design, such as modification of the output cavity gap length and optimization of drift distances which might result in a further improvement in efficiency of between 2 and 5%, and a radical design change involving the use of a two-gap extended interaction output circuit. The design and cold test work is completed for this extended interaction circuit and we expect to build one or two tubes next quarter incorporating this improvement.

As was mentioned earlier, we intend to procure facilities for remagnetizing permanent magnets received from all sources. Procurement for the necessary coils has been initiated, and we are planning to use either dc generators available at Hansen Laboratories or to make arrangements with the Research Division for occasional use of their high power magnet power supplies.

F. KLYSTRON INSTALLATION AND MAINTENANCE

Ten klystrons are installed in the first sector of the Klystron Gallery, four of which are Stanford built tubes, operated in electromagnets. In addition, the Modulator Group has two diodes in continuous operation.

During the quarter, two diodes failed due to temperature-limited cathodes after 2750 and 6850 hours of operation respectively. Two klystrons failed by rf output window after 108 and 176 hours respectively, and one failed by temperature-limited cathode in 300 hours. In addition, one tube suffered a punctured high-voltage seal during operation in the gallery after 140 hours of operation.

In addition to the tubes in use, the following tubes were available at the end of the quarter:

Gallery Spares — 3 Stanford on tank, 1 RCA on tank, 1 Sperry on tank

General Purpose Spares — 8 Stanford klystrons, 2 Stanford diodes

The klystron control program has been made operational. All klystrons are registered by vendor serial number, as well as location, on a filing system. The file contains all pertinent information on each tube, e.g., power output, gain, etc., as well as operating time, date of acceptance, and final tube disposition. As each tube is received it is tagged and registration cards are completed. Mechanical inspection reports, electrical inspection reports and all other pertinent data are filed by tube number. From the above data the cards are filled out.

In addition to tube information, a complete file has been established according to socket number in the Klystron Gallery. Station cards carry a complete history of tubes entering and leaving a particular socket. Additional equipment sockets are also registered, recording usage of klystrons in equipment other than the line. From the above data, statistical information will be compiled regarding tube life and usage over the appropriate intervals of time.

G. HIGH POWER KLYSTRON WINDOWS

1. Resonant Ring Tests

a. Klystron Window Pre-Testing

Routine tests in the high vacuum ring (up to 36 MW at 33 kW) revealed coating deficiencies on four of the 13 klystron windows constructed during the quarter. One of the four windows rejected had overheated because of excessive coating which had to be removed by wet-blasting. Four windows, including the heavily coated one after it had been cleaned and recoated, suffered multipactor and some overheating during ring tests and were recoated (one or more times) until they could be operated without indicating multipactor.

b. RCA Coated Windows

The series of high-vacuum ring tests on RCA windows begun last quarter* has been completed with the testing of five AL-300 windows, all but one of which had been coated with titanium by evaporation at RCA. Results of the tests performed on these windows, including results referred to in the previous status report, are summarized in Table I. Interpretation of the above results can be broken down into effect of the RCA coating, effect of bake cycle on coating, effect of tube reprocessing on coating, and effect of coating on one side of the window only.

Tests on RCA-5 and RCA-6 demonstrate the effectiveness of the RCA coating. Even though these windows displayed some of the visible symptoms usually associated with multipactor, they were not subject to overheating. The added effectiveness of a slightly heavier evaporated coating is shown by tests of RCA-7 and RCA-9, both coated more heavily than RCA-5 and RCA-6.

Tests on RCA-7-B and RCA-9 indicate that the RCA coating does not deteriorate during a normal bake cycle. Test of RCA-7-C shows that the formic acid rinse employed during RCA tube reprocessing has no apparent ill-effect.

The partial effectiveness of on-the-tube window coating was shown by tests RCA-8-B and RCA-8-D. RCA-8-C, however, would seem to indicate that generator surface coating is at least as important as load surface coating. The group of tests on RCA-8 indicate that load side coating is required to suppress the mode-shift phenomenum often associated with multipactor.

c. Material Study Tests

Two AL-300 windows tested were samples from the most recently received batch of ceramics which had been burnished to provide surface finishes similar to those typical of the previous batch of AL-300 ceramics. Both windows withstood maximum available peak and average power levels (70 MW, 45 kW, respectively) without multipactor, overheating, or damage of any kind. One of these windows was purposely mounted with considerable tilt

*Ibid. p. 81.

TABLE I

WINDOW TEST RESULTS

Test Label	Treatment		Operation						Remarks
			Center temperature at:						
	Coating	Processing	6 MW	12 MW	18 MW	24 MW	36 MW	48 MW	
RCA-5-A	Evap.	None	---	---	---	---	---	108°	Blue glow
RCA-5-B	None	Wet-blast	135° ---	250° 108°	--- 128°	--- 142°	--- 158°	--- 162°	Alternate (hot-cool) modes
RCA-6-A	Evap.	None	---	---	---	---	91°	96°	Blue glow
RCA-6-B	None	Wet-blast	128°	260°+ 150°	cracked at 12 MW ~ 265°C				Alternate (hot-cool) modes
RCA-7-A	Evap.	None	---	---	---	---	70°	100°	Dim Blue Glow
RCA-7-B	Evap.	Bake (SLAC)	---	---	---	65°	85°	101°	No glow
RCA-7-C	Evap.	Formic Acid	---	---	---	---	82°	100°	No glow
RCA-8-A	None	None	156°	---	---	---	---	---	230° at 9 MW
RCA-8-B	Sput.	Coating-load	---	164°	243°	---	---	---	Load side dark
RCA-8-C	Sput.	Coating-gen.	--- ---	132° 102°	148° 100°	--- 70°	--- ---	--- ---	Alternate (hot-cool) modes
RCA-8-D	Sput.	Coating-load	95°	157°	220°	---	---	---	Load side dark
RCA-9	Evap.	Bake (RCA)	---	---	---	80°	85°	92°	Blue glow

Evap. = Evaporated titanium coating, applied at RCA.

Sput. = Sputtered titanium coating, applied at SLAC.

while the other was not tilted. Results of this test, considered with results on specially fired AL-300 samples tested last quarter* and on windows tested earlier as part of the window tilt study, seem to indicate that the history of a particular batch of ceramics is probably of more importance than the effect of window tilt in determining the likelihood of window failure.

Another AL-300 window tested was one of two samples of AL-300L, a variant of the standard ceramic body in which smaller crystal grain size is intended to increase mechanical strength. After exhibiting characteristic symptoms of multipactor throughout all stages of its operation, this window failed thermally while at an average power of 30 kW when its center temperature had reached 415°.

The test program on boron nitride windows was completed with the test of a single sample of the pyrolitic version of the material. Despite improper mounting, which caused poor operating pressure, and the deposit on the window of a substantial amount of material from an O-ring near the generator side surface, this window survived maximum available peak and average power (67 MW and 45 kW) without multipactor, overheating, or window damage of any kind. On the basis of this single test, pyrolitic boron nitride does appear to merit consideration as an alternative window material.

d. Litton Klystron Window

A Litton klystron window, coated with titanium by sputtering at Litton, was tested in the high vacuum ring. The window was mounted in a ring test section by means of a tear-away heliarc seal in order that the window may be installed on a klystron upon completion of ring testing. The window operated relatively well, without overheating, but marginal multipactor symptoms persisted. The window will be recoated and tested again in hopes of suppressing multipactor entirely before tube installation.

2. Window Life Test

After approximately 3100 hours of operation at power levels up to 15 MW, the power available to the window life test facility was increased to 24 MW by installation of a SLAC klystron which meets full power specifications. During the first few days of operation at higher power levels (upon reaching 20 MW peak power) one of the six windows in the life test chain

*Ibid.

heated to 320° (center temperature), was removed and replaced by another. Since the replacement, the life test stand has operated for some 600 hours at 20 to 24 MW power levels with no further window difficulties.

3. Other Window Work

a. Material Study

The experimental phase of the material study program consisted of ring tests on AL-300 and pyrolitic boron nitride windows as described above. The analytical phase devoted to investigation of particular physical properties included continued work on a secondary emission measuring device and dielectric constant measurements on samples of AL-300L ceramic.

Construction was completed early in the quarter on a prototype secondary emission measuring device mounted in a glass bell jar evacuated by an oil diffusion pump. During this quarter, effort was directed toward making the secondary emission apparatus operational prior to installing it in a hard vacuum, ion-pumped system where meaningful secondary emission data can be made on samples of various window materials. Difficulties remain to be resolved in analyzing the primary and secondary electron components of currents detected on the various electrodes of the target structure.

Ghost mode measurements were made on the two samples of AL-300L ceramic prior to testing the material in the ring; they indicate that the dielectric constant of AL-300L is substantially the same as that of normal AL-300. (The real part of the complex dielectric constant is greater than that of AL-300 by $\approx$0.3%; the complex component, loss tangent, is roughly half that of AL-300 based on rather crude Q measurements made on ghost resonances.)

b. Window Coating Activity

Windows to be installed on vendor klystrons are being coated when requested to aid in initial vendor window studies. Three windows of Frenchtown ceramic were coated for use in RCA klystrons before the results of ring tests of the RCA coating had demonstrated the apparent effectiveness of the RCA evaporated coating. Sixteen windows (AL-995 ceramic) were coated for use on Sperry klystrons.

Several windows required cleaning and/or recoating during the quarter due to excessive or insufficient coatings. Routine resistivity measurements identified several instances of excessive window coating (indicated by low resistance). Windows with insufficient coating, however, cannot be identified except by resonant ring testing. Changes were made in coating parameters to decrease or increase the amount of titanium coating as necessary. The correlation between coating parameters and coating effectiveness is not easily demonstrable without a coating control monitor, especially in cases where insufficient coating is evident.

Preliminary tests were made on one possible method of monitoring the thickness of window coating as it is applied. This technique involves measurement of the resonant frequency shift of a quartz crystal located in the vicinity of the window being coated. The resonant frequency of the crystal varies as a function of its mass and is thus dependent upon the thickness of coating deposited. Quartz crystals resonant at ≈ 3 Mc/sec were mounted in several locations near the window surface or window sleeve and exposed to moderate and heavy applications of coating. These tests indicated that coating is relatively uniform across the entire window surface and that the crystal resonance is capable of discriminating between moderate and heavy layers of coating. Further tests of the crystal resonance method of coating control will be made using 8 Mc crystals. Consideration is also being given to alternative methods of monitoring coating thickness.

H. SUB-BOOSTER KLYSTRONS

During the quarter, 13 sub-booster klystrons were received; 11 were accepted, and two were rejected because of pulse droop. No shelf life tests were made during this quarter. The vendor is completing his shelf life improvement program, but it will take at least six months to determine the results. Thirteen sub-booster klystrons are now in operation, with the longest life on record at the present time slightly less than 11,000 hours. There have been no failures of tubes in operation during the past quarter.

IX. SECTOR TESTS

The installation of accelerator sections and control equipment progressed sufficiently during the quarter so that high-power tests could be continued. The first high-power tests had been made on a temporary 40-foot accelerator segment on August 4, 1964. These tests had provided an early evaluation of the system comprising the water supply variable voltage substation, modulator, klystron, modulator-klystron protection package, rectangular waveguide and accelerator structure. The tests proved that the over-all system operated satisfactorily, and that no major redesign work was necessary.

The temporary segment and its waveguide was removed and replaced by a permanent segment. During the installation of the accelerator segments in Sector 1, six modulators at Stations 1-1B, 1-4, 1-5, 1-6, 1-7 and 2-8 were installed and operated continuously at full power for several days into salt water which was used to provide the loads.

A temporary personnel protection system was connected to interlock all entrances into the accelerator housing. By mid-December, Stations 1-2, 1-3, 1-4, 1-5, 1-6, 1-7, and 1-8 were operating and sending power into the permanent accelerator 40-foot segments at those stations. By the end of the quarter, these stations were operating at full power.

A temporary injector was installed at station 00 in preparation for the beam tests that are to be made early in the next quarter.

X. BEAM SWITCHYARD

A. GENERAL

The beam switchyard housing construction proceeded rapidly, but rain and design changes caused delays which threaten the completion schedule.

The detailed design of the materials handling system was virtually completed.

Design work on the water and electrical distribution systems was more than 50% completed.

The beam switchyard site and utilities construction bid package passed the 90% mark.

Work was begun on the installation drawings for the beam switchyard equipment installation subcontract.

B. INSTRUMENTATION AND CONTROL

The Cerenkov beam profile monitor was tested in the 900-MeV electron beam at the Mark III Accelerator. The sensitivity and the resolution were observed to be somewhat better than with conventional zinc-sulfide screens. The Cerenkov cell is preferred in the switchyard because it is not affected by radiation damage. Redesign was necessary and has been started on the retraction mechanism and the reference system.

A fixed frequency NMR probe was developed for calibration of the energy-defining magnets. The probe consists of a 0.1-cm^3 glass bottle containing a solution of $LiCl_2$ in water with the addition of 0.1-M $MnSO_4$. The probe uses only one coil; the maximum diameter is 3/8 inch. Sweeping is performed by frequency modulation.

The bid package for the control computer for the switchyard was approved in December 1964, and the bids are due 14 January 1965.

C. MAGNETS

In view of the uncertain copper market, it was decided to procure hollow square copper conductor in sufficient quantities for the majority of the switchyard magnets in advance of the magnet procurements. An order for 50,000 pounds of the copper coil conductor has been placed.

The bids were received for fabrication of the 3° bending magnets. Two separate contracts were awarded, one for the fabrication of 13 cores, the other for coil fabrication and assembly of the magnets.

The 0.25° emergency bending magnets were redesigned to make it possible to pulse the magnet occasionally, if necessary. The use of a laminated core (1/8-inch laminations) gives a rise time of approximately 1 second.

The 0.1° pulsed bending magnets were redesigned to make it possible to can them in the event that the internal ceramic vacuum chambers prove unsuitable. It is hoped that ceramic chambers can be procured which will have a sufficiently low volume resistivity (10 ohm·cm to 10^{8} ohm·cm) to enable them to resist breakdown resulting from build-up of internal charge due to radiation exposure. However, no reliable source of supply of such a material has been discovered, so the canning alternative seems necessary as a back-up.

The prototype 0.1° pulsed magnet was canned and an attempt was made to evacuate the can. Since this magnet was not designed to operate in a vacuum, no attempt had been made to limit the vapor pressure of the epoxy adhesives used to cement the core laminations; the vacuum test indicated that the magnet manufacturer had used toluene as a vehicle for application of the epoxy to the laminations. It proved impossible to reduce the pressure in the magnet can below about 350 microns until several liters of toluene had been evaporated from the magnet. Ultimately, the pressure was reduced to about 10^{-2} torr, but at this pressure the tests were discontinued due to concern for the integrity of the magnet. (Subsequent tests of the magnet at full excitation showed no appreciable effect other than an apparent increase in noise level.) The magnet was excited for short periods while under vacuum. As would be expected, at the high pressure and voltages used, glow discharge was observed. (The conductor ends were bare.) When the conductors were covered with insulation, the glow discharge ceased and the magnet performed satisfactorily.

As a result of this test, an attempt will be made to limit the vapor pressures of all materials used in the pulsed magnets.

D. POWER SUPPLIES

1. Pulsed Magnet Power Supplies

The prototype pulsed magnet power supplies were used for a number of tests of the pulsed magnet during the period and performed satisfactorily. It was decided to request proposals from electrical manufacturers on a performance specification, without restriction on the method of switching. The ignitrons used for switching in the prototypes are satisfactory but are being used outside of the manufacturer's ratings. Higher voltage silicon-controlled rectifiers have recently become available and it is believed they will be competitive with ignitrons in this application.

2. DC Supplies

Proposals for the 55.3-kW and 27.5-kW quadrupole magnet power supplies were received. Several of the proposals were deemed technically responsive, and AEC approval to negotiate with the company whose proposal was most attractive was requested. These power supplies have nominal ratings of 27.5 kW, 50 volts, 550 amps, and 55.3 kW, 65 volts, and 850 amps, with a regulation accuracy of ±1% over the range from 10% to 100%. Seven of the 55.3-kW power supplies and eight of the 27.5-kW power supplies are being purchased. They will be used to energize the 8-cm and 18.6-cm quadrupoles, the dc emergency magnets, and the B-beam magnetic slit in the switchyard.

E. VACUUM CHAMBERS AND EQUIPMENT

Design and preparation of drawings of vacuum chambers, vacuum isolation valves, fast vacuum valves, remote disconnect vacuum couplings, magnet vacuum chambers, and associated equipment was about 50% complete at the end of the period.

F. BEAM DUMP

The detailed drawings of the beam dump were virtually completed and the technical specification was in preparation.

Design was started on the dump window removal mechanism. Tests of a two-bolt window clamp were made using an impact wrench to tighten and loosen the one nut which applies the gasket force. The seal proved to be vacuum tight.

G. SLITS AND COLLIMATORS

1. High Z Slits

The layout drawings of the high Z collimator were completed. Detailed drawings were being prepared.

2. High Power Slits

Detailed drawings of the energy-absorbing modules of the slits and collimator were prepared. The estimated cost of fabrication was extremely high; intensive efforts were made to discover less expensive alternatives. It was decided to procure the aluminum forgings and to supply them to the fabricators. It was also decided to request fabricators to submit proposed fabrication procedures to meet the detailed specifications for the final product. The difficult requirements are for machining of long straight holes with thin walls and for distortion-free vacuum welds. The possible hole-machining methods are electric discharge machining, electrochemical milling, and gun drilling. Proposers will be requested to supply samples for testing.

The design of the support structure for the modules, the vacuum envelope, and the positioning and alignment mechanisms is proceeding satisfactorily.

H. ALIGNMENT

The 8-cm quadrupole pairs immediately downstream of the pulsed magnet group have an alignment tolerance (displacement) of ±0.010 inch total. This is the closest tolerance in the switchyard beam transport systems. In order to test and develop techniques for the alignment of these items, a mock-up of a quadrupole and of the alignment equipment was made.

Magnetic axis reference targets and alignment targets were installed on the quadrupole mock-up. A platform was set up over the mock-up to enable a test alignment to be made under conditions similar to those in the switchyard. Measurements were transferred from the simulated magnetic center and magnetic axis of the quadrupole to the magnetic axis targets and from these to the alignment reference targets. The "magnet" was positioned by means of the alignment target. The loop was then closed checking back to the simulated magnetic center and magnetic axis.

Test results showed that the simulated magnet center could be positioned reproducibly within a few thousandths of an inch. The procedure requires development to improve speed, accuracy, and reliability.

XI. TARGET AREA DEVELOPMENT

Plan views of the entire target area, both end stations, the research area substation and the counting house are illustrated in Figs. 19, 20, and 21. The substation and counting house are adjacent to End Station A, but on top of the shielding fill over the beam switchyard and 45 feet above the floor elevation of End Station A.

The floor of End Station A is 200 feet long (along the beam direction) by 125 feet wide. The clear height to the 50-ton crane hook is 50 feet. The walls and ceiling are constructed of concrete two feet thick. Ninety-five feet of the downstream end of the building is open from floor level to a height of 15 feet. A 105-foot strip on each side of the building is also open to a height of 15 feet. These openings, which will be covered with removable concrete shielding blocks during operation, allow experimental equipment to extend outside the building. Beam height is nominally seven feet above the floor. A mechanically operated concrete door 32 feet high by 40 feet wide by two feet thick in the southwest corner of the building provides access for large pieces of experimental apparatus.

End Station B is similar in construction to End Station A. The floor is 150 feet long by 75 feet wide, with clear height to the 50-ton crane hook of 35 feet. With the exception of space required for two columns, the entire downstream end wall and the downstream half of the side walls are open from floor level to a height of 12 feet. Beam height, as in Station A, is nominally seven feet above floor level. A mechanically operated concrete door 20 feet high by 20 feet wide by two feet thick is provided on the south side of the building.

Immediately upstream of End Station B is a target area and beam-port funnel. The target room is designed to house targets that are used to produce intense beams of secondary particles. Entrance to the target room is gained by means of a separate target room access tunnel. A 15-ton crane is housed in the target room. The beam-port funnel is located between the target room and End Station B proper. The funnel area is 33 feet long, 39 feet at its widest part, and 25 feet high. It

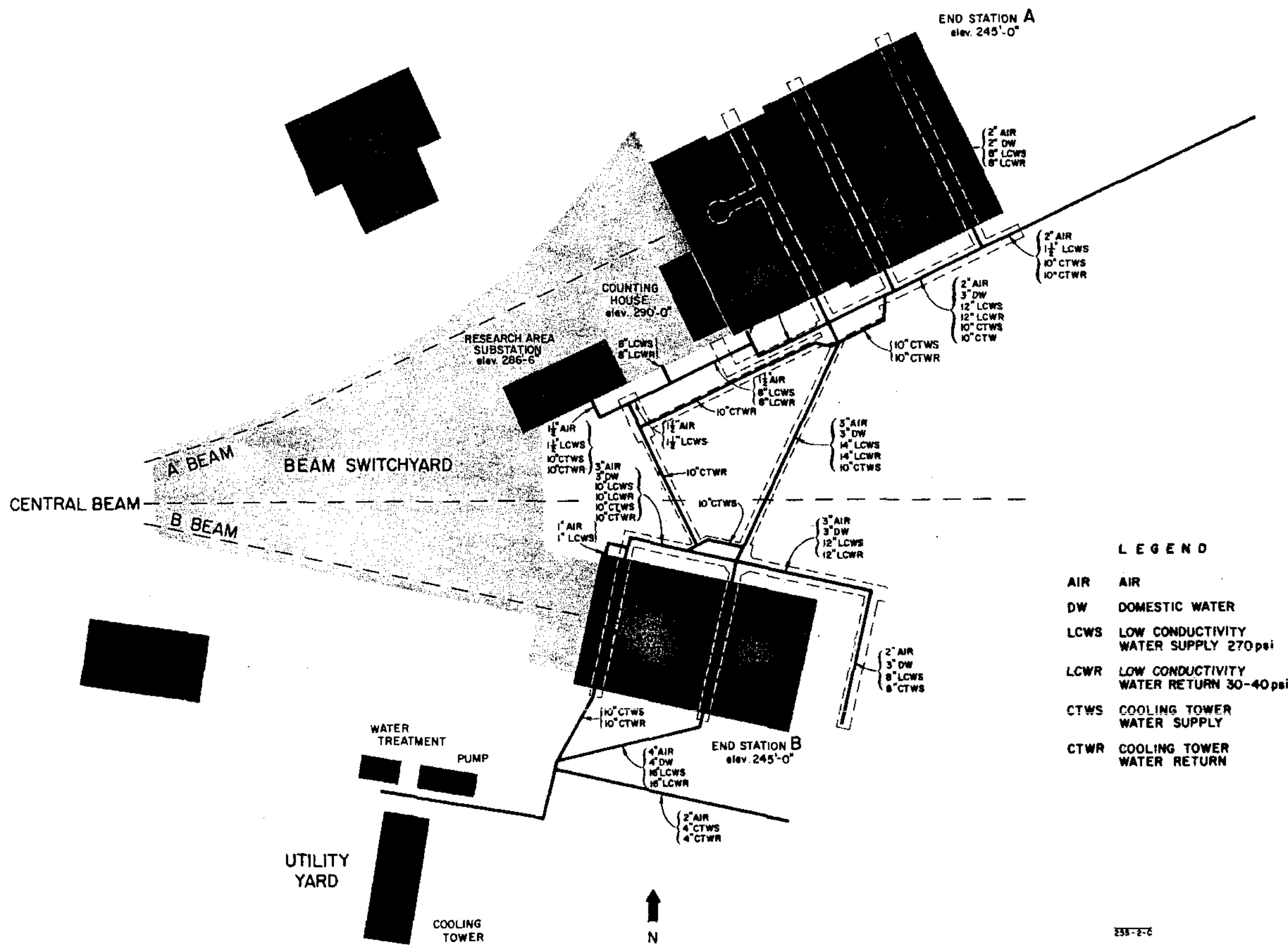

FIG. 19 - TARGET AREA UTILITIES.
MECHANICAL AREA PIPING PLAN

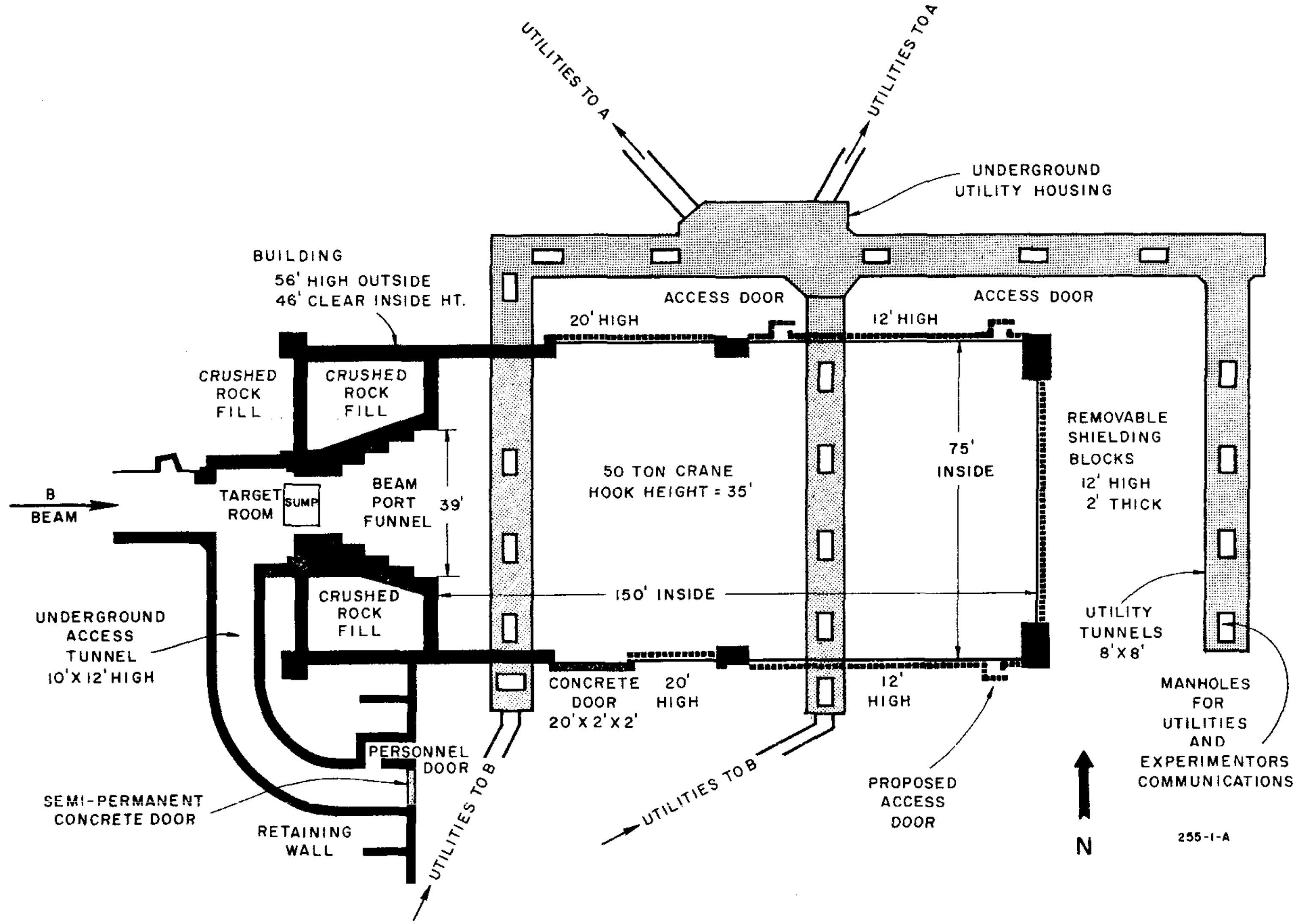

Fig. 20-END STATION B

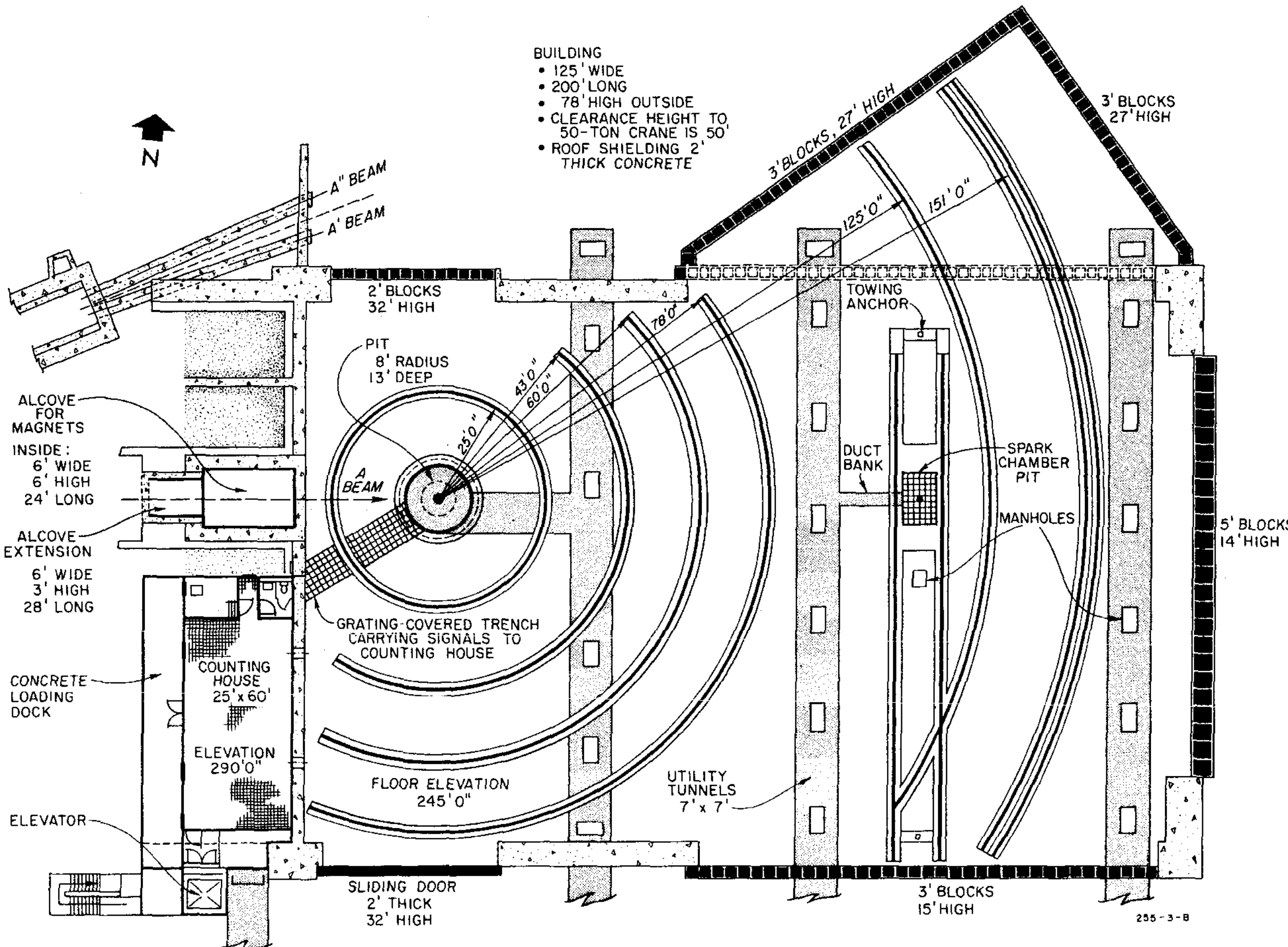

FIG. 21 - END STATION A.

will house the beginning of various secondary beam transport systems that extend into or through End Station B to the target area pad. Shielding blocks are placed around the magnets and vacuum pipes in the funnel to prevent most of the radiation produced in the target room from reaching End Station B. An extension of the End Station B roof allows use of the crane over the beam-port funnel.

A counting house is located adjacent to the west wall of End Station A and 45 feet above the floor of End Station A. It will be used by several research groups performing experiments in the adjacent end station. The building extends 60 feet along the west wall, with provision for future extension of another 60 feet; it is 25 feet wide and 15 feet high. A computor floor two feet above the main floor slab is provided to facilitate the distribution of signal, power, and control cables. Access from the counting house to the target area is provided by an elevator and a stairway.

XII. PRE-OPERATIONS RESEARCH AND DEVELOPMENT

A. EXPERIMENTAL GROUP A

1. 20-BeV Spectrometer (Forward Angle Spectrometer)

Further calculations on the configuration initially proposed showed significant second-order aberrations. Efforts to eliminate them were only partially successful, and other spectrometer configurations were considered. Spectrometers with a single upward bend sufficient to provide the required dispersion would be constrained to remain inside the end station, severely restricting the angular range covered. An S-shaped vertical bend which minimizes the vertical displacement from the focus to the beam was considered. It is possible to avoid some of the difficulties by bending downward and excavating a large pit in the end station floor. No final decision had been made by the end of the quarter.

2. 8-BeV Spectrometer

Second-order calculations on the simple vertical bend system consisting of 3 quadrupoles and a vertically deflecting pair of 15° uniform field magnets showed no serious difficulties. A difficulty of this design is the large θ dispersion which results in a rectangular θ - p focal plane of 6:1 aspect ratio. This gives rise to a problem in counter design as the momentum-counter in the focal plane hodoscope must be very long and thin. It has been decided that this problem is soluble. The magnetic system was slightly modified to allow the addition of a fourth quadrupole at some future date; this will permit a large reduction in the θ dispersion with a slight increase in aberrations.

Preliminary designs of magnets and supports for this spectrometer were undertaken. The two bending magnets will weigh approximately 100 tons each. The quadrupoles have exceptionally high field tolerances, and pole-tip configurations are being studied. The alignment of the various elements required positional tolerances on some of the elements ranging down to 5/1000 of an inch. Systems to continuously monitor alignment are being considered.

A conceptional sketch of the proposed system of support is shown in Fig. 22. The heavy shield (shown schematically) is supported separately from the magnetic system. A large pit will surround the pivot point to allow connection of services to the spectrometer.

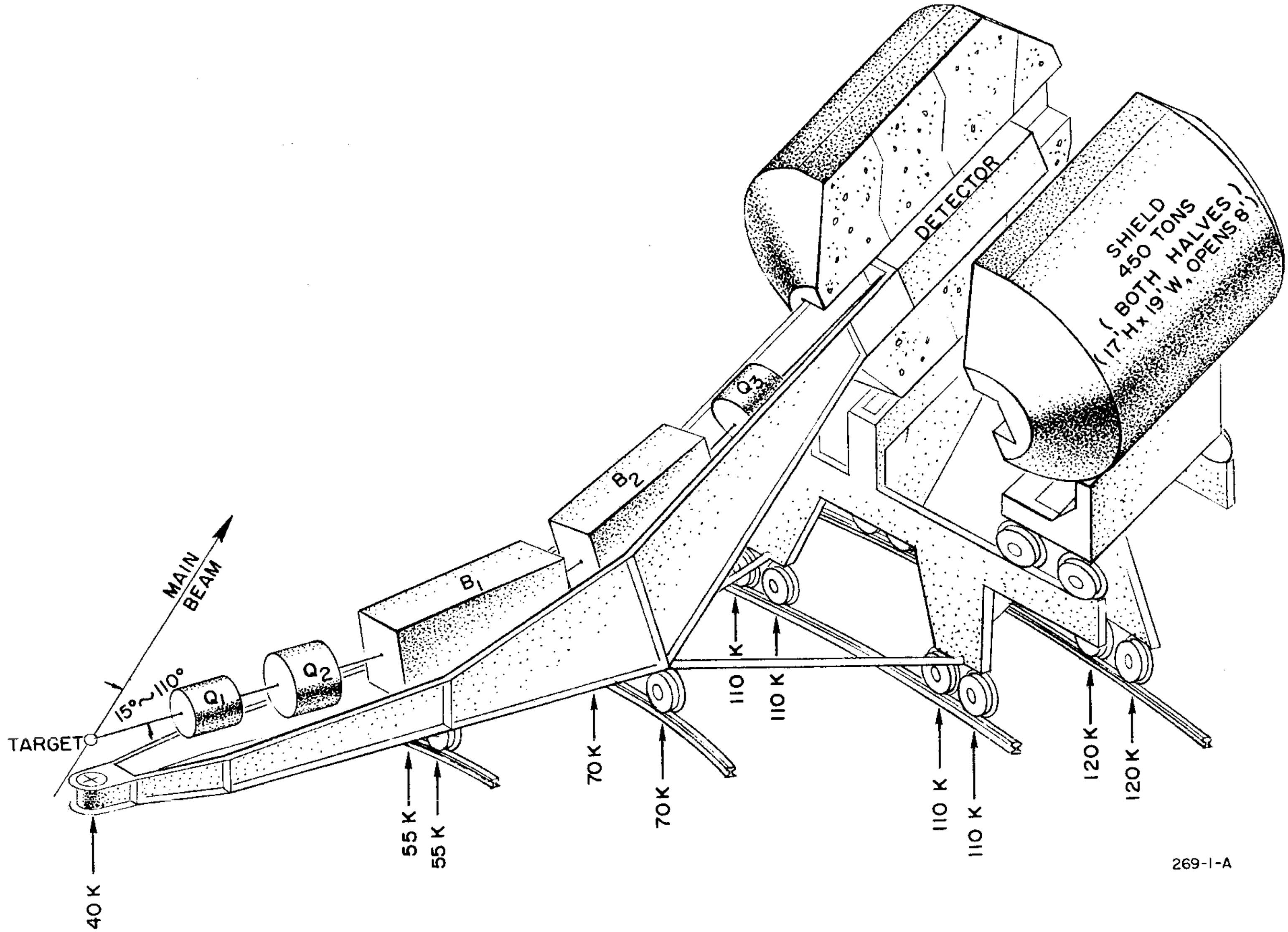

FIG. 22--Support system for the 8 BeV spectrometer.

3. Detectors

Conceptual design, prototype construction and testing of the focal plane counters has begun. Phototube and light pulse requirements are being studied. Various principles for the distinguishing of particles are being investigated.

4. Data Handling

The large amount of data collected by the spectrometers requires sophisticated data acquisition and preprocessing. The requirements for such a system are being developed. Fast (nanosecond) logic will be combined with a high speed (microsecond) digital processor to allow data storage and sampling. An attempt to devise a system flexible enough to sample and reduce data quickly enough so that a physicist can use this information to modify and improve the experiment while it is in progress, is being made. Discussions covering the processor have been held with several computer manufacturers.

5. Positron Source

The positron radiator, which will be located at the beginning of Sector 11, is required to provide both a continuous source of positrons (i.e, 360 pulses per second), and also a single positron pulse on demand. Separation of these two functions will simplify the design problem. Two radiators are therefore planned: one, the wheel target, will consist of a series of rotating discs cooled and driven by water; the other, the wand target, will consist of a series of small plates enclosed in the end of a water-cooled wand that can be snapped through the electron beam.

The wheel target rotates at right angles to the beam axis, inside a vacuum case. Windows in the case are needed to separate the cooling water inside from the accelerator vacuum outside while permitting the beam to enter and leave the target rings. Because of electron showering through the target material, the exit window will have a much higher heat load than the entrance window, and is therefore the limiting component in the design. At present, the design calls for a double window composed of a flat titanium foil and a spherical beryllium cap separated by a gap filled with pressurized helium. The titanium, chosen for its low density (low heat deposition) and high corrosion resistance, is supported against the water pressure by the helium. The beryllium, chosen for its low density and strength at elevated temperatures, is cooled by the helium and by conduction. Analysis shows, however, that the exit window will not accept the full 500-kW beam intensity. The design is being critically reviewed to find methods of obtaining acceptance of the full intensity.

The wand target will require a bellows seal capable of several million cycles of bending through 8°. In addition, the wand must retract to allow the wheel target to be moved into position to intercept the beam.

B. EXPERIMENTAL GROUP B (BUBBLE CHAMBER)

The bubble chamber group essentially completed its organization during this period. Several of the key people reported and others were scheduled for later arrival.

The significant parameters of the bubble chamber are as follows:

1. The chamber will be at least 20 inches deep, with the visible region nominally 40 inches in diameter at the chamber bottom.
2. The magnetic field is to be 20 kG, uniform within at least 5 percent.
3. The glass window of the chamber is to be vertical; therefore, the magnet must be capable of being readily split for servicing the chamber.
4. The optics are to employ three lenses located at the corners of an equilateral triangle. Scotch-lite is being studied in a number of laboratories as a substitute for coat hangers in retrodirective illumination, and we are hoping to employ it in this chamber.
5. A major problem, unique to bubble chambers used with electron accelerators, is the thin beryllium beam window required for photon physics. A literature search of the properties of beryllium has begun and a number of suppliers have been contacted.
6. It has been decided to employ a bellows expansion system. This expansion is believed to be inherently better than a piston expansion and will provide a cleaner chamber for deuterium operation.

In order to facilitate design of the magnet, certain dimensions of the vacuum tank have been provisionally fixed. The o.d. of the vacuum tank is to be 53 inches, and the coils are to be 14 inches apart. Preliminary design of the vacuum tank has begun, and it has been determined that the magnet structure will be able to withstand the design pressure of 150 psi.

A design permitting the splitting of the magnet, to allow access to the chamber body, optics, beam window, and piping, has been established in principle. The chamber will be suspended in one-half of the vacuum tank, which in turn will be rigidly mounted on the magnet. The magnet halves will be held together by bolts. The magnet will be split by means of low-friction Teflon* or oilite plates sliding on rails.

Preliminary studies of various methods of moving the 300-ton magnet and associated equipment were begun. The most novel (and economical) method is the use of professional riggers to accomplish the infrequent moves. A suggested method was the use of hardwood rollers.

Preliminary consideration of the chamber casting and beryllium beam entrance window has dictated that the beryllium window be a separate assembly bolted to the chamber body.

The film format has been studied in detail. Specifications for the chamber optical window are virtually completed and procurement is scheduled for early January.

C. EXPERIMENTAL GROUP C

1. Streamer Chamber Development

Measurements have been made on the amount of scatter of streamer dots from the trajectory of a particle in the view along the E field. This scatter depends on the time delay τ between the passage of the particle and the application of the high voltage pulse on the chamber. At $\tau = 0.25$ μsec, the standard deviation of the scattering per dot was found to be ±0.19 mm.

Straight tracks of high energy particles were fitted to a quadratic function to determine the amount of curvature that can be detected. For a 25-cm-long track, with about 40 dots per track, the statistical error in the curvature due to the scattering of the dots is 0.02 m^{-1}. This number was also observed from the distribution of curvatures for 50 different tracks. Hence, in principle, momenta up to 15 BeV/c could be detected from a track length of only 25 cm in a 10-kG magnetic field. It appears that the streamer chamber will be a good momentum detector.

The memory of this type of chamber was studied by varying the time delay τ between the passage of the particle and the application of the high voltage pulse. It was found that the chamber has a long memory, greater than 100 μsec. The width of the track increases with the delay τ, owing to the

*Registered trademark

diffusion of ionization electrons produced by the passing particle. The width of the track was found to be proportional to $\sqrt{\tau}$, as expected from diffusion theory.

The above long memory and the resulting spread of tracks are undesirable. Plans have therefore been made to study the possibility of reducing the memory of the chamber by "chemical poisoning."

2. Vertices and Recoils

Preparations were completed for a run at the Berkeley Cyclotron where positive and negative pions will be stopped in the gas of the chamber. The purpose is to study vertices produced in the gas by decay of positive pions as well as short recoils from stars produced by negative pions.

3. Pulsers

A 600 kV Marx generator was designed with special stress on minimizing the inductance of leads; fabrication is now half completed. It will be used to drive larger chambers and to study the best way to pulse a low-impedance terminated chamber. Until now the chamber has been pulsed directly from the generator with the pulse being chopped with a shorting triggered spark gap. For large terminated chambers the most economical method from a voltage point of view and for simplicity of connection is to use the Marx generator to charge a "small inductance" capacity and discharge this through the chamber using a series gap and a chopping gap. The optimum value of this capacity is the geometric mean of the generator capacity and the chamber capacity.

Pulsers utilizing cables for obtaining square pulses of desired width in the range of 500-1000 kV are also being investigated.

4. Photography

Preliminary work was done on amplifying the light from the chamber using a two-stage image intensifier. Photographs were taken with the object lens set at f/2.8, f/5.6, f/8. The pictures taken with f/5.6 were comparable with pictures taken without the intensifier with the lens set at f/1.5. It was concluded that a three-stage intensifier (which has subsequently been ordered) is needed. With better lenses and the three-stage tube, photographic tracks with f/16 lens setting, which will give good depth of field, are anticipated. Distortions and resolution of the system will be systematically studied.

5. Vacuum

Effort during the quarter was concentrated on improving the diode desorption apparatus. A gas introduction system was added, making it possible to introduce pure oxygen, hydrogen, nitrogen and helium in a controlled manner.

A cycloidal mass spectrometer was also installed on the system, permitting analysis of the gases released during electron bombardment of the surfaces under study.

Before incorporating the mass spectrometer, some preliminary total gas desorption measurements were made, using a cold cathode gauge to measure pressure changes during bombardment. These preliminary desorption measurements, made on a stainless steel target at room temperature, were in close agreement with data obtained on other systems reported earlier.*

Current efforts are being directed toward measuring changes in desorption rates as influenced by various gas-surface reaction.

D. EXPERIMENTAL GROUP D

1. Two-Meter Spark Chamber Magnet

Conceptual design has been completed on the two-meter magnet and power supply.

The magnet (shown in Fig. 23) has a one-meter gap, two meters in diameter. It will weigh 427 tons and will be assembled from pieces weighing less than 50 tons. It will be made to operate in several configurations.

The poles will be removable for viewing. In this case and with both poles inserted the magnet coils will be symmetrical. With a 4-megawatt supply and with both poles in place, a field of over 19 kG will be produced

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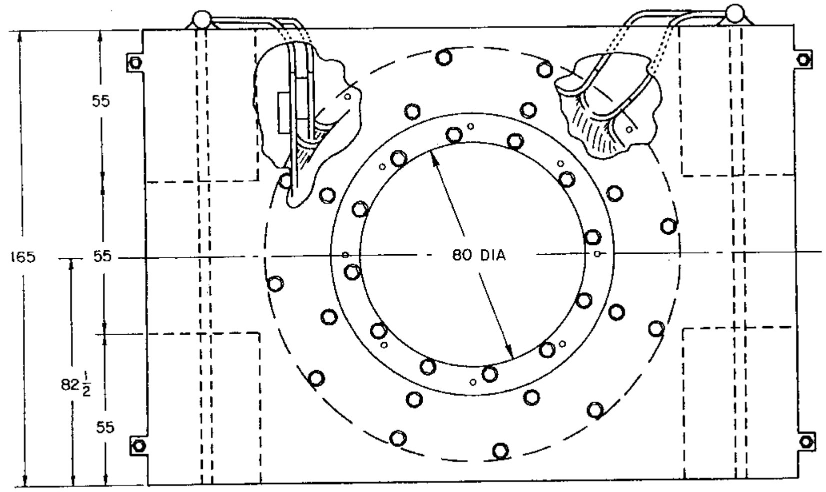
*E. L. Garwin, Presentation (unpublished) at the Second Annual Sherwood Vacuum Meeting, Germantown, Md. (January 30-31, 1964).

"Two-Mile Accelerator Project, Quarterly Status Report, 1 July to 30 September 1964," SLAC Report No. 34, Stanford Linear Accelerator Center, Stanford University, Stanford, California (1965), pp. 98-100.

M. Bernardini and L. Malter, "Vacuum Design Problems of Electron Storage Rings," Laboratori Nazionali di Frascati (Italy) - 64/19, March 1964, p. 33.

G. E. Fisher and R. A. Mack, "Vacuum Design Problems of High Current Electron Storage Rings," Cambridge (Mass) Electron Accelerator - (1)+, October 1964, p. 35.



MAJOR PART WEIGHT SUMMARY				
ITEM	DESCRIPTION	No REQ'D	UNIT WT. (TON)	TOTAL WT. (TON)
1	TOP UPPER PLATE	1	43.6	43.6
2	TOP LOWER PLATE	1	52.8	52.8
3	BOTTOM UPPER PLATE	1	43.6	43.6
4	BOTTOM LOWER PLATE	1	52.8	52.8
5	COLUMN	4	34.6	138.4
6	BOTTOM POLE	1	31.7	31.7
7	BOTTOM POLE TIP	1	5.67	5.67
8	DOUBLE PANCAKE COIL	14	4.0	56.0
9	COIL RETAINER UPPER	1	0.5	0.5
10	COIL RETAINER LOWER	1	0.65	0.65
11	TIE DOWN BOLTS	4	0.15	0.6
12	COIL RETAINER BOLTS	48	0.01	0.48
	TOTAL WEIGHT . . . . 426.8 TOTAL STEEL WEIGHT . . . . . 369.65 TOTAL COPPER WEIGHT . . . . . 56.0 TOTAL ALUMINUM WEIGHT 1.15			

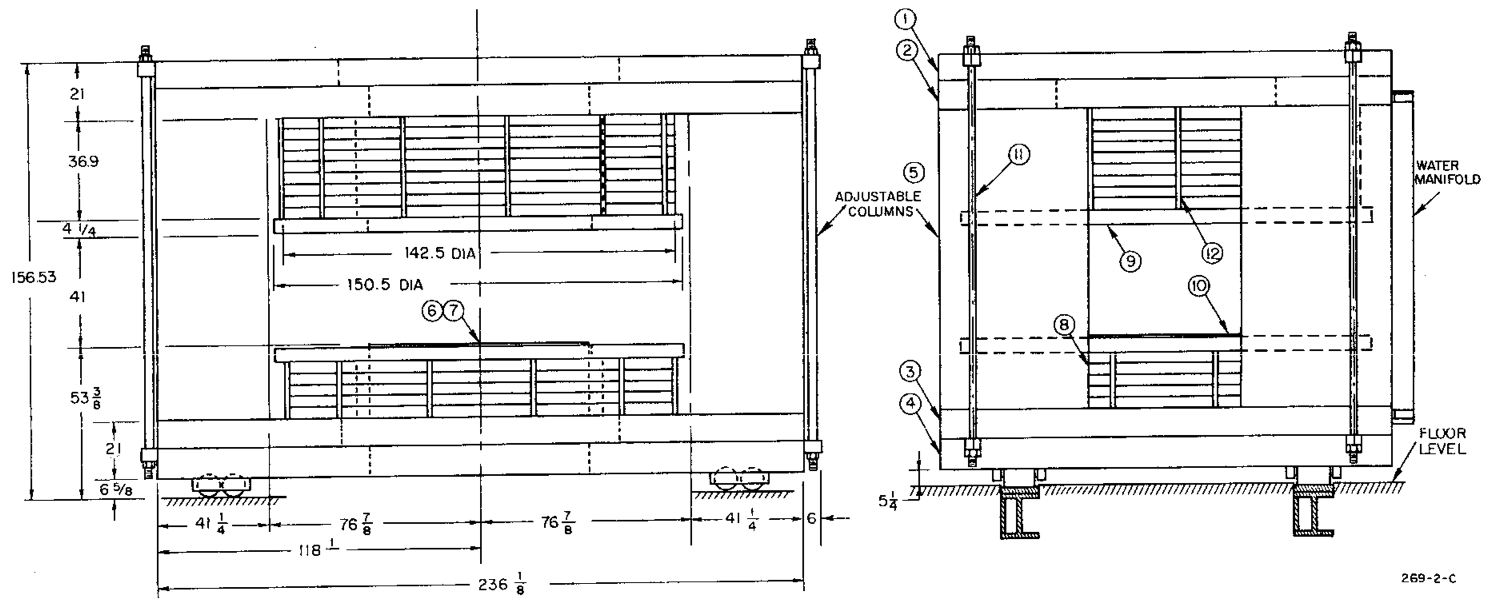


Fig.23--GENERAL LAYOUT OF THE LARGE VOLUME SPARK CHAMBER MAGNET

across the one-meter gap. With both poles out, the field will be over 10 kG. The power supply will be built so that it can be expanded, and at 8 megawatts the magnet will produce over 13 kG with both poles removed. With one pole in place and one out, the coils will be assembled in a non-symmetrical manner and a field of over 12 kG will be produced at 4 megawatts.

The coil assembly consists of 14 independent double pancakes which can be assembled in combination as desired. The return path of iron will occupy 2/3 of the side of the magnet, and the region occupied will be adjustable. If possible, the returns will be made to mount on their sides and thus allow a reduced gap and higher fields.

A carriage of rollers will be provided for the magnet which can be mounted on a track. This mount is not intended to be accurate; the magnet will be jacked into position.

2. Mark III Program

Preliminary runs have been made to produce a parasitic beam in the new target area of Mark III. Work is continuing on the components necessary for this beam.

A small magnet and spark chamber system is under construction for use in the target area in studying background problems. The magnet has been partially installed. The spark chamber is under construction, and a Marx generator developing 200-kB pulses has been completed.

3. Spark Chamber Development

Since it is desirable to use the streamer mode in wide-gap spark chambers, and because the light-intensity problems are significant, the use of high-resolution image intensifiers is being studied in cooperation with Group C. A newly-developed tube with 30 lines per mm resolution is being considered.

Work is continuing on the development of high-voltage pulsers for driving the wide-gap chamber. If a one-meter chamber is used and divided into two parts, pulses of 500 kV, 10 nsec wide, will be required. So far, satisfactory operation has been obtained only for a smaller gap chamber. The large size of the chambers makes cleaning them by evacuation very difficult, and as a result, a gas purification system is being built to get rid of the unwanted gases which evolve.

4. Data Analysis

In developing a data-analysis system for experiments using spark chambers and analyzing magnets, two areas in the preparation of the necessary computer programs are under investigation:

(a) Computer programs which will be used for the handling and analysis of future experimental data.

(b) Programs for simulation of experimental data (event types, coordinates, etc.) which test the correctness of the results of (a) and in addition, are very convenient for testing the approximate resolution and the bias of the experimental setup.

Some of the necessary programs for (a) are being tested with simulated data. In general, the following problems are being studied:

1. The acceptance of the experimental readouts; for example, the stereo coordinates as measured on the film or coordinates measured by other techniques, such as wire chambers and the subsequent reconstruction of the coordinates in space. Alternative solutions to the spatial reconstruction problems as used in more modern versions of bubble chamber programs are being considered.

2. Fitting of the coordinates to a function $F(x,y,z,\alpha_i)$, where $F(x,y,z)$ represents the particle track and α_i represents the relevant physical parameters such as particle momenta and spatial angles. The fitting procedure has to find the best estimate of α_i which is compatible with the measured (and reconstructed) coordinates. The problem in which the mathematical form $F(x,y,z,\alpha_i)$ is to be represented is under study. Representing the track by a polynomial inside the magnetic field and by numerical integration of the equation of motion for the particle passage through the fringe field is being considered. The fitting programs and the procedures for track generation, written in ALGOL, now run only for uniform fields and are presently being generalized for arbitrary fields.

3. Using the fitted parameters, the input format for GRIND is to be prepared. GRIND is a bubble chamber program which does the testing of various hypotheses on the type of interaction observed on film.

A larger program was written for (b) which in its present state performs the following major operations:

(a) Generates random particle momenta and angles in a phase space distribution of N particles.

(b) Generates an event type with three particles in the final state, two forming a resonance state.

(c) Computes invariant masses and constructs a Dalitz plot (kinetic energy) of two out of three final state particles.

(d) Chooses random target coordinates for each event and computes the particle tracks through a uniform magnetic field; indicates whenever a particle hits any boundary of the magnetic field or when it begins spiraling; samples the "observed" track at a number of points and gives the coordinates; varies the coordinates randomly for a given normal distribution and prints out the pseudo-experimental coordinates. These pseudo-experimental coordinates are then fed into our fitting procedure which will give back the now-fitted momenta and angles and, e.g., invariant masses of the simulated event which was generated. Thus (b) serves as a test for (a). Program (b) will be generalized further.

E. EXPERIMENTAL GROUP E

1. General Research

a. Experiments Being Prepared for SLAC

Design, and in some cases construction, has started on the following experiments:

(1) μ^-+p Inelastic Interaction. The purpose is to study the inelastic interaction of the type

$$\mu^- + p \rightarrow \mu^- + p + \pi^0$$
$$\mu^- + p \rightarrow \mu^- + n + \pi^+$$
$$\mu^- + p \rightarrow \mu^- + p + \pi^+ + \pi^-$$
$$\mu^- + p \rightarrow \mu^- + p + \pi^+ + \pi^0$$

and similar types and to measure the total and differential (in μ energy loss) cross sections for μ^-+p. A μ^- beam of momentum variable from 2 to 12 GeV/c will be used to produce these interactions in a liquid hydrogen target, spark chamber and magnet system. As far as it is possible with an apparatus of moderate size and complexity, complete event type identification will be attempted. This experiment will use the very large magnet being built by Group D and a smaller magnet being built by Group E.

(2) High Energy $\gamma+p \rightarrow \gamma+p$ and $\gamma+p \rightarrow \pi^0+p$. This experiment is designed to measure the high-energy, small-angle regions of these two reactions, these regions having a four-momentum transfer squared less than $1(\mathrm{GeV/c})^2$ and an incident photon energy greater than several GeV. Spark chambers and the magnet being built by Group E will be used.

(3) Survey Experiment. In collaboration with Group B, a survey experiment for charged and neutral beams is being designed for End Station B. The survey will be rather crude, being directed toward obtaining secondary beam estimates. However, particular attention will be directed toward a search for new particles.

b. Experiments at Other Accelerators

An extensive spark chamber measurement of $n+p$ elastic scattering was completed at the Lawrence Radiation Laboratory Bevatron. Neutrons of 1 to 6 GeV were used, and the diffraction-scattering region, large-angle scattering region, and charge-exchange region were studied. This experiment was performed in collaboration with M. Longo and S. Powell of the University of Michigan.

Analysis of K^-+d interactions in a hydrogen bubble chamber continued. Beam design and preparation continued for an exposure of the Brookhaven National Laboratories 8 - inch hydrogen bubble chamber to 30-GeV/c and 10-GeV/c π^- mesons and protons. These two experiments are collaborations with some members of Groups A and B.

c. Publications

Martin L. Perl and Mary C. Corey, "Empirical Partial-Wave Analysis of $\pi+p$ Elastic Scattering Above 1 GeV/c," Phys. Rev. 136, B 787 (1964); Martin L. Perl, Yong Yung Lee (University of Wisconsin), Erwin Marquit (University of Michigan), "Large Angle π^-+p Elastic Scattering at 3.63 GeV/c," to be published in Phys. Rev. (SLAC PUB-58).

2. Electronic Development

A small digital instrument was designed and constructed for the purpose of selecting a single trigger pulse to trigger a spark chamber after a preset number of pulses have been accumulated. The single trigger pulse is passed with a delay of 50 nsec, and the preset number is adjustable between

13 and 8×10^6. This instrument, which is constructed of commercial digital modules, operates in conjunction with a 10-Mc pulse counter.

A high-power, low-duty-cycle, 10-kc, square-wave generator has been built to drive panelescent lamp fiducial marks. The fully transistorized unit is capable of delivering 10 amperes at 500 volts for driving 30 $inches^2$ of panelescent lamps.

A prototype of a delay box using coaxial rotary switches has been constructed. The delay is adjustable between 6 nsec and 30 nsec in 1 nsec steps. The unit is larger than those commercially available, but a higher degree of reliability is expected.

3. Automatic Film Measuring Devices

In order to be able to handle the large quantities of spark and bubble chamber film expected in the coming years, a system for the automatic evaluation of these films will be necessary. Work will be directed toward the construction of such a system in the near future.

The design of a digitizer incorporating a high resolution cathode ray tube was started at the end of this quarter. This device will be used as a film-to-magnetic-tape converter for spark chamber film that is presently available, while valuable experience will be gained for the construction of a more sophisticated device at a later date.

4. Data Reduction Equipment

Two additional measuring machines for bubble chamber film were received during the period. The down-times, due to repair, were 47 and 21 hours for the new machines and 328 hours for the old machine, the latter due to major redesign. Near the end of the quarter, when the machines were already debugged, the percentage of operating time lost due to repair and maintenance was less than five percent of the total for each of the three machines.

Circuit design for the scanning projector, SPVA, continued. The method of time modulation on amplifiers using SCR's for control of the film servo-drive was tried experimentally and performed according to design. The development of the "window amplifier" referred to in the previous report* was completed. All circuits were tested under extreme temperatures to check

*"Two-Mile Accelerator Project, Quarterly Status Report, 1 July to 30 September 1964," SLAC Report No. 34, Stanford Linear Accelerator Center, Stanford University, Stanford, California (1965), p. 105.

for design and component reliability and were constructed on "printed" plug-in modules. Mechanical construction of two SPVA machines was completed. The electronics for one machine was 80 percent complete by the end of the quarter.

Design of the circuitry for two image plane digitizers continued. Logic decisions will be made, as much as possible, by solid-state circuitry. Mechanical design proceeded and construction has begun.

Specifications for a measuring machine of one-micron accuracy were initiated.

F. PHYSICAL ELECTRONICS

Development work on transmission type KCl electron multipliers was continued this quarter. Gain (δ_t) and lifetime measurements for incident electrons in energy range 0 – 20 keV were performed on low density KCl dynodes and on bulk density KCl dynodes deposited on the Al_2O_3 plus evaporated Al substrates discussed in the previous report.

Low density KCl dynodes were prepared by evaporation at 2 torr of argon; bulk density KCl dynodes were prepared by evaporation in a vacuum of $\approx 1 \times 10^{-6}$ torr. All evaporations and measurements were carried out in a liquid-nitrogen-trapped, oil-diffusion-pumped, non-bakeable system.

The following results have been obtained for low density KCl dynodes:

1. Maximum gains as a function of primary energy are in the range 30-80.
2. δ_t decreases approximately exponentially with time exposed to the residual atmosphere of the vacuum system. Typical time constants are $\approx$ 80 minutes with an incident current of $\approx 5 \times 10^{-8}$ A/cm^2, and $\approx$ 350 minutes without an incident current.
3. δ_t is strongly dependent on the potential of the following electrode, and if this potential exceeds $\approx$ 300 volts a breakdown occurs, resulting in destruction of the dynode.
4. δ_t is unaffected by exposure to atmospheric pressure of argon, making handling of the dynodes possible in a controlled environment.

The results obtained for bulk density KCl dynodes are:

1. Maximum gains of 5-6.
2. No deterioration of δ_t resulting from exposure to the residual atmosphere of the vacuum system without an incident current was in evidence.

With an incident current of $\approx 1 \times 10^{-7}$ A/cm^2, δ_t decreases by 15 percent for a total charge incident of $\approx 5 \times 10^{-4}$ C/cm^2. This is approximately a factor of two worse than reported by Sternglass and Wachtel.*

3. δ_t is unaffected by the potential of the following electrode to ≈ 1 kV.

4. The gain is unaffected by exposing the dynode to the atmosphere.

Because of the above deterioration of δ_t with time, the diffusion pumped system now in use is being rebuilt to give more efficient trapping of oil vapor, and a bakeable ion pumped system is being constructed for performing the gain and lifetime measurements. As an electron source in the latter system, a gold photocathode has been found suitable. The thickness of the photocathode is such as to give a resistance of 6.7 ohms/sq (ohms/sq = resistivity/thickness), which is ≈ 100 Å. This cathode emits 4×10^{-9} A/cm^2 when illuminated at a distance of 6 inches through a quartz window by a BH-6 high pressure mercury arc.

It has been necessary to fabricate sapphire windows for the ion pumped system due to multiple failures in the quartz windows initially used. In the coming quarter, gain and lifetime measurements will be carried out in the clean environment of the bakeable ion pumped system. It is also hoped that the gain for minimum ionizing electrons at the Mark III accelerator can be measured and the theoretical prediction of 2-3 secondaries per incident electron confirmed.

G. MAGNET RESEARCH

1. Water-Cooled Magnets

a. Positron Solenoids

Basic conceptual design of the magnets has been completed. The detailed design has been started and is near completion. The schematic configuration of the solenoids and the required and actual distribution of the axial field is illustrated in Fig. 24. The solenoid is basically split into three sections:

(1) Upstream Magnet — The reason for using this coil is to produce a field of 20.4 kG at the downstream end of the radiator and guarantee a fast

*E. J. Sternglass and M. M. Wachtel, "Transmission Secondary Electron Multiplication for High-Speed Pulse Counting," IRE Trans. Nuc. Sci. NS-3, 29 (1956).

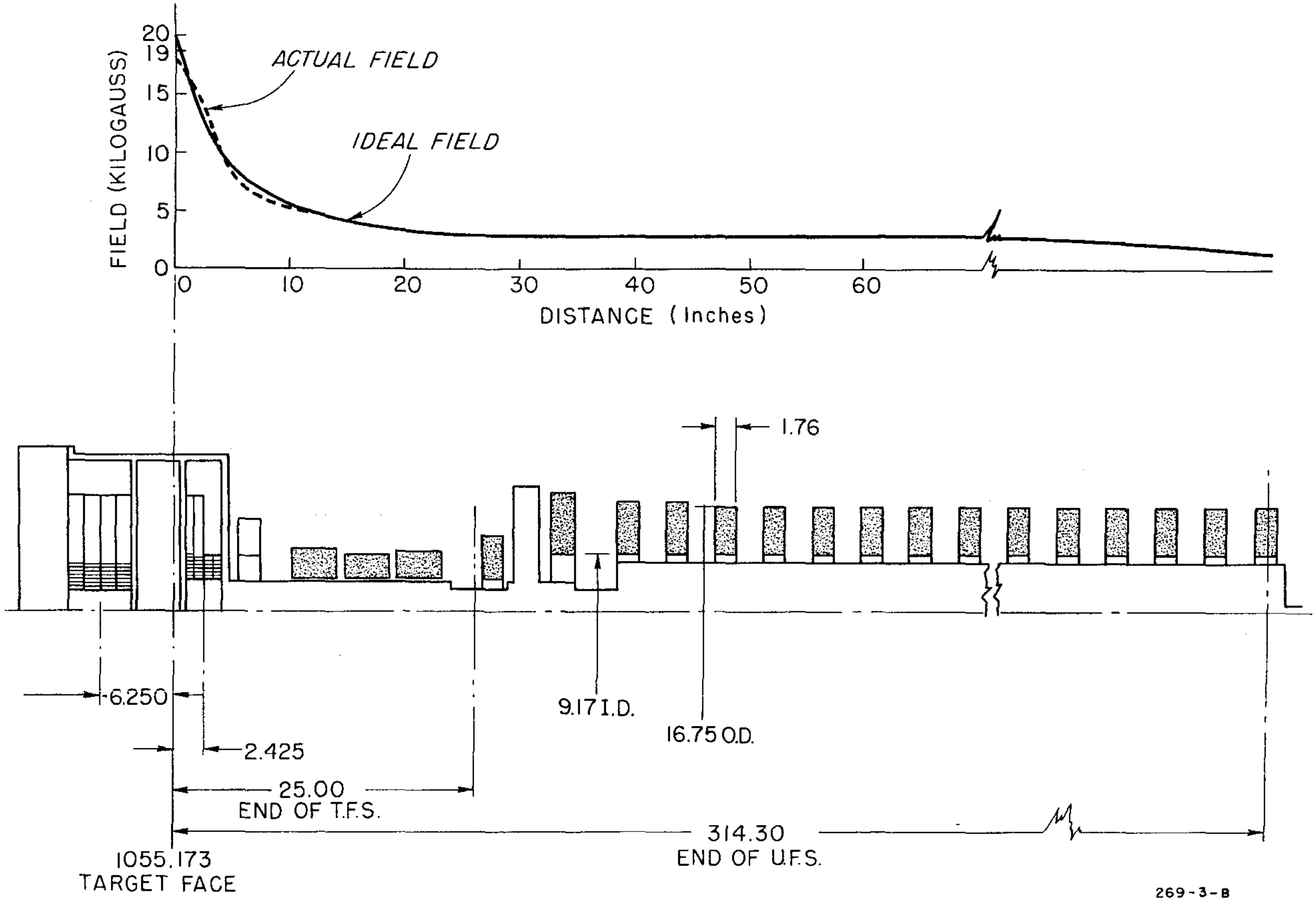


Fig.24--SCHEMATIC LAYOUT OF POSITRON SOLENOID

drop of the field in axial directions. The magnet consists of four double pancakes consisting of copper strips, insulated by glass fiber impregnated strips. Due to the high level of radiation, the SLAC epoxy system will be used. Each pancake is separated by means of glass phenolic sheets, and radial insulation strips provide the spacing between adjacent double pancakes that are iron bound. The water enters the coil from the outer circumference and, flowing radially over the coil surfaces, is collected in the inner circumference. Due to the high speed of water the danger of corrosion is acute. The double pancake surfaces are therefore machined carefully, etched and chromeplated. Figure 25 gives the configuration of one such double pancake. Low carbon iron provides an additional 3 kG to the solenoidal field and helps as a mechanical reinforcement structure.

(2) Tapered Solenoid - As can be seen from Fig. 24, the axial field must drop over an axial length of 10 inches from 20.4 kG to 5 kG. In order to achieve this requirement, solenoids were designed and located along the accelerator so that the driving ampere turns of each solenoid add to and subtract from the field along the accelerator axis generated from the upstream coils mentioned above. The coils of this section are built essentially in the same fashion.

(3) Homogeneous Field Solenoids - Over a length of 29 feet, 144 double pancakes are placed around the accelerator. The required field in this area is 2.4 kG; the actual field deviates from this field by $\approx$ 100 gauss. The copper conductors used for these solenoids are hollow and water cooled. The basic design of these solenoids did not require the sophisticated techniques used for the upstream magnet and tapered solenoids.

The power requirement for the total positron solenoid is about 1.2×10^6 watts, of which 700 kW are used in the upstream solenoid mentioned in (1) above. The solenoid data and features are given in Tables I, II, and III.

b. Beam B Magnetic Slit

A dc magnetic slit (shown in Fig. 26) located in the beam switchyard area is capable of deflecting the beam of 20 GeV/c to an angle of $\pm 1.8^{\circ}$ on either side of the undeflected beam in the horizontal plane. The beam is deflected by a pulsed magnet first to $\pm 0.25^{\circ}$, and enters the slit where it

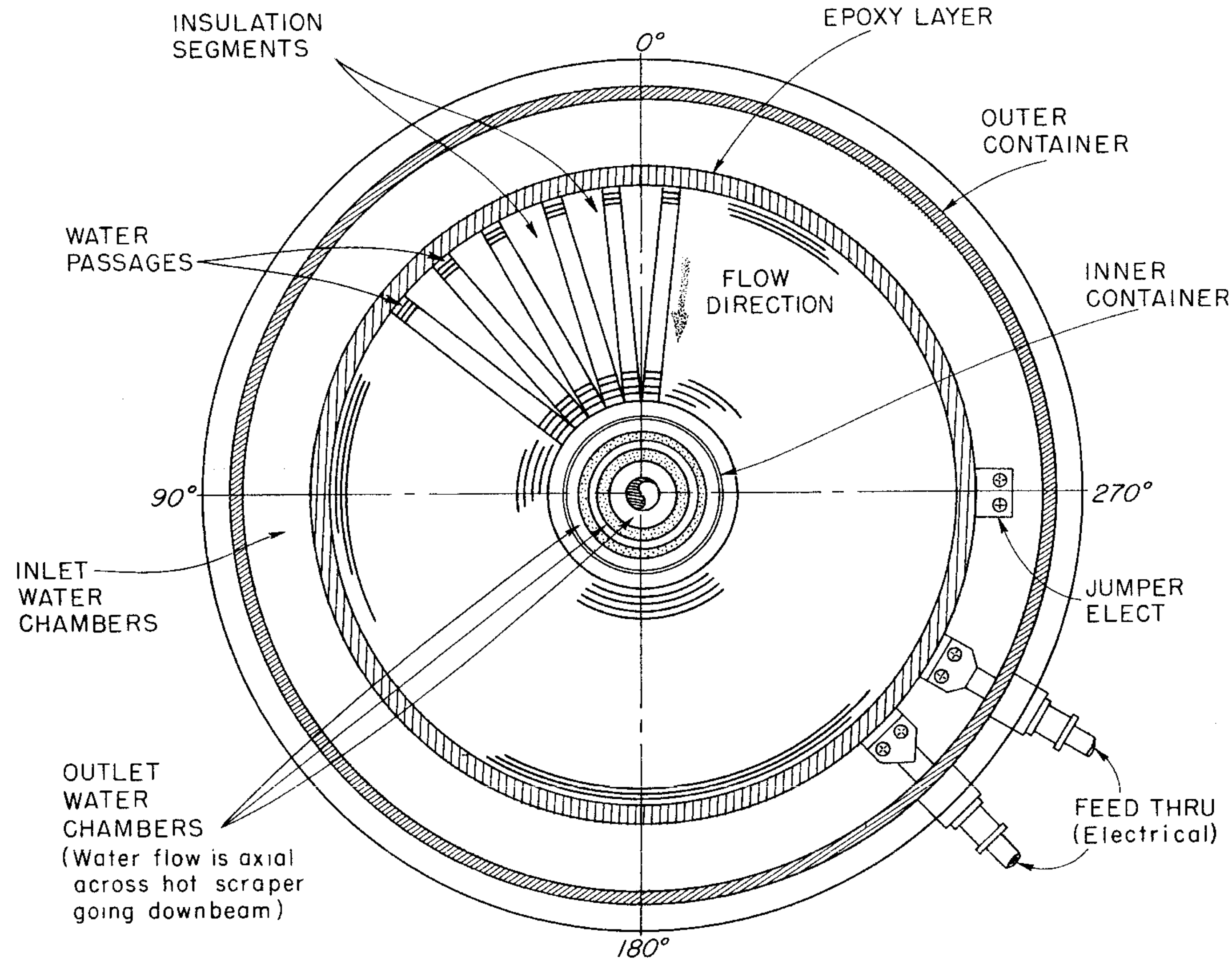


FIG. 25--Coil configuration of upstream magnet in positron source.

TABLE I

UPSTREAM SOLENOID

Maximum field	40,000 gauss
Bore diameter (Coil i.d. = 3.50 inches)	8.89 cm
Outer coil diameter (Coil o.d. = 19.5 inches)	49.5 cm
Total ampere-turns	9.1×10^5
Number of double pancakes	4
Number of turns per double pancake	60/62
Maximum current	3730 amps
Maximum operating voltage	190 volts
Magnet power at 4000 amps	700 kW
Magnet resistance at 100°C	0.0505 ohms
Magnet inductance	10^{-2} Hy
Water flow for 8.25°C bulk temperature rise (316 gpm)	20 liters/sec
Maximum water velocity	6.6 meters/sec
Temperature rise in the boundary layer	41.4°C
Copper temperature rise	26°C
Hot spot temperature (inlet temperature 40°C)	125°C
Water pressure drop (30 psi)	2.15 kg/cm^2
Iron weight (638 lbs)	290 kg
Copper weight (446 lbs)	203 kg
Total weight (1,500 lbs)	682 kg

TABLE II

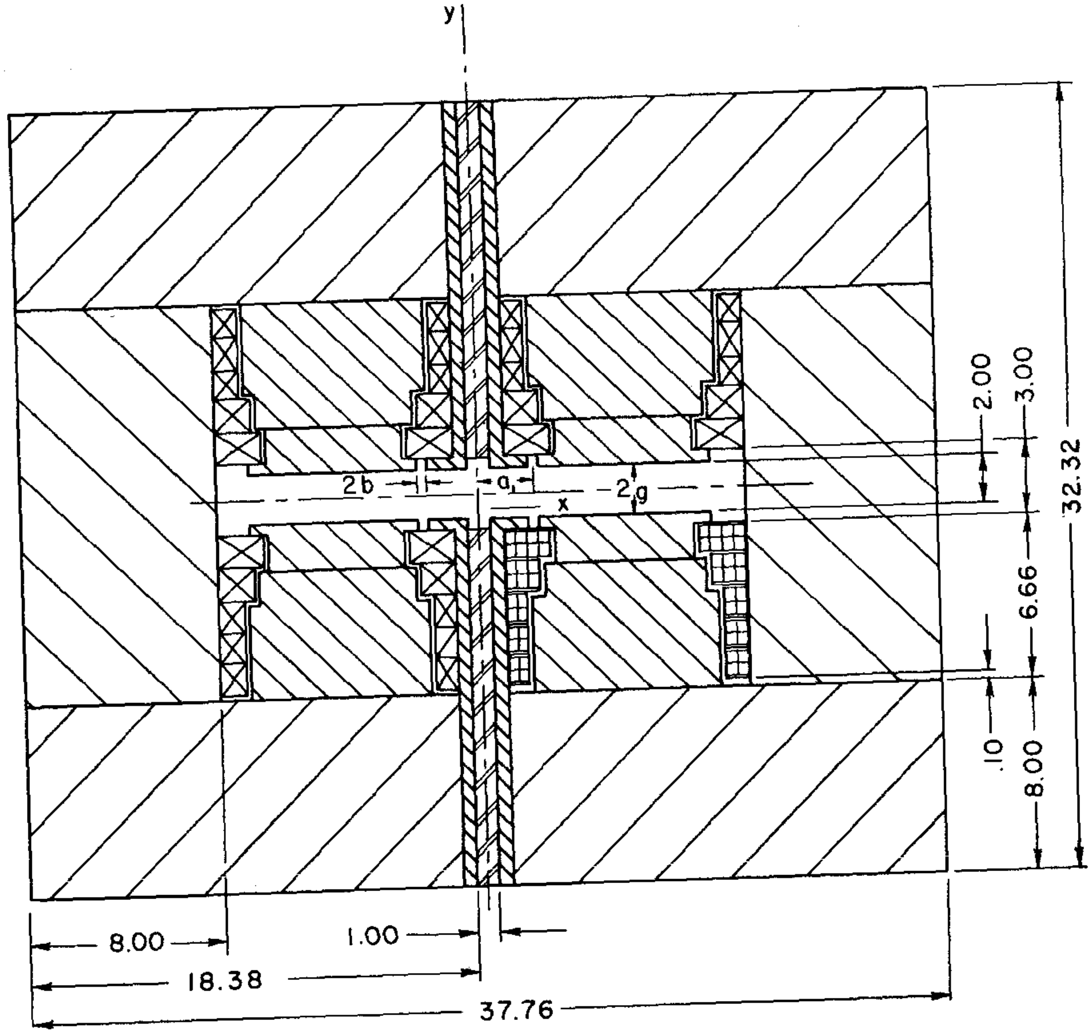
TAPERED SOLENOIDS

Maximum field	7.2 kG
Bore diameter (Coil i.d. = 5.75 inches)	14.6 cm
Outer coil diameter (Coil o.d. = 18.87 inches) max	48 cm
Total ampere-turns (absolute value)	2.97×10^5
Number of double pancakes	18
Maximum current	2000 amps
Maximum operating voltage	90 volts
Magnet power at 2000 amps	180 kW
Inductance	2.5×10^{-3} Hy
Coil resistance at 90°C	4.5×10^{-2} ohms
Maximum water velocity	1.5 $msec^{-1}$
Amount of water (4.3 liters/sec)	91 gpm
Coil hot spot	120°C
Water pressure drop	1 kg/cm^2
Copper weight (370 lbs)	168 kg
Total weight (670 lbs)	305 kg

TABLE III

HOMOGENEOUS FIELD SOLENOID

Maximum field	2.4 kG
Bore diameter (Coil i.d. = 9.25 inches)	23.5 cm
Coil outer diameter (Coil o.d. = 16.5 inches)	42 cm
Number of double pancakes	146
Number of turns per double pancake	32
Maximum current	1250 amps
Ampere-turn total	2.92×10^6
Conductor cross section (0.422 × 0.372 inch)	0.810 cm^2
Cooling hole diameter (0.2 inch)	0.508 cm
Maximum voltage	200 volts
Maximum power at 1250 amps	325 kW
Inductance	10^{-2} Hy
Coil resistance at 50°C	0.208 ohms
Maximum water velocity	2 meters/sec
Amount of water (2.6 liters/sec)	42.2 gpm
Water pressure drop	2 kg/cm^2
Copper weight (3870 lbs)	1760 kg
Total weight (4500 lbs)	2045 kg



LENGTH OF POLES: 100.00 IN.
OVERALL LENGTH: : 112.50 IN.

Dimensions in Inches
269-5-A

Fig.26--BEAM B MAGNETIC SLIT

is bent further by ±1.8°. The total deflection on either side of the straight beam is approximately 88 cm. If the slit width 2b is small compared to the gap width 2g, the potential function in the midplane may be expressed as:

$$W = U + jV = \frac{-gB_m}{\pi} \cdot \ln \left[\cosh \left(\frac{\pi}{2} \frac{x - a_1 + jy}{\delta} \right) \cdot \cosh \left(\frac{\pi}{2} \frac{x + a_1 + jy}{\delta} \right) \right]$$

The magnetic slit data are given in Table IV.

c. One Meter Bubble Chamber Magnet

The final decision to build a 20 kG magnet with a 1.35-meter bore and total effective value of 1.25 cubic meters was made in the last part of 1964. A preliminary calculation of an optimized bubble chamber magnet is given in Table V.

d. Spark Chamber Magnet

The spark chamber magnet consists of a nonsymmetrical coil configuration because of the shape of the iron. The magnet can be operated with both poles in place, or one pole, or both poles taken out. The data on this magnet are given in Table VI. More details about the magnet field are discussed in the Group D report.

e. Computer Program for Iron-Bound and Iron-Core Magnets

The field contribution of iron around the coils is generated from the magnetic dipoles in the iron. The maximum contribution of iron is obtained when the iron is saturated and the dipole moments have an optimum direction. In order to calculate the exact field contribution in a three-dimensional magnet configuration, a computer program is being written.

2. Radiation

The effect of nuclear radiation on organic materials, specifically magnet insulation, has been under investigation during the past 18 months. Numerous thermosets have been investigated at radiation levels up to 3.25×10^{14} ergs·gr^{-1}. It was found that commercially available epoxies did deteriorate at levels less than 10^{12} ergs·gr^{-1} and new ones were explored. The results of this work are reported in SLAC Report No. 40* and in a paper presented at the Particle Accelerator Conference held in Washington, D.C., March 10-12, 1965.

*H. Brechna, "Effect of Nuclear Radiation on Organic Materials, Specifically Magnet Insulations in High-Energy Accelerators," SLAC Report No. 40, Stanford Linear Accelerator Center, Stanford University, Stanford, California (1965).

TABLE IV

2.5-METER MAGNETIC SLIT (BEAM B)* FOR 20 GeV/c

Beam deflection angle	1.8^{o}
Central field strength	8,500 gauss
Gap height (2 inches)	5.08 cm
Pole width (7 inches)	17.8 cm
Effective length	250 cm
Ampere-turns per pole	2.21×10^{4}
Maximum current (turns in series)	850 amps
Turns per pole	26
Number of double pancakes per pole	5
Conductor dimensions: Bare (0.45 × 0.6 inches)	$(1.144 \times 1.52)cm^{2}$
Insulated (0.478 × 0.62 inches)	$(1.215 \times 1.6)\ cm^{2}$
Diameter of cooling hole (0.25 inch)	0.635 cm
Conductor cross section	$1.25\ cm^{2}$
Number of cooling passages per pulse	3
Magnet resistance including leads (70°C)	5.88×10^{-2} ohms
Voltage	≈50 volts
Power at 850 amps	42.5 kW
Slit inductance	4.5×10^{-2} Hy
Water flow for 30°C temperature rise	5.5 gpm
Water pressure drop (70 psi)	$5\ kg/cm^{2}$
Iron weight (19,800 lbs)	9×10^{3} kg
Copper weight (925 lbs)	420 kg
Slit weight (22,000 lbs)	10×10^{3} kg
Physical length (including 8 inches for flange)	3 meters

*The data given in the table are for half the slit.

TABLE V

1-METER BUBBLE CHAMBER MAGNET

Magnetic field intensity at chamber center	20 kG
Weight of the coil	17 tons
Weight of the iron return path	160 tons
Copper cross section 1.6 × 1.6	1.6 × 1.6 square inches
Diameter of water hole	0.9 inches
Number of turns	224
Length of copper conductors	4600 feet
Number of pancakes	16
Number of water circuits	16
Cooling water flow (30°C temperature rise)	410 gpm
Water pressure	80 lbs. psi maximum
Coil voltage	250 volts
Coil current	11,000 amperes
Coil power	2.7 megawatts
Coil dc resistance (70°C)	23 milliohms
Inductance	60 millihenries
Time constant	2.75 seconds
Stored energy	2×10^6 joules

TABLE VI

2-METER SPARK CHAMBER MAGNET

Central field strength		15,000 gauss
Gap height		1 meter
Pole diameter		2 meters
Turns per pole:	Upper	256
	Lower	192
Coil i.d. (88.6 inches)		2.25 meters
Coil o.d. (140 inches)		3.556 meters
Ampere turns per pole:	Upper	2.4×10^6
	Lower	1.9×10^6
Number of turns per pancake		16
Number of pancakes:	Upper pole	18
	Lower pole	10
Hydraulic passages per double pancake		4
Magnet current (coils in series)		10,000 amps
Conductor dimensions (1.5 × 1.8) inches		$(3.8 \times 4.57)\text{cm}^2$
Diameter of cooling hole (0.9 inches)		2.286 cm
Conductor cross section		$13.19\ \text{cm}^2$
Magnet resistance including leads (60°C)		6.6×10^{-2} ohms
Voltage		660 volts
Power at 10,000 amps		6.6×10^6 watts
Magnet inductance		50×10^{-2} Hy
Water flow for 25° temperature rise		1000 gpm
Water pressure drop (56 psi)		4 atü
Iron weight (690,000 lbs)		314,000 kg
Copper weight (112,000 lbs)		51,000 kg

The epoxy system which will be used in the BSY magnet insulation is:

Epoxy DER 332 LC	100 parts by weight
MPDA	11 parts by weight
MDA	7 parts by weight
Pure alumina granules (10-20μ)	100 parts by weight
Thixotropic material	1 part by weight
Wetting agent Z6040	1 part by weight

The weight ratio of organic to inorganic material in the insulation should be approximately 25/75. Less organic binder in the system may be good from a radiation point of view, but its mechanical strength is inadequate.

The glass fiber cloth must be heat cleaned and chemically treated in order to insure optimum bonding of the epoxy to the glass cloth.

3. Pulsed Magnet Laboratory and Magnets

a. Pulse Laboratory and Model

The installation of the capacitor banks, wiring and connection of busbars, as well as safety circuits has begun. A pulsed magnet prototype for the spark chamber magnet described above was built at a linear scale of 1:10. The magnet has for the first test series a symmetric pole and coil configuration. It has produced at a level of 1000 amps approximately 24 kG in the gap and has a homogeneity of about 8 percent over 50 percent of the pole surface area. Further tests with the magnet will be reported later.

b. Beam B Switching Magnet

The calculation of the magnet has been completed. The detail design work will be carried out by the magnet engineering group.

4. Superconductive Magnet Research

a. Cryogenic Lab

The cryogenic lab is now equipped with an operating helium cryostat, liquefying about 10 liters/hour of helium. Power supplies for use of high current magnets up to 100 amps have been installed. The lab is equipped with dewars ranging up to 500 liters capacity, dewars for handling coils up to 8 inches o.d., welding and winding equipment, and a complete test and monitoring setup.

b. Investigation of the Behavior of Coils

In order to investigate the best possible coil winding arrangement, study the joint problems, winding and layer insulation, degradation effect, forces, etc., a number of small coils with an i.d. = 0.4 inch and o.d. = 3 inches, have been built and tested. The first series of coils consist of 10-mil 3NbZr and the later coils of 3NbZr 7-stranded cable with and without insulation. At 58 kG the current-carrying capacity of the 10-mil wire coils was 26 amps, and using cables at 38.6 kG, the maximum cable current, 298 amps (equivalent to 42.5 amps/strand) was obtained. Joints between copper bars and 3NbZr have been under investigation, and approximately 580 amps total current has been reached without any defects at the joint. However, the wire has burned several times and we are investigating the cause of it.) A 1.4-inch i.d. and 6-inch o.d. coil producing about 85 kG is now under construction.

c. Special Dewars

A dewar capable of testing coils up to 12 inches i.d. has been built. Because the coils placed in the dewar have their bore exposed to air, experimental equipment may be placed into the bore.

d. General

We are now able and equipped to investigate superconductive magnets up to bore sizes of 12 inches i.d. and 10 inches axial length. For larger coils the winding machine and the dewars, etc., have to be rebuilt.

5. Glass Fiber Epoxy Structures

The investigation of filament structures at cryogenic temperatures as a possible use for magnet research and bubble chamber work is still continuing. We have finished static tests on straight structures at liquid N_2 and liquid H_e temperatures. The samples have been under flexural stress for 10^7 cycles and the new tests investigate the permeability and fatigue properties of cylinders. The tests which are completed are:

(a) Choice of proper binder

(b) Ratio between glass fiber and binder

(c) Static flexural strength up to $4.2^{\circ}K$

(d) Fatigue properties up to $4.2^{\circ}K$

(e) Effect of impervious films on strength of structure

(f) Effect of beryllium sheets on the strength

Most tests have been carried out with 0.25-inch thick, 6-inch long, and 1-inch wide samples.

H. THEORETICAL PHYSICS

The following papers not previously reported by title have appeared, or have been prepared for publication:

1. S. M. Berman, "Weak Interactions," Ettore Mojoranna summer school lectures, volume entitled "Strong,Electromagnetic, and Weak Interactions," Benjamin (1964).
2. S. D. Drell and J. D. Bjorken, Relativistic Quantum Mechanics, Vol. I, McGraw-Hill (1964). Vol. II (in proof).
3. J. A. McClure and S. D. Drell, "Analyses of Muon Electrodynamic Tests," (to be published).
4. H. P. Noyes, "Estimate of Neutrino Event Rates at SLAC," Internal Report, Stanford Linear Accelerator Center, Stanford University, Stanford, California (1964).
5. M. Bander, "Three Nucleon Problem with Separable Potentials," (submitted to Phys. Rev. Letters and Phys. Rev.).
6. H. P. Noyes, "The Interaction Effect in n-p Capture," SLAC-PUB-59 (submitted to Nuclear Physics).
7. S. D. Drell and M. Jacob, "Photoproduction of Neutral K-Mesons," SLAC-PUB-65 (to be published).
8. S. M. Berman and M. Jacob, "Systematics of Angular and Polarization Distributions in 3-Body Decays," (submitted to Phys. Rev.).
9. R. G. Parsons, J. S. Trefil and S. D. Drell, "Double Charge Exchange Scattering of Pions from Nuclei," SLAC-PUB-63 (submitted to Phys. Rev.).
10. M. Bander, "Double Bremsstrahlung in e-e Collisions," SLAC Internal Report, Stanford Linear Accelerator Center, Stanford University, Stanford, California (1964).
11. J. D. Bjorken and B. Hellesen, "Nonleptonic Baryon Decays and Eightfold Way," Phys. Letters 12, 141 (1964).
12. J. D. Bjorken and S. L. Glashow, "Elementary Particles and SU(4)," Phys. Letters 11, 255 (1964).
13. C. Itzykson, "On the Possibility of Relating Internal Symmetries and Lorentz Invariance," SLAC-PUB-66 (submitted to Math. Phys.).
14. M. Jacob and C. Itzykson, "Symmetries of Strong Interactions," (to be published in the Journal de Physique).
15. M. Bander, P. W. Coulter and G. L. Shaw, "Non-Equivalence of the One-Channel N/D Equations with Inelastic Unitarity and the Multi-Channel ND^{-1} Equations," SLAC-PUB-70 (submitted to Phys. Rev. Letters).
16. J. S. Bell and C. J. Goebel, "Double Poles and Non-Exponential Decays," SLAC-PUB-62 (submitted to Phys. Rev.).

Items 1 through 6 have been described in previous progress reports. Work not previously reported is briefly discussed below.

1. Production Processes and High-Energy Reactions

It has been shown that the possibility of K^* vector meson exchange implies a very large photoproduction cross section for neutral K mesons at energies that will be available at SLAC. Typically, a lower limit for the cross section for the photoproduction of K^0 at 2° by 15-BeV photons is 20 μb/sr[7]. This implies that it should be possible to achieve a K_2 beam of at least 10^6 particles/sec, which opens a number of exciting experimental possibilities. A general method for measuring the polarization and alignment of a particle of arbitrary spin from the analysis of its three-body decays has been presented. This allows the determination of the spin and parity of the decaying system independent of the dynamics of the decay process. The method is illustrated for three-pion and baryon two-pion decays.[8] The usefulness of high energy pions as a probe of nuclear structure has been demonstrated by the calculation of double charge exchange scattering from He^3 and O^{18}[9]. Double bremsstrahlung in e-e collisions has been evaluated.[10] Work is also in progess on the calculation of the production of weak vector bosons to be expected (if they exist) in the colliding-beam storage ring. The absorption correction to peripheral production processes is under investigation.

2. Symmetry Schemes

A five-parameter fit to eight independent experimental non-leptonic baryon decay parameters assuming SU_3 symmetry has been achieved. It is particularly interesting since the two parameters which can be compared in this way are found to have the same values obtained from the analysis of strong interaction processes.[11] A classification of elementary particles based on SU_4, which is subject to experimental checks, has been presented.[12] The possibility of relating internal symmetries to Lorentz invariance has been explored,[13] and a review paper on the symmetries of strong interactions has been prepared for publication.[14]

3. Other Theoretical Physics

By explicit comparison of a multi-channel ND^{-1} calculation with a single-channel calculation using the appropriate inelasticity, it has been shown that specifying the inelasticity does not uniquely determine the single-channel amplitude, as has often been assumed. The difficulty arises when the diagonal interaction in the channels not explicitly considered is strong enough to lead to a bound state.[15] The problem of simple decaying particle models which do not lead to the usual exponential decay law has been shown to be more general than the results of Goldberger and Watson, and models are exhibited for which the observed decays depend explicitly on the production and detection arrangements.[16] Work is in progress on the G_A/G_V ratio in β-decay, the vacuum Regge trajectory in perturbation theory, and the electromagnetic mass splittings of particle multiplets. An approximate method has been developed for computing the α^3 correction to the magnetic moment of the electron and an explicit result achieved.

I. HEALTH PHYSICS

The Health Physics group moved to the site during this period. Most of its efforts have been directed at purchasing and testing the necessary equipment for the laboratory. One of the group assisted in the design of the 30- and 600-foot beam dumps and the beam stoppers. An experiment was carried out with the Mark III and IV accelerators with neutron sources to determine the slowing down of giant resonance neutrons in concrete. Its purpose is to design shielding to reduce the activation near beam scrapers.

Design of the peripheral monitoring stations is nearly complete and construction of a prototype has started. Design work and testing of prototypes for other fixed and portable monitors in the personnel protection system is proceeding.

A computer program has been written and tested for analyzing neutron activation foil data.

Equipment was installed for monitoring radiation levels during sector tests.