SLAC-112
UC-28
(SR)

TWO-MILE ACCELERATOR PROJECT

1 July to 30 September 1969

Quarterly Status Report

STANFORD LINEAR ACCELERATOR CENTER
STANFORD UNIVERSITY
Stanford, California

PREPARED FOR THE U. S. ATOMIC ENERGY COMMISSION
UNDER CONTRACT NO. AT(04-3)-400 AND CONTRACT NO. AT(04-3)-515

December 1969

ABSTRACT

A status report on the Stanford Linear Accelerator Project covering the period July 1, 1969 to September 30, 1969 is presented. Topics included are accelerator and research area operations, accelerator and research area equipment development, and physics research equipment development.

Previous reports in this series of Quarterly Status Reports:

SLAC-1,	1 April - 30 June 1962.
SLAC-8,	1 July - 30 September 1962.
SLAC-10,	1 October - 30 December 1962.
SLAC-16,	1 January - 31 March 1963.
SLAC-18,	1 April - 30 June 1963.
SLAC-23,	1 July - 30 September 1963.
SLAC-27,	1 October - 31 December 1963.
SLAC-30,	1 January - 31 March 1964.
SLAC-32,	1 April - 30 June 1964.
SLAC-34,	1 July - 30 September 1964.
SLAC-42,	1 October - 31 December 1964.
SLAC-45,	1 January - 31 March 1965.
SLAC-48,	1 April - 30 June 1965.
SLAC-53,	1 July - 30 September 1965.
SLAC-59,	1 October - 31 December 1965.
SLAC-65,	1 January - 31 March 1966.
SLAC-69,	1 April - 30 June 1969.
SLAC-71,	1 July - 30 September 1966.
SLAC-73,	1 October - 31 December 1966.
SLAC-80,	1 January - 30 June 1967.
SLAC-85,	1 July - 30 September 1967.
SLAC-87,	1 October - 31 December 1967.
SLAC-89,	1 January - 31 March 1968.
SLAC-90,	1 April - 30 June 1968.
SLAC-93,	1 July - 30 September 1968.
SLAC-98,	1 October - 31 December 1968.
SLAC-105,	1 January - 31 March 1969.
SLAC-110,	1 April - 30 June 1969.

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INTRODUCTION

This is the twenty-ninth Quarterly Status Report of work under AEC Contract AT(04-3)-400 and the twenty-third Quarterly Status Report of work under AEC Contract AT(04-3)-515, both held by Stanford University. The period covered by this report is from July 1, 1969 to September 30, 1969. Contract AT(04-3)-400 provides for the construction of the Stanford Linear Accelerator Center (SLAC), a laboratory that has as its chief instrument a two-mile-long electron accelerator. Construction of the Center began in July 1962. The principal beam parameters of the accelerator in its initial operating phase are a maximum beam energy of 20 GeV, and an average beam current of 30 microamperes (at 10% beam loading). The electron beam was first activated in May 1966. On April 27, 1969, a beam energy of 21.5 GeV was achieved. Beam currents up to 70 milliamperes peak have been obtained.

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 is possible to perform certain exploratory studies, such as measurement of the intensity and energy distribution of various secondary-particle beams.

Contract AT(04-3)-515, which went into effect January 1, 1964, provided support for the various activities at SLAC that were necessary in order to prepare for the research program which is being carried out with the two-mile-accelerator, and also provides for the continuing operation of the Center after completion of construction. Among the principal activities covered in the scope of Contract AT(04-3)-515 are theoretical physics studies, experiments performed by the SLAC staff at other accelerators, research-equipment development programs (such as particle separators, specialized magnets, bubble chambers, etc.), and research into advanced accelerator technology.

I. ACCELERATOR OPERATIONS

A. Operating Hours

Manned Hours	July	Aug.	Sept.	Quarter
Physics Beam Hours[1]				
Machine Physics	23	30	18	71
Particle Physics	341	182	8	531
Total Physics Beam Hours	364	212	26	602
Non-Physics Hours				
Scheduled Downtime	16	16	32	64
Unscheduled Downtime Due to Equipment Failure	25	29	8	62
All Other (machine Tune-Up, etc.)	43	23	14	80
Total Non-Physics Hours	84	68	54	206
TOTAL MANNED HOURS	448	280	80	808

B. Experimental Hours[2]

1. Particle Physics

(3) Beam Line	Sched. Hrs. Electronic Experiments (a)	Electronic Experimental Hrs.		% $\left(\frac{b}{a}\right)$	Actual Bubble Chamber Hours	Actual Test And Check-Out Hours	Total Experimental Hours	
		Actual Hours (b)	(4) Charged Hours				Actual Hours	Charged Hours
A	479	261	203	54.5	---	4	265	207
B_N	---	---	---	---	---	263	263	263
B_C	---	---	---	---	119	14	133	133
B_S	590	489	512	82.9	---	12	501	524
C	4	4	6	100.0	220	395	619	621
Total	1,073	754	721	70.3	339	688	1,781	1,748
2. Machine Physics							73	73
TOTAL EXPERIMENTAL HOURS							1,854	1,821

(1) Number of hours accelerator is run with one or more beams excluding accelerator beam tune-up and other non-physics beam time.

(2) Number of hours an experiment is run including actual beam hours and beam downtime "normal to the experiment."

(3) Refer to Fig. 1 for beam line location.

(4) Total number of experimental hours actually run multiplied by factor (F), where $F = \frac{\text{Average repetition rate}}{180 \text{ pps}}$ (F maximum = 1.5 even if calculated amount exceeds this value). This product represents the hours charged to the experiment.

C. Overall Experimental Program Status

1. Electronic Experiments

Approved research hours at beginning of quarter	3,065
Hours charged during the quarter	721
New hours approved during the quarter	1,762
Approved hours remaining at end of quarter	4,106

2. Bubble Chamber Experiments

	40" BC	82" BC
Approved pictures at beginning of quarter	920 K	1,658 K
Pictures taken during the quarter	264 K	501 K
New pictures approved during the quarter	300 K	393 K
Approved pictures remaining at end of quarter	956 K	1,550 K

D. Beam Intensity

	July	August	September	Quarter
Peak	30 mA	25 mA	5 mA	30 mA
Average	2.8 μA	2.3 μA	1.5 μA	2.2 μA

E. Klystron Experience

	July	August	September	Quarter
Total Klystron Hours	104,964	62,551	12,295	179,810
Number of Klystron Failures	1	3	3	7

F. Data Analysis

	July	August	September	Quarter
Spark Chamber Events Measured	19,325	24,156	30,796	74,277
Bubble Chamber Events Measured	7,149	8,936	15,206	31,291

G. Computer Operations

Manned Hours

	July	August	September	Quarter
Computation Hours				
SLAC Facility Group	92	112	109	313
User Group	431	411	412	1,254
Total Computation Hours	523	523	521	1,567
Non-Computation Hours				
Scheduled Maintenance	92	87	105	284
Scheduled Modifications	19	13	32	64
Unscheduled Downtime and Reruns	29	43	6	78
Idle Time	2	1	27	30
Utility Failure	1	2	--	3
Total Non-Computation Hours	143	146	170	459
TOTAL MANNED HOURS	666	669	691	2,026

H. <u>Special Operating Features</u>

1. Positrons

Using the fixed "wheel" as a source, interlaced positrons and electrons were delivered for 10 hours of check-out and 124 hours of experimental use during July. The positron run originally scheduled for September was postponed until October because of problems with the 40" bubble chamber.

2. Beam Knockout

The beam knockout was used for a total of 520 hours during the quarter, including 9 hours of check-out. It was operated at both 10 and 40 MHz.

3. Power Supplies

The 3.4 MW power supply was run for 738 hours with the 54" spark chamber, 149 hours with the 2-meter spark chamber, and 10 hours with a test load for a total of 897 hours during the quarter.

The 5.8 MW power supply was run for 364 hours with the 54" spark chamber, 156 hours with the 2-meter spark chamber, and 20 hours for magnetic measurement for a total of 540 hours during the quarter.

The motor generator facility was run for 185 hours with the 54" spark chamber, 159 hours with the 40" bubble chamber, and 67 hours for magnetic measurements for a total of 411 hours during the quarter.

4. During July the accelerator was run for a three-week cycle and during August for a two-week cycle. A four-week cycle was scheduled to start September 16, but because of faults in the 40" bubble chamber and some delay in preparation of other experiments it was decided to postpone the run until October. A few shifts of machine physics experiments and hot maintenance were conducted before the machine was shut off for two weeks.

II. RESEARCH AREA OPERATIONS AND DEVELOPMENT

A. General Beam Switchyard and Research Area Developments

Primary activity in Research Area and BSY during the period consisted of support of scheduled experiments, preparation for future experiments, and maintenance. Many changes in experimental setups were made. (1) Equipment installation for E-44* was completed during July, including the earthquake protection of the concrete cave. (2) Installation work on the K_0 beam through End Station C was completed in July. This beam will be used in conjunction with the streamer chamber facility for Experiment E-48. (3) The E-38 muon experiment was completed in July and the experimental equipment was dismantled and sent back to the University of Washington. (4) Beam path 2† in End Station B was changed over in preparation for BC-10. (5) A test beam (beam path 13) for E-48 was completed in August. (6) Change in beam line 1 from a μ-beam line to a π-beam for E-40 was begun, including removal of cosmic ray experimental equipment in Building 109 and preparation of magnet and area around magnet. (7) Beam line 2 was changed back to an annihilation beam line for BC-6, 18, and 19. (8) The laser beam was re-established up to a point in front of the 82" hydrogen bubble chamber. (9) Buildup of collimators and shielding for the E-48 beam line continued. (10) Hofstadter's parasite experiment was removed from End Station B. (11) Beam path 1 was converted from a muon beam to a pion beam. This beam is required for Experiment E-40 which will study the production of ρ mesons, f^o mesons, and nucleon isobars by pions. The setup required extensive modification of equipment in the B Target Room and modification of the secondary beam path to accomplish the proper arrangement to deliver and control the pion beam to the experiment. A preliminary beam check of the arrangement during the brief period of accelerator operations in September indicated that the new arrangements operated satisfactorily.

B. Power Supply Group Activities

Delivery of the 5.0 MW power supply was further delayed. An insulation failure during retesting of the rebuilt transformer in July required repair of one of the three transformer coils. It was repaired without the necessity of rewinding,

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*See Table I for Titles of Experiments.

†See Fig. 3 for beam path numbers.

and passed all tests. A twenty-four-hour acceptance test was conducted in September. Except for some minor problems the supply is satisfactory. With this unit there are now four large (greater than 3 megawatts) power supplies available for use by experimenters in the Research Area.

The 3.0 MW motor-generator set also required major repair in July. Wedges that retain the stator windings in one of the motors had to be replaced. A similar repair was done on the other motor about a year ago.

The six new 400 kW power supplies delivered in May were found to be unacceptable because of excessive heating of the transformer and choke. Rewinding of the defective units was necessary; power supply tests should resume in October. Tests of the prototype of a new regulator intended for use with the new 400 kW power supplies have been completed. Eight such new regulators will be built at SLAC over the next three months.

A variety of modifications to upgrade the pulsed switching supplies are being tested or designed. These included the addition of remotely operated reversing switches, the addition of variable autotransformers, the addition of another charging tube to operate in parallel with the existing one, and improvement of the regulator. The work is being done whenever the operating schedule makes this equipment accessible.

C. Liquid Hydrogen Target Group Activities

The target for E-44 was installed and operated during August. The E-41 target reservoir, scattering chamber, and vacuum system have been checked out with liquid nitrogen in the reservoir and flask. The Norelco cryogenerator was tested with a dummy heat load consisting of 150 pounds of lead. It passed the 50 watts at $20^{O}K$ requirement. The mounting frame for the cryogenerator and the target were prepared for mounting the target assembly. The flexible transfer lines to carry the $20^{O}K$ helium from the cryogenerator to the target were installed and found leaky. Testing was attempted the week of 25 August. In spite of the poor vacuum caused by the porous hose, the refrigerator cooled the target to $21^{O}K$ and condensed some hydrogen in the reservoir. Because the refrigeration capacity at that vacuum level is not adequate, the target is being installed to operate as a direct fill liquid hydrogen target until fabrication of a better transfer line is complete. The target is ready for installation and alignment.

The hardware for Experiment E-40 for the B beam was being tested. The scattering chamber for the experiment has more than the usual number of conflicting requirements so it may require some changes after testing.

D. Spectrometer and Bubble Chamber Operations and Developments

1. Spectrometers

Four new carriages were planned for experiments in End Station A. Three carriages required by Group F in experiments E-21c and E-50 which are, respectively, measuring photoproduction of π^0, η, ρ^0, ω, and ϕ mesons and Compton scattering at high energies, were completed and are ready for installation of experimental equipment. Initial construction was started on a large shielding carriage for Group G to be used in their experiment E-42 on photon-proton scattering at forward angles.

2. Bubble Chambers

The 82" chamber took about 220,000 pictures for BC-14 and 279,000 pictures for BC-15 with 1,367,685 expansions. A new 35 mm camera was used and considerable difficulty was experienced.

Changes in the camera system have been completed and testing is about to begin. The MIT counter system is now being tested at MIT and will be re-installed in the chamber in October.

As part of a program to reduce vibration damage to certain parts of the chamber during pulsing, extensive modifications are being made to the chamber expansion system and the chamber mounting system. A new vacuum tank beam window is being installed as part of these modifications.

The 40" chamber operated on hydrogen for BC-10 in August. The chamber was expanded 572,776 times and produced 263,901 pictures. A filter circuit was tested in the refrigeration system and proved satisfactory. Valve plugging which has plagued this chamber in the past was non-existent with this filter. The chamber was warmed up at the end of August to install a permanent filter system.

In September the chamber cooled down with deuterium for obtaining pictures of γ-d reactions for Experiments BC-6, -18, and -19. The new multilayer Scotchlite, which was installed for these runs, separated during the early period of test pulsing and it was decided to warm up and install a single layer Scotchlite. As of September 30, the chamber is filled with deuterium and is ready for the October experimental cycle.

E. Storage Ring Project - SPEAR

Design activity on SPEAR (Stanford Positron-Electron Asymmetric Rings) increased greatly. A comprehensive review of the project cost estimate and time schedule was made and the results are reported in the "SPEAR Design Report," issued in August.

F. Description and Status of Approved Experiments

Figure 1 is a Research Area plan drawing showing the location of the various experiments. Table I is a list of presently approved high energy physics experiments. The right-hand column of Table I gives the status and activity of each experiment during the period. The prime users of the accelerator during the period were: E-29, E-38, N-5, E-41, BC-14, E-44, BC-10, E-53, and BC-15.

During the 5-6 August 1969 meeting of the Program Advisory Committee, Experiments E-49a, E-49b, E-52, E-55 (check-out only), and BC-28 were approved. and BC-6 and BC-19 were granted extensions.

Figure 2 gives the most recent Tentative Long Range Schedule.

1. Status of Running Experiments

E-29 — Search for T-Violation in Inelastic e-p Scattering

This experiment ran in End Station A for about four cycles; the data taking is now completed. The experiment consists of scattering electrons inelastically from a polarized proton target made of butanol alcohol. The free proton content of the target is approximately 14% and can be polarized to a maximum value of 38%. The scattered electron is detected and its momentum is measured using the 20 GeV/c magnetic spectrometer facilities. In the one-photon approximation, any difference in the rate of scattering when the sense of the target polarization normal to the scattering plane is reversed would be evidence for T-violation of hadrons in electromagnetic interactions.

Approximately four to six hours per day were used for replacing and/or annealing the target to repair the radiation damages. Good electron or positron scattering events were observed at the rate of 4 to 5 $\times 10^6$ events/day. Also, approximately 10^6 events were taken daily for calibration purposes using a carbon or a CH_2 target.

During the cycles data were taken for the incident energies of 18, 15, and 12 GeV. Measurements were made at q^2 equal to 0.3, 0.4, 0.6, and 1.0 $(GeV/c)^2$ for missing mass values of 0.94, 1.236, 1.512, 1.688, and 2.0 GeV.

Within the accuracy of the experiment, no indication of a violation of time-reversal invariance in the electromagnetic interaction was found but the results will provide a new lower limit to the size of any violation over a range of four-momentum transfer from 0.4 to 1.0 $(\mathrm{GeV}/c)^2$ for missing mass values up to about 2.0 GeV. Also with the positron data taken at 0.4 $(\mathrm{GeV}/c)^2$ four-momentum transfer earlier, it may be possible to comment on the magnitude of the two-photon effect.

E-38 — $\mu^+ e^-$ Scattering

Experiment E-38 completed the measurement of the $\mu^+ e^-$ elastic scattering cross section. Most of the data were taken in June. Although the data showed general agreement with the cross section predicted by quantum electrodynamics, there were certain aspects of the data which were not understood. The experiments performed in July helped answer some of these questions, and the results will be valuable in the detailed analysis of the cross section measurement.

E-41 — Rho Production by π^- Mesons

The early phase of this experiment is directed toward finding out whether $\pi^{\pm}$ photoproduction experiments which yield anomalous results in the forward direction can be related to the production of rho mesons by π^- mesons via vector dominance calculations.

Check-out continued on the π^- beam for this experiment. The pulsed magnet, septum magnets, and the other standard components of the beam are operating satisfactorily. The building that houses the experiment has been erected and the main analyzing magnet installed. Work is proceeding on installation of the spark chambers and hodoscopes, and the very large Cerenkov counter was completed.

Preliminary studies on the beam optics with the beam hodoscopes which measure the momentum, the vertical and horizontal angles, and positions of individual particles indicate that the beam performance is as calculated by TRANSPORT runs.

E-44 — Coherent Regeneration from Hydrogen

This experiment was designed to measure the regeneration phase and amplitude of K_2^o's on liquid hydrogen. These parameters are important in the phenomenology of K^o physics. It has now been completed. The experiment detected π^+-π^- pairs originating in the decay volume using the wire spark chamber spectrometer.

The spectrometer system consisted of six 1-meter-by-1-meter wire spark chambers followed by the 72-D-36 magnet set to a field of 10 kg-m. This was followed by five 1-meter-by-2-meter wire spark chambers. A shower counter bank and a muon-counter bank were located behind the hodoscope. These were used for electron and muon identification in order to tag the leptonic decays of the K_2^{0}'s. Data were routed through digitizers and interfacing to the on-line IBM 1800 computer using the modified MIDAS software package. Data were stored on tape and a partial analysis of the data was made on-line in order to monitor the progress of the experiment.

During the July cycle 600,000 events were measured with target full and 400,000 events with target empty. An anti-counter had been placed at the downstream end of the 40"-long LH_2 target.

During the August cycle, the anti-counter was placed at the upstream end of the target and π^+-π^- pairs from decays originating in the target as well as the original decay volume were measured. The trigger rate in this configuration was three times higher. During this short cycle at 16 GeV we measured 627,000 events with the target full and 452,000 events with the target empty. Some data were collected at 19 GeV. These consisted of 155,000 events and 79,000 events with the target full and empty, respectively.

The August data should yield approximately 2,000 decays in the π^+-π^- mode with target full and 700 with target empty. Similar numbers apply to the July data.

The analysis for these data is being performed at Johns Hopkins University and UCLA. The computer programming necessary for such analysis has been used for a previous experiment (E-32) and requires relatively small modifications to be adapted to these new data.

E-53 — Survey of Photon and π^0 Yields

E-53 used about five shifts of 20 pps time in the C beam on August 9th and 10th to compare five shower counter designs for the experimental run in December, and to test a light pulser calibration system. Starting from the shower counter design for E-37, an attempt is being made to improve energy resolution, to enlarge the area of uniform response (this will probably determine the data rate), and to measure the energy linearity. It was hoped to test the final design; however, due to time limitations this will have to be done later. In addition, the five actual counters to be used in the experiment must be checked out and calibrated with the light pulser, since calibration during the experiment will be difficult or impossible.

BC-10 — K_2^0P Interactions with 40" Bubble Chamber

263,901 pictures were taken for BC-10 in August. Further running time is scheduled.

BC-14 — 7.5 and 13 GeV/c π^+-π^- Exposures in the 82" Bubble Chamber

220,000 pictures were taken for BC-14. This completes the run.

BC-15 — Exposure of Deuterium-Filled 82" Bubble Chamber to a 7 GeV/c π^- Beam

BC-15 completed its run in July. 278,000 pictures were taken.

N-5 — Sodium Iodide Counter Test (C Beam)

There is interest in the feasibility of operating large volume total absorption crystal spectrometers in the environment encountered in electron scattering experiments at SLAC. A shielded enclosure was installed in End Station A in a sector of the floor space between the 1.6 and 20 GeV spectrometers. On a purely parasitic basis tests were conducted during the accelerator cycle in July and August.

2. Summaries of Newly Approved Experiments

E-49a — Inelastic Scattering from D_2 and Other Nuclei

This experiment plans to use the 20 GeV spectrometer to obtain the momentum spectra of electrons inelastically scattered from D_2. Energies and angles will be matched to those for which e-p data has already been obtained. The object of the experiment is a comparison of the structure functions for the neutron with those of the proton.

A small amount of the new data on e-p scattering will be obtained to improve the knowledge of the behavior of the cross section for large energy losses and high q^2.

Measurements of the A-dependence of the scattering cross sections are planned to check the procedures for extraction of the neutron cross sections from D_2 and to test the theory of hadron dominance for e-m interactions.

E-49b — Inelastic Scattering from D_2 and Other Nuclei: Large Angles

This experiment plans to use the 8 GeV spectrometer to obtain the spectra of electrons scattered inelastically from D_2. Energies and angles will be matched to those for which e-p data has already been obtained. The object of the experiment is to complete the program of measurements begun in Experiment 49a to obtain a set of measurements of the structure form factors of the neutron.

The completed program will extend the measurements to values of q^2 near 20 $(GeV/c)^2$ and furnish information on the longitudinal and transverse electron cross sections.

Measurements of the A-dependence of the cross sections are planned to test the theory of hadron dominance in electromagnetic interactions.

E-52 — Determination of γ_ρ^2 and the Total N Cross Section from Coherent ρ-Photoproduction on Deuterium

This experiment plans to determine both the γ-ρ coupling constant and the total ρN cross sections from a measurement of the coherent ρ-production from the deuteron at t-values from -0.1 $(GeV/c)^2$ to -1.0 $(GeV/c)^2$. The experiment will be done by observing the recoil deuteron with the 1.6 GeV/c spectrometer as a function of missing mass.

The cross section for the reaction $\gamma + d \rightarrow \rho + d$ will in the Glauber approximation mainly be determined by the single scattering terms as $t \rightarrow 0$. Since the deuteron is an isoscalar, only the isovector part of the photon can contribute. Using the vector dominance model (VDM) and the optical theorem, the parameters determined at low t-values are σ_T^2/γ_ρ^2, where σ_T is the total ρN cross section. At large t-values $\left(|t| \geq .6\ (GeV/c)^2\right)$ the second scattering terms, which are independent of the form factor, dominate. Thus, at high t-values the parameters determined are σ_T^4/γ_p^2.

It is therefore obvious that a measurement of coherent photoproduction of ρ's on the deuteron is independently able to provide a determination of γ_ρ^2 as well as of σ_T. It should be noted that in the case of elastic πd scattering there is a good agreement between the measured cross section and a Glauber-type calculation using realistic wave functions for the deuteron as well as realistic single particle scattering amplitudes.

A small fraction of the running time is planned to make a quick survey of the reactions $\gamma + d \rightarrow \pi^0 + d$, $\gamma + d \rightarrow \eta + d$, $\gamma + d \rightarrow \phi + d$. A measurement of these cross sections on deuterium together with earlier measurements of the same processes on hydrogen will enable a separation of the isovector and isoscalar part of the amplitude.

E-55 — Study of Dalitz Plot for the Decay $K_L^0 \rightarrow \pi^+\pi^-\pi^0$

The aim of this experiment is to study the Dalitz plot distribution of the decay products of the reaction $K_L^0 \rightarrow \pi^+\pi^-\pi^0$ and to compare its Dalitz distribution to that of the decay $K^+ \longrightarrow \pi^+\pi^+\pi^-$ in order to search for the presence of I=2 final states in the latter reaction. There is strong evidence for a $\Delta I \neq 1/2$ amplitudes in the K decays, from the relative decay rates for the various modes. In the first reaction, however, the I=2 final state is forbidden, or strongly suppressed by CP "conservation," and consequently it acts as a "monitor" for the latter reaction.

The aim is to get $\sim 10^6$ events which is comparable to the number which will be obtained for the K^+ decay in an experiment currently being run at the AGS. The spectrometer system presently being built by Group G for use in the neutral K beam will be used with a bank of lead glass Cerenkov counters to detect the γ rays from the π^0.

BC-28 — A Proposal for a 5 GeV/c π^+p Experiment in the SLAC 82-Inch HBC

For this experiment, it is proposed to take 500,000 π^+p pictures at 5 GeV/c in the SLAC 82-inch HBC. Up to $\sim$800,000 interactions are expected ($\sim$30 events per μb) including $\sim$120,000 boson resonances and $\sim$100,000 quasi-two-body final state events (excluding elastic scattering). Five GeV/c is sufficiently high energy so that reactions could simply be described in terms of t-channel exchanges and information concerning boson spectra up to $\sim$2 GeV could be obtained. On the other hand, it is low enough so that the cross sections for quasi-two-body reactions are still large and a good mass resolution is possible. In the present high statistics experiment the properties of resonances and the mechanisms of the quasi-two-body reactions will be investigated. It is anticipated that the relatively known processes will be learned in much more detail, and rarer reactions and resonances will be observed. The goals of this experiment include: (i) A detailed study of the boson mass spectrum between 1-2 GeV in an attempt to discover unknown resonances (like the I=0 members of the 1^+ nonets) and to determine the spin-parity of known resonances, when in doubt, like the g meson, the $\rho(1720)$ and the $\rho(1900)$. (ii) An investigation of the production mechanism, fine structure of $d\sigma/dt$ and decay correlations of many quasi-two-body reactions (i.e., Δ^{++} with ρ^0, ω^0, π^0, and A_2^0. The last two reactions are pure ρ-exchange). (iii) A study of the possible splitting of the 2^+ nonet and its decays in the rare modes (between 150-300 $A_2 \longrightarrow (K\bar{K})$ events are expected). (iv) An investigation of the diffractive reactions, hoping to test the Pomeron trajectory factorization.

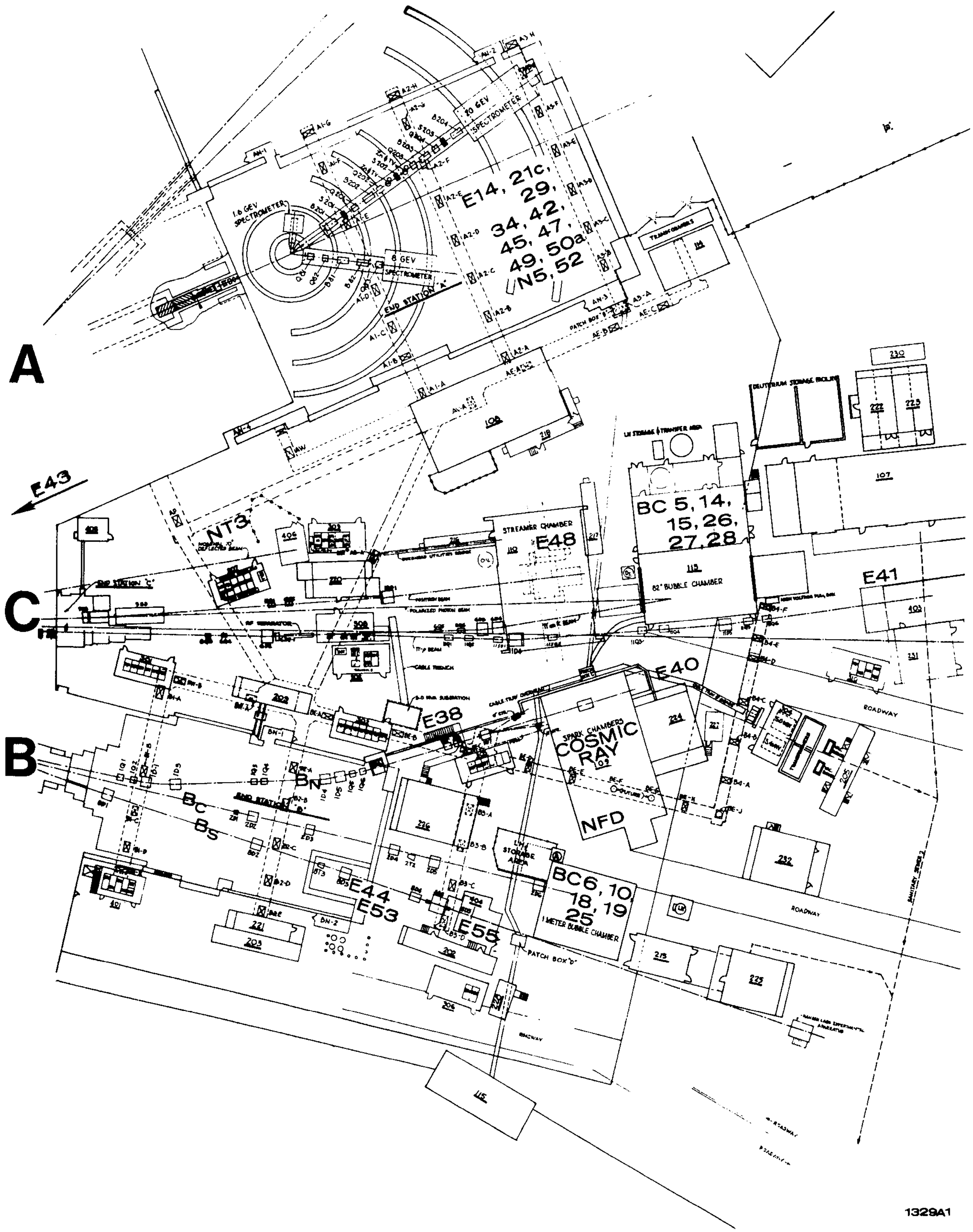

FIG. 1--Experiment locations.

TABLE I

TABLE OF PROGRAMMED EXPERIMENTS

Number	Title	Authors	Date Approved	Status
E-14	Proposal for Testing of Quantum Electrodynamics by Photoproduction of Asymmetric Muon Pairs	STANFORD (Group A) W. Panofsky, D. H. Coward H. DeStaebler, J. Litt, A. Minten, L. W. Mo, R. E. Taylor MIT J. I. Friedman, H. W. Kendall, L. VanSpeybroeck	11/18/66	d
E-21c	Proposal for Measurements on the Photoproduction of π^0, η, ρ^0, ω and ϕ Mesons at Small Momentum Transfer t and Photon Energies Up to 18 GeV and a Search for Mesons of Other Masses	STANFORD R. Anderson, D. Gustavson, J. Johnson, R. Prepost, D. Ritson N. E. UNIV. R. Weinstein, M. Gettner CAL TECH R. L. Walker, G. Jones, D. Kreinick, A. V. Tollestrup	3/11/67	d
E-29	Search for T-Violation in Inelastic e-p Scattering	U. C. BERKELEY O. Chamberlain, G. Shapiro, H. Steiner, H. Weisberg, C. Morehouse, T. Powell, P. Robrish, S. Rock, S. Shannon STANFORD R. Taylor, L. Mo, E. Bloom, J. Litt MIT H. Kendall, J. Friedman	12/16/67	a, h
E-34	Electron-Deuteron Quasi-Elastic Scattering	STANFORD E. Bloom, D. Coward, H. DeStaebler, J. Drees, J. Litt, R. E. Taylor MIT J. Friedman, G. C. Hartmann, H. W. Kendall CAL TECH B. C. Barish	7/2/68	d
E-38	Proposal to Stanford Linear Accelerator Center for an Experiment on μ^+e^- Scattering	UNIV. OF WASHINGTON S. Neddermeyer, N. Scribner, P. Kotzer, G. Eilenberg, T. Koss	8/5/68	b, h

Table of Programmed Experiments (cont'd) - 2

Number	Title	Authors	Date Approved	Status
E-40	High Statistics Study of the Production of Charged $\rho^{\pm}$ Mesons, Neutral ρ^{0} Mesons, f^{0} Mesons and Nucleon Isobars by Pions	SLAC J. Cox, B. Dieterle, W. Kaune, M. Perl, J. Pratt, J. Tenenbaum, W. Toner, T. Zipf	8/5/68	c
E-41	Rho Production by Pions — A Test of Vector Dominance	SLAC F. Bulos, W. Busza, G. Fischer, E. Kluge, R. R. Larsen, D. W. G. S. Leith, B. Richter, H. Williams IBM M. Beniston	8/5/68	c, b
E-42	Photon-Proton Scattering at Forward Angles	SLAC A. Boyarski, F. Bulos W. Busza, R. Diebold, S. Ecklund G. Fischer, H. Lynch, B. Richter	3/22/69	d
E-43	Velocity of Light Experiment	UCSD G. Masek	12/14/68	a, b, c
E-44	Coherent Regeneration from Hydrogen	UCLA D. Drickey, H. Ticho D. Stork, C. Buchanan, D. Rudnick, P. Shephard SLAC E. Dally, E. Seppi JOHNS HOPKINS L. Ettlinger R. Zdanis CERN P. Innocenti	2/8/69	a, b, c, h
E-45	Proposal for the Measurement of π^{+} Photoproduction with Polarized Photons at SLAC	MIT D. Luckey, L. S. Osborne, R. Schwitters SLAC A. Boyarski, R. Diebold, S. Ecklund, B. Richter	12/14/68	d
E-47	π^{+} Photoproduction with a Polarized Target	LRL O. Chamberlain, C. Morehouse, T. Powell P. Robrish, S. Rock, S. Shannon, G. Shapiro, H. Weidsberg SLAC A. Boyarski, R. Diebold, S. Ecklund, Y. Murata, B. Richter	2/8/69	d

Table of Programmed Experiments (cont'd) - 3

Number	Title	Authors	Date Approved	Status
E-48	Proposal to Measure the ξ Parameter in the Decay $K_L^0 \longrightarrow \pi\mu\nu$	BNL D. Hill, R. Palmer, M. Sakitt, N. Samios SLAC D. Fries, F. Liu, R. Mozley, A. Odian, J. Park, W. Swanson, F. Villa	2/8/69	c
E-49a	Inelastic Electron Scattering From D_2 and Other Nuclei	SLAC E. Bloom, L. Cottrell, D. Coward, H. DeStaebler, C. Jordan, R. E. Taylor MIT J. Elias, J. I. Friedman, H. W. Kendall, M. Sogard, K. Tsipis, M. Breidenbach, R. Verdier	2/8/69	d
E-49b	Inelastic Scattering From D_2 and Other Nuclei: Large Angles	SLAC D. Coward MIT J. Elias, J. I. Friedman, H. W. Kendall, M. Sogard, K. Tsipis, M. Breidenbach, R. Verdier	8/6/69	d
E-50a	Compton Scattering at High Energies From Hydrogen	SLAC R. Anderson, D. Gustavson, J. Johnson, I. Overman, D. Ritson, B. Wiik HARVARD UNIV. J. Walker NORTHEASTERN UNIV. R. Weinstein	3/22/69	d
E-52	Determination of γ_ρ^2 and the Total ρN Cross Section From Coherent ρ-Photo-production on Deuterium	SLAC R. Anderson, D. Gustavson, J. Johnson, I. Overman, B. H. Wiik NORTHEASTERN UNIV. R. Weinstein	8/6/69	d
E-53	Survey of Photon and π^0 Yields	U. C. SANTA BARBARA D. Caldwell, V. Elings, D. Fancher, A. Greenber, G. Jahn, A. Kaushal, B. Kendall, R. Morrison, F. Murphy, S. Tyler, B. Worster	6/11/69	b

Table of Programmed Experiments (cont'd) - 4

Number	Title	Authors	Date Approved	Status
E-55	Study of Dalitz Plot for the Decay $K_L^o \longrightarrow \pi^+\pi^-\pi^o$	SLAC H. Saal U.C. SANTA CRUZ D. Dorfan UNIV. COLORADO U. Nauenberg	8/6/69*	d
BC-6	Proposal to SLAC for Study of the One Pion Exchange Contribution to γ-Nucleon Scattering (in 40-Inch Deuterium Bubble Chamber)	OAK RIDGE H.O. Chon, R.D. McCulloch UNIV. OF TENNESSEE G.T. Condo, W.M. Bugg	9/28/68	d
BC-10	A Proposal to Investigate K_2^op Interactions with the 40-Inch HBC	STANFORD B.C. Shen, D.W.G.S. Leith, A.D. Brody W.B. Johnson, R.R. Larsen, G.A. Loew, R. Miller, W.M. Smart	5/11/68	a, c
BC-14	Proposal for 7.5 and 13 GeV/c, π^+ and π^- Exposures in the SLAC 82" HBC	MIT P.L. Bastien, D. Brick, T. Dao, B.T. Feld, R.I. Hulsizer, L. Kirkpatrick, V. Kistiadowsky, H. Lubatti, D. Miller, A. Nakkasyan, G. Ouannes, I. Pless, A. Sheng, T. Watts, F. Winkelmann, J. Wolfson, R. Yamamoto	8/5/68	a
BC-15	Proposal for an Exposure of the 82-Inch Deuterium-Filled Bubble Chamber to a 7 GeV/c π^- Beam at SLAC	UNIV. OF ROCHESTER T. Ferbel, W. Katz, P. Slattery, S. Stone, H. Yuta	9/28/68	a, h
BC-18	A Proposal for a 4.25 GeV γ-Deuterium Experiment in the SLAC 40" Bubble Chamber	WEIZMANN INSTITUTE Y. Eisenberg, B. Haber, U. Karshon, L. Lyons, E.E. Ronat, A. Shapira, G. Yekutieli	9/28/68	d
BC-19	A Proposal for a γ-d Experiment with an Annihilation Beam of 7.5 GeV in the SLAC 40" Bubble Chamber	TEL AVIV UNIV. G. Alexander, I. Bar-Nir, A. Brandstetter, S. Dagan, J. Gunhaus, A. Levy Y. Oren	9/28/68	d

Table of Programmed Experiments (cont'd) - 5

Number	Title	Authors	Date Approved	Status
BC-25	Proposal to Study Pomeranchon, Meson and Baryon Exchanges by Triggering the SLAC 40" Bubble Chamber on Fast Forward Particles	CAL TECH B. Barish, W. Ford, R. Gomez, C. Peck, J. Pine, F. Sciulli, B. Sherwood, A. Tollestrup, G. Zweig	6/18/69	d
BC-26	Determination of Quantum Numbers for Resonances in the R, S, T, and U Region Using $\pi^+ + d$ Interactions at 12 BeV	DUKE UNIV. M. Binkley, D. Carpenter, L. Fortney, C. Rose, E. Fowler, J. Elliot, J. Golson, V. Joshi, J. Kronenfeld, T. Snow, W. Yeager	6/11/69	d
BC-27	Study of the "A_2" Problem and Other Members of the $J^P = 2^+$ Nonent	BROOKHAVEN NAT. LAB. D. Crennell, U. Karshon, K. Lai, R. Kinsey, J. O'Neall, W. Sims, J. Scarr	6/11/69	d
BC-28	Proposal for a 5 GeV/c $\pi^+ p$ Experiment in the SLAC 82-Inch HBC	WEIZMANN INSTITUTE OF SCIENCE Y. Eisenber, B. Haber, U. Karshon, E. Ronat, A. Shapira, G. Yekutieli	8/6/69	d
NT-3	Fast Cycling Bubble Chamber Development	SLAC H. Barney, R. Blumberg, A. Rogers, S. St. Lorant	12/15/68	c, g
N-5	Sodium Iodide Counter Test	HEPL R. Hofstadter, E. B. Hughes	6/2/69	c, g, h
NFD	A Proposed Study of High Energy, Cosmic Ray Muons at Sea Level	U. C. BERKELEY S. M. Flatté, M. L. Stevenson SLAC W. Toner, T. Zipf	8/23/68	j, h
D-9	Magnetic Bremsstrahlung	ILLINOIS INSTITUTE OF TECH T. Erber, F. Herlach, H. G. Latel	2/8/69	d

Table of Programmed Experiments (cont'd) - 6

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a. Experiment is in data collection phase and was a prime user of accelerator time during the period.
b. Experiment is in check-out phase and used accelerator time for check-out purposes.
c. Experiment was being set up in the research yard during the period.
d. Experiment was inactive in the research yard during the period.
e. Bubble chamber beam is under construction and check-out.
f. Experiment ready for future scheduled run.
g. Used parasite beam time during the period.
h. Experiment completed.
i. Special test run performed.
j. In data collection phase — did not use accelerator beam.
* Approved for check-out only.

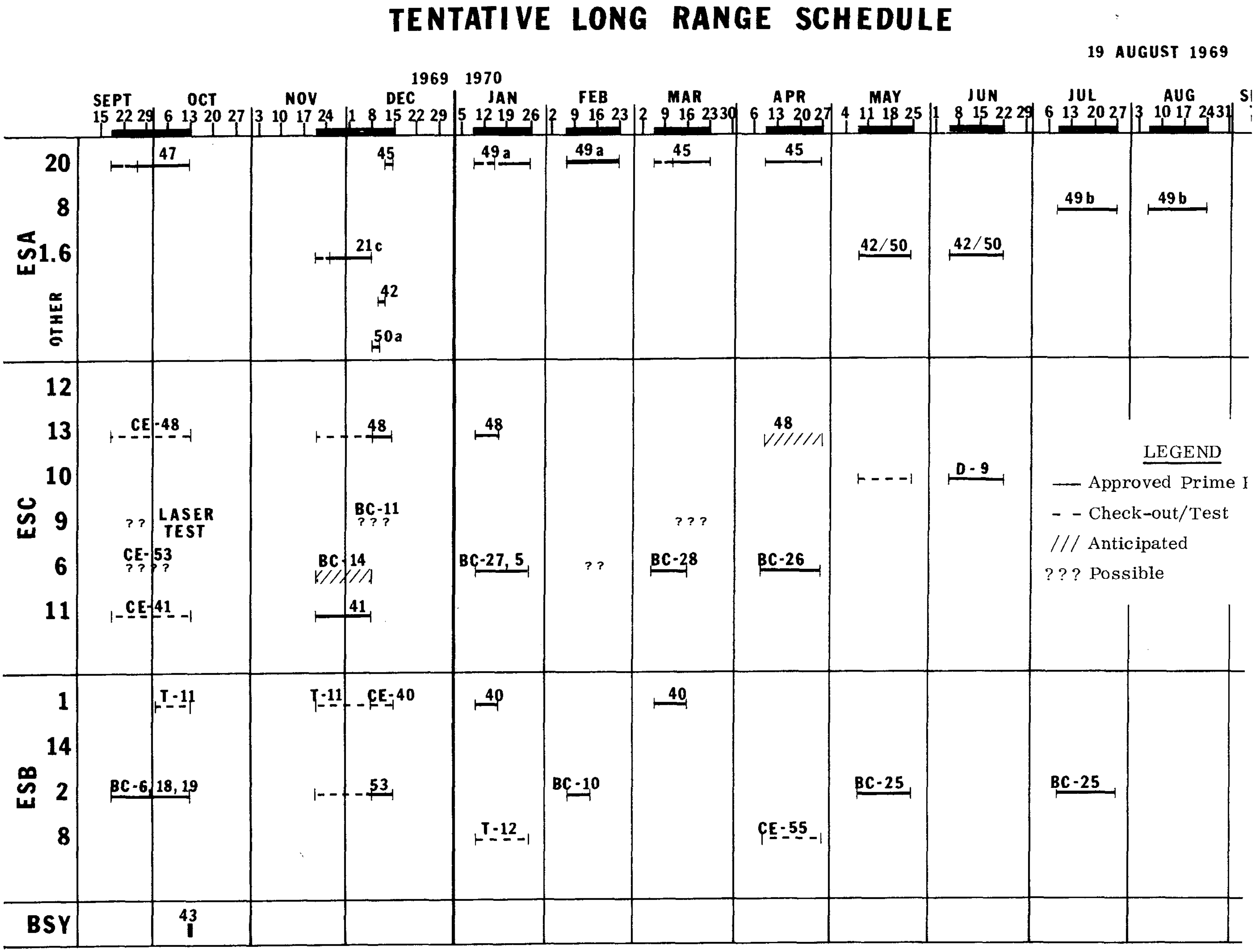

FIG. 2--Tentative long-range schedule.

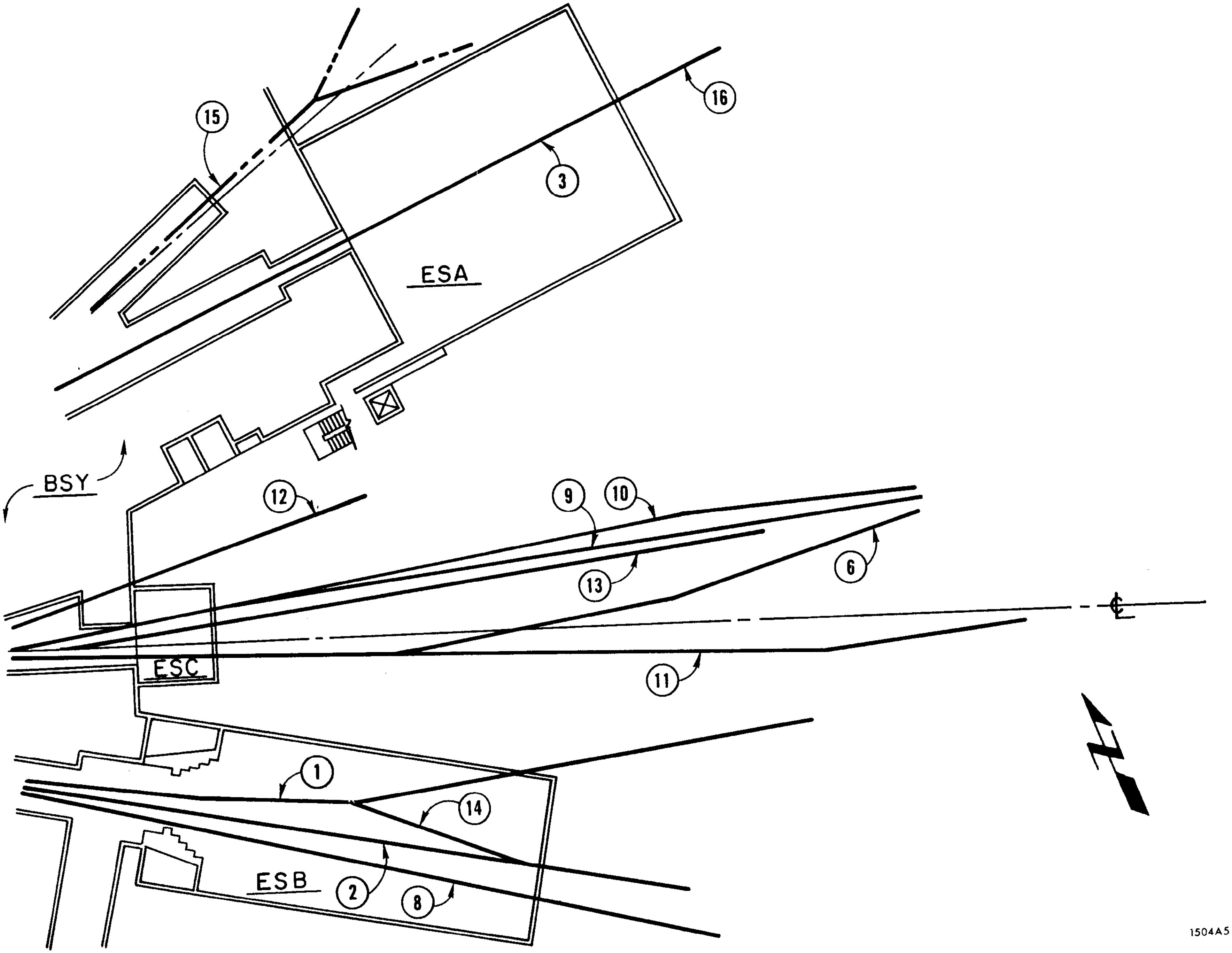

FIG. 3--Beam path identification plan.

III. ACCELERATOR IMPROVEMENTS

Beam breakup studies were continued during the quarter. Tests were conducted in early July with a small cathode gun and later with a standard SLAC gun to determine if the beam breakup threshold is related to cathode diameter, but the results were inconclusive. Six additional sectors were blind tuned by 2 MHz during the quarter and one sector was blind tuned by 4 MHz. Tests made during September indicated that the beam breakup threshold had been increased to approximately 70 mA.

Installation of pulsed steering and focusing in four sectors continued during the quarter. Pulsed steering power supplies were installed in Sectors 10 and 28 to operate the existing dipoles and two more are available for later installation. The first pulsed quadrupole doublet has been installed in Sector 28 and the second will be installed in Sector 11 during the November shutdown. The other two doublets will be installed during subsequent shutdowns. One power supply has been installed and three more are being built and will be completed by the end of November.

The first phase of the off-axis injector, using a dc alpha magnet, will be installed during November. The magnet has been built and tested and the vacuum components and lenses are being built. The nominal entry angle is 75°, but the actual angle will be determined by a computer run. The existing gun modulator will be used for initial operation, but a new modulator is being built for later use.

Completion of the first phase will permit use of either the main injector or the off-axis injector, but not both simultaneously. By the later substitution of a pulsed alpha magnet for the dc magnet and the use of a new gun modulator, both injectors can be used simultaneously delivering interlaced beams on a pulse-to-pulse basis. Completion of the first phase will improve the reliability of the machine by providing a readily accessible back-up injector in case of failure of the main injector, and completion of the second phase will improve the operation of simultaneous beams with radically different intensities.

IV. RESEARCH DIVISION DEVELOPMENT

A. Applied Physics

Semiconductor Secondary Emitter

After rebuilding and bakeout of the GaAs measuring tube, 10^{-11} torr vacuum was obtained. The GaAs crystal (3×10^{19} Zn doped) was cleaved and treated with Cs and O_2 to form about 6 layers of CsO, with a surface layer of Cs. Absolute photoemission measurements indicated a quantum efficiency about half that of the best reported results of James at Stanford. Secondary emission measurements over the range of incident energies from 3 to 9 keV showed a nearly linear dependence of yield on energy with a measured yield of about 130 at 9 keV. Correcting for the factor 2 in quantum efficiency, and the longer secondary mean free path expected in 1×10^{19} Zn doped GaAs, gives an adjusted yield of 400 at 10 keV, which corresponds well with the theoretical prediction of 500 at 10 keV, made in SLAC-PUB-619. The design of a tube to measure the emission statistics from a practical GaAs surface, for 5- keV, 1- MeV and GeV electrons is nearly complete. Fabrication of components is underway. Use of CsI as a matching layer instead of Cs_2O is being studied, in hopes of providing more stable, practical emitters.

Glass Semiconductors

Several 3×3 array devices were fabricated and successfully switched on and off before blowing up. Most failures were traced to open-circuit conditions in metal overlayers, as a result of which we are now evaporating thicker contact strips.

Rf induction heating was successfully used to raise one ampule to $1100^{\circ}C$ while obtaining vigorous stirring of the molten solution due to the rf field.

Resistivity measurements have shown that a slow evaporation will deposit a low resistance glass, whereas a more rapid evaporation will deposit a high resistance layer. Moreover, resistance increased as a function of temperature in the first case and decreased in the second, suggesting the existence of metallic and semiconducting structures, respectively.

Several attempts have been made to produce additional material of Batch 202 formulation. This composition, used by Rockstad at Corning Glass Works, contains Si and Ge and is reported to have good switching properties.

Rf heating of this glass did not provide sufficient stirring as in the case of simpler mixtures. Moreover, after 45 hours heating in a furnace at $1200^{\circ}C$, it was found that the ampule had exploded (in a well-contained manner) and the glass mixture evaporated.

The explosions have been traced to the use of unnecessarily high furnace temperatures and long heating cycles. It was also determined that the duration of heating cycles could be reduced by improved stirring of the melt; the furnace was accordingly modified to also operate with a rocking motion.

The covered evaporation boat was replaced with a flash evaporator and a vibrator was built to supply it with powdered glass. Results have been encouraging but refinements are still necessary.

Two devices (021, 022) were fabricated to measure glass capacitance and resistance at different temperatures. A small vacuum system with heating and cooling facilities was built for these measurements.

B. Magnet Development

2-Meter Wire Chamber Magnet Model

The 3-dimensional field mapping, as well as modifications to improve field homogeneity, is being continued. Early in the quarter, the following stage had been reached: Deviation of $\int B\,d\ell$ from central value over the median plane $\approx 1\%$; over 80% of the total gap volume it $\approx 4.2\%$. Improving the homogeneity of $\int B\,d\ell$ further over the gap volume makes the homogeneity of $\int B\,d\ell$ over the median plane worse.

The first set of measurements, using cyclotron-type shimming, showed that with the present magnet model, further improvement beyond $\pm$ 2% over 80% of the gap volume would be extremely difficult.

It seems that the shimmed yokes must be replaced in order to make a complete field map and superconducting screens must be used to shape the field to 1%. The material for the iron return yoke has been ordered and we are expecting the iron sheets in November. In the meantime, drawings will be prepared and calculations made to start simultaneously the field-correcting effect and the superconducting screens.

Thermal Conductivity of Multicrystal Niobium

Measurements of the thermal conductivity of a niobium bar, diameter 0.75 in., length 9 in., have been made from 4.2^{o} to 1.7^{o}K, with an accuracy of better than 10^{-3}. The niobium bar was then annealed at 1800^{o}K in high vacuum of 10^{-8} mm or better, with programmed heating and cooling cycle. The conductivity measurements will be repeated in order to evaluate the effect of cold work, grain boundaries, etc.

C. Conventional Data Analysis

Maintenance

Spiral Reader system check-out continues. The automatic gain control system for bright-field film format shows improvement but problems persist. A Nuclear Research Instruments (NRI) type stage control ball has been installed on the Vanguard MA measuring machine and seems to be working satisfactorily. NRI grating packages have been installed on three machines; the final check-out awaits the EMR (Electro-Mechanical Research, Inc.) computer. NRI rework is to start on the first machine within the next two weeks.

Hummingbird III film drive has been interfaced to the computer and is operating within specifications; on-line testing is now in progress. Design of NRI Model 2 is nearly complete. Work on Model 4, a prototype, will begin early in October.

Scanning and Measuring Operations

During the quarter 105,200 events were measured in 9600 hours on the NRI system. Production was down about 40% during the last month because of EMR computer problems; it is hoped that installation of the new core and tune-up of the old memory core will enable us to resume full production some time in October. Production measuring has begun again on the Hummingbird.

D. Storage Ring Development — SPEAR

The "SPEAR Design Report" was issued in August. Design and development work continues on the magnet, vacuum, and rf systems. A prototype quadrupole was fabricated and is presently in a magnetic measurement program. A prototype bend magnet is in fabrication. Prototype steel and reinforced concrete girders have been fabricated and are presently undergoing short and long term stability tests. Prototype extruded aluminum vacuum chambers have been ordered for gas desorption, vacuum, and fabrication tests.

V. PLANT ENGINEERING

Several projects were completed and the facilities placed in use during the quarter. These were: air conditioning of the high bay space in the Electronics Building; installation of a dust collector system in the Crafts Building; extension of low voltage ac electrical services in the South Staging Yard; installation of additional air conditioning in the Temporary Computer Building; and the erection of a magnet enclosure for K^0 Beam in the target area.

Field work is in progress on various other projects as follows:

1. Relocation of SLAC Library — the contractor was given a notice to proceed in September 1969 and work has begun.

2. Enclosing of Fabrication Building Cleaning Shop — construction will be completed next month (October).

3. Enclosing of Pulse Tank Maintenance Area — construction is essentially finished.

4. Front Entryway Improvements — mechanical and electrical services are being installed. Landscaping and a permanent information booth at the new site are in the planning stage.

5. Enclosing of Room 109B at Cryogenic Laboratory — construction is essentially complete.

6. Addition to the LCW Pumping and Heat Exchanger Capability in the Research Yard — these installations have been made and are operational but not finally checked out.

7. Modification to Radioactive Water Service in End Station B Target Room — the installation is well along and will be completed as scheduled outages of the accelerator permit during the next several months.

8. Upgrading of Building 101 — construction bids will be opened on October 1, 1969 for the modifications needed to establish a developmental vacuum laboratory in this building.

9. Data Assembly Building Annex — bids have been invited for a 1000 gross square foot extension of the existing building.

Preliminary work on a number of items, as stated below, is underway:

1. Upgrading of Buildings 102 and 104 — design for modifications of these target area buildings is well along.

2. Temporary Computer Building — engineering has been started on needed modifications and on the installation of a communications duct bank to the Central Laboratory Addition.

3. Central Utility Building Expansion — a preliminary proposal for the addition of a 500-ton chiller is being prepared.

4. Superconducting Accelerator — an engineering study for the conversion of the SLAC two-mile machine is being continued.

5. SLAC 230 kV Tap Line — consideration is being given to the installation of load limit assemblies on several post-type insulators as a preventive maintenance measure. A feasibility report on this subject is currently under study.

6. End Station A North Wall — design of a proposed triangular extension of the shielding wall is nearly complete.

Services to other SLAC groups were provided throughout the quarter, chiefly in the extension of electrical and mechanical services for new beam line facilities and the adaptation of target area buildings for changing customer requirements. The ongoing program of plant utility operation and minor modifications to buildings as a general service to SLAC was continued.

VI. KLYSTRON STUDIES

A. Development

1. High Power Klystrons

Litton Subcontract. During the quarter Litton appears to have resolved their last fabrication difficulties; in spite of their usual vacation in July, they were able to submit 22 acceptable tubes.

RCA Subcontract. RCA has also been able to deliver some of the 30 MW 270 kV variety tubes towards the end of the quarter but full evaluation of these tubes has not been completed.

SLAC. The yield of SLAC tubes through test and acceptance has been much better than we had experienced during the previous year. Three SLAC tubes were accepted for 30 MW, 270 kV operation.

2. Klystron for Superconducting Accelerator

The beam tester built in preparation for this work has been satisfactorily tested and indicates excellent transmission characteristics for the beam at the expected magnetic field and perveance. The electrical design of the first tube is completed and we expect to start fabrication of the components during October.

3. High Power Windows

Three RCA high power tubes experienced window failures. Two were of catastrophic nature including complete disappearance of the window.

One SLAC window failed during processing when a leak opened in the ceramic metal braze joint. The excessive temperatures reported previously have apparently been corrected by a combination of surface roughness and coating thickness specification changes. It is particularly important to decrease the operating window temperature in anticipation of the expected increase in the number of tubes operating in excess of 30 MWs.

4. Driver Amplifier Klystrons

No major problems were encountered in spite of a tube which was not accepted because of a temperature-limited cathode.

B. Operation and Maintenance

During the quarter we experienced 8 high power klystron failures for approximately 180,000 hours of operation. The number of spares available continued to increase.

We also have sufficient 270 kV tube spares to enable us to propose an increase in the number of 30 MW sockets during the next shutdown of the accelerator.

There were 3 driver amplifier klystron failures for approximately 28,000 hours of operation.

1. High Power Klystron Operation

Table II gives a summary of the usage and failures since the beginning of operation (exclusive of the hours accumulated by Sperry tubes). A correction of the cumulative hours which resulted from a miscalculation of 3,300 hours for the Sperry tubes has been introduced in this quarter and not carried back to the beginning of operation.

The tube age distribution of all operating tubes is given in Fig. 4. It can be seen that more than 60 tubes have exceeded 15,000 hours of operation.

The mean age of all living tubes is 10,070 hours, the median age 11,700 hours.

Figure 5 gives the age distribution of all failures through October 1, 1969, with a mean age of 4,450, and a median age of 3,650.

The failure probability and survival probability for all the vendors has been computed from the data of Figs. 4 and 5. The results are shown in Fig. 6.

Figure 7 gives the summary of mean time between failures (MTBF), mean age at failure, mean age of all operating tubes, and cumulative hours of sockets since the beginning of operation.

We have been concerned about the effect of operating levels on the total number of failures. The MTBF has continued during the quarter to be higher than the cumulative MTBF which leads us to believe that we will not experience any substantial increase in failure rate caused by the increase of operating level initiated in April 1969. It is also comforting to realize that there were no failures this quarter in klystrons operating at 265 kV. Although the sample is very small (7 stations in the gallery, plus the beam separator) the indications are that the failure rate at 265 kV may not be substantially higher than is observed at 245 kV.

It is entirely possible that the increase in MTBF since April in spite of the increase of mean operating level is due to the different operating technique of the accelerator which is now normally operating for 4 weeks continuously rather than a start up every other week.

2. High Power Klystron Maintenance

Operating experience through the end of the quarter is shown in Fig. 8 which indicates a substantial decrease in the number of replacements as well as in the

TABLE II

KLYSTRON MTBF

Dates	PER QUARTER				CUMULATIVE			
	Operating Hours	Failures Number	Failures Mean Age	MTBF	Operating Hours	Failures Number	Failures Mean Age	MTBF
To 6/30/66					129,400	19	260	7,200
To 9/30/66	111,000	8	610	14,000	240,400	27	360	9,000
To 12/31/66	154,000	11	1,100	14,000	394,400	38	575	10,300
To 3/31/67	207,000	13	1,490	15,900	601,400	51	810	11,800
To 6/30/67	287,000	9	2,490	32,000	888,400	60	1,060	14,800
To 9/30/67	330,500	25	2,860	13,300	1,218,900	85	1,590	14,500
To 12/31/67	263,000	21	3,520	12,500	1,481,900	106	1,980	14,100
To 3/31/68	309,500	17	4,800	18,200	1,791,400	123	2,360	14,700
To 6/30/68	306,000	15	3,820	20,400	2,097,400	138	2,520	15,200
To 9/30/68	314,200	24	5,500	13,100	2,411,600	162	2,960	14,900
To 12/31/68	349,800	23	8,350	15,200	2,761,400	185	3,630	15,000
To 3/31/69	328,600	20	6,610	16,400	3,090,000	205	3,930	15,100
To 6/30/69	335,000	17	7,280	19,700	3,425,000	222	4,190	15,400
To 9/30/69	179,800	8	11,670	22,500	3,608,100	230	4,450	15,750

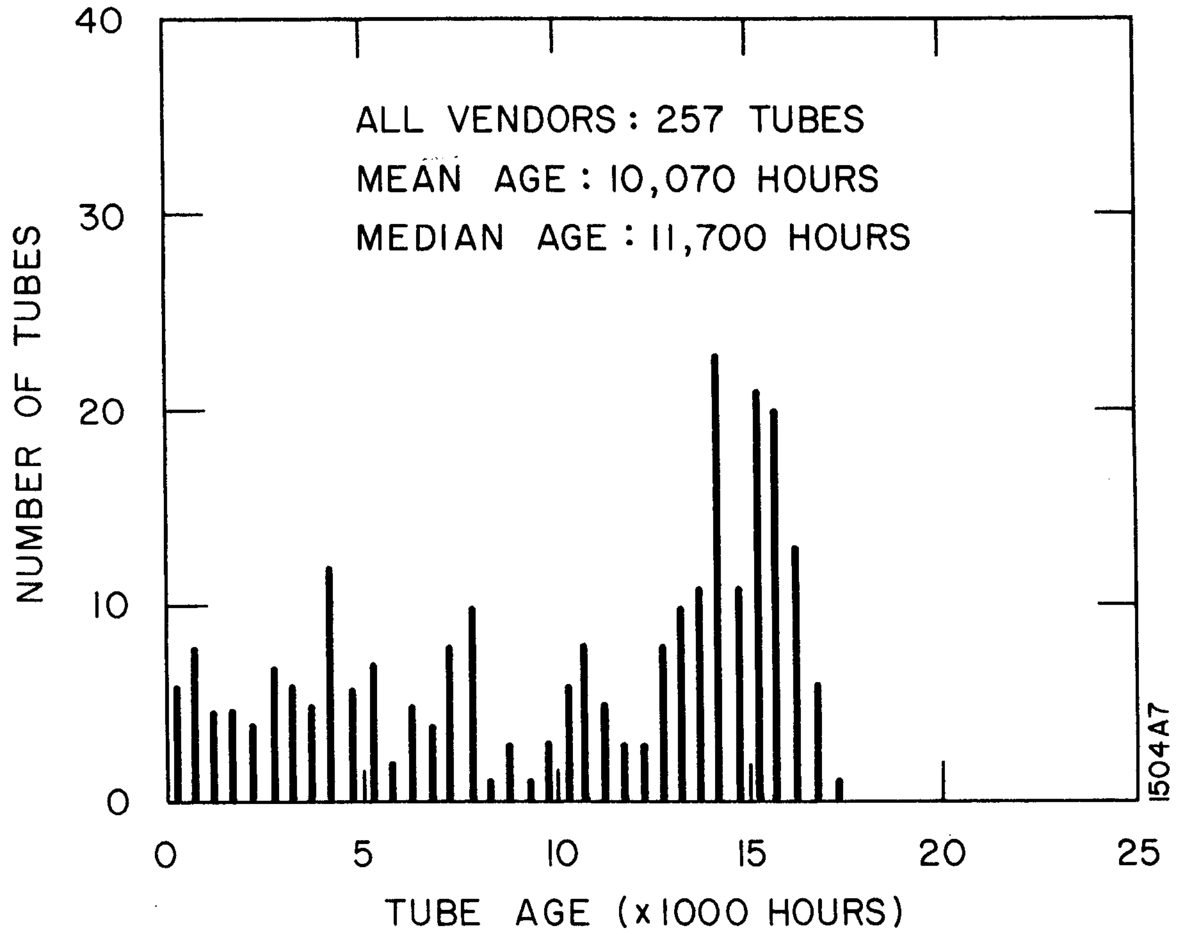

FIG. 4--Age distribution, all operating high-power tubes, Oct. 1, 1969.

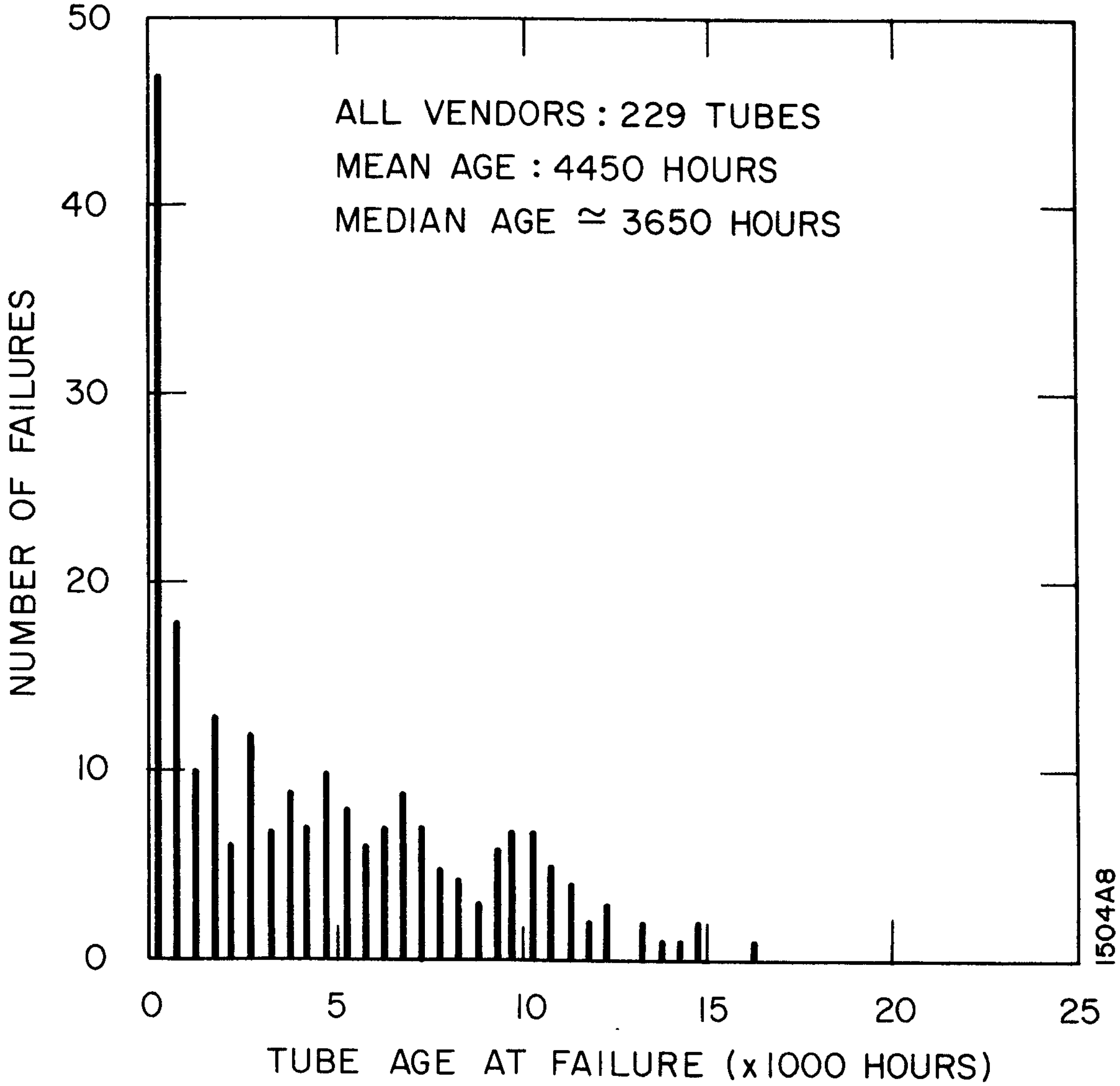

FIG. 5--Age-at-failure distribution, high-power tubes, Oct. 1, 1969.

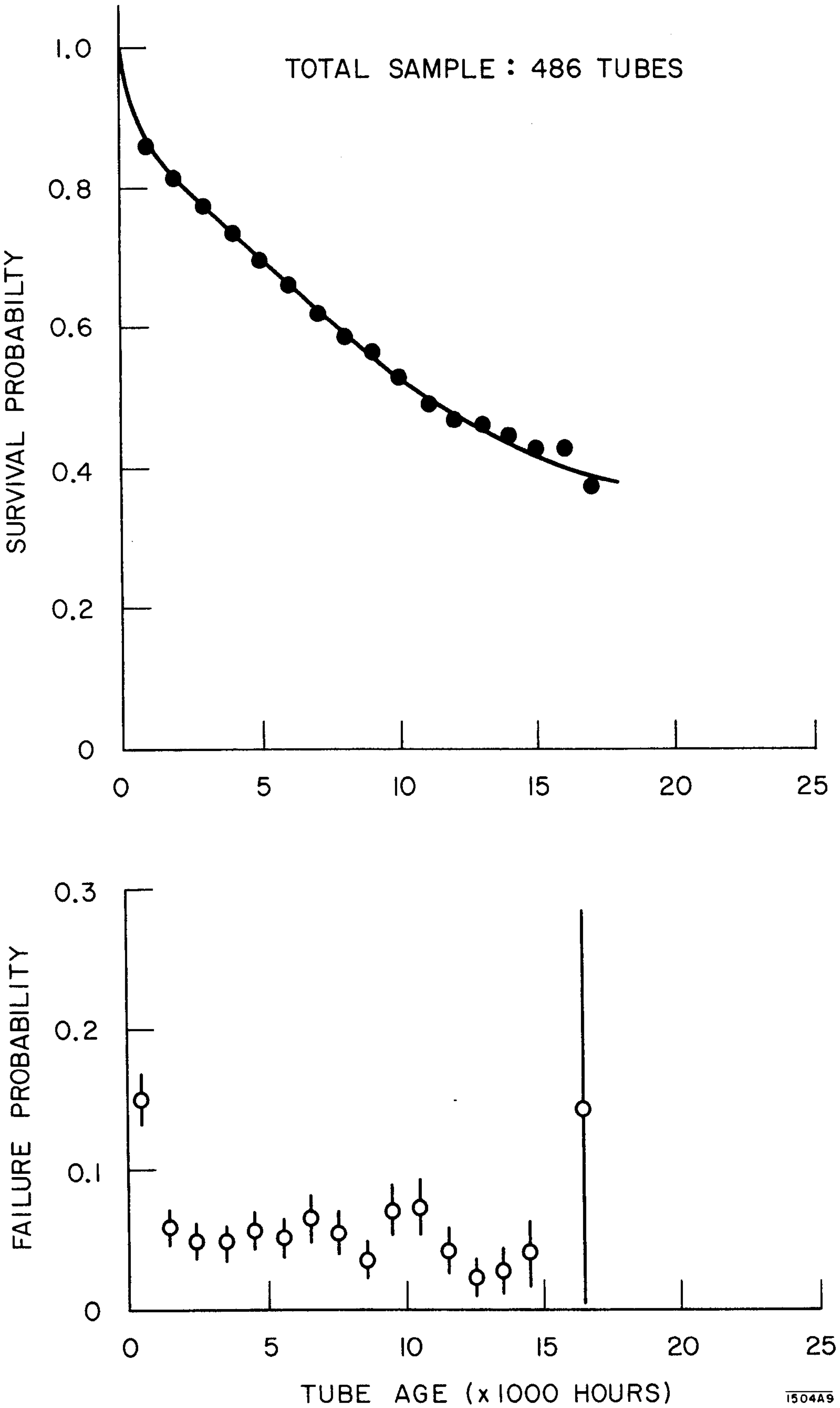

FIG. 6--Survival and failure probability, high-power tubes, Oct. 1, 1969.

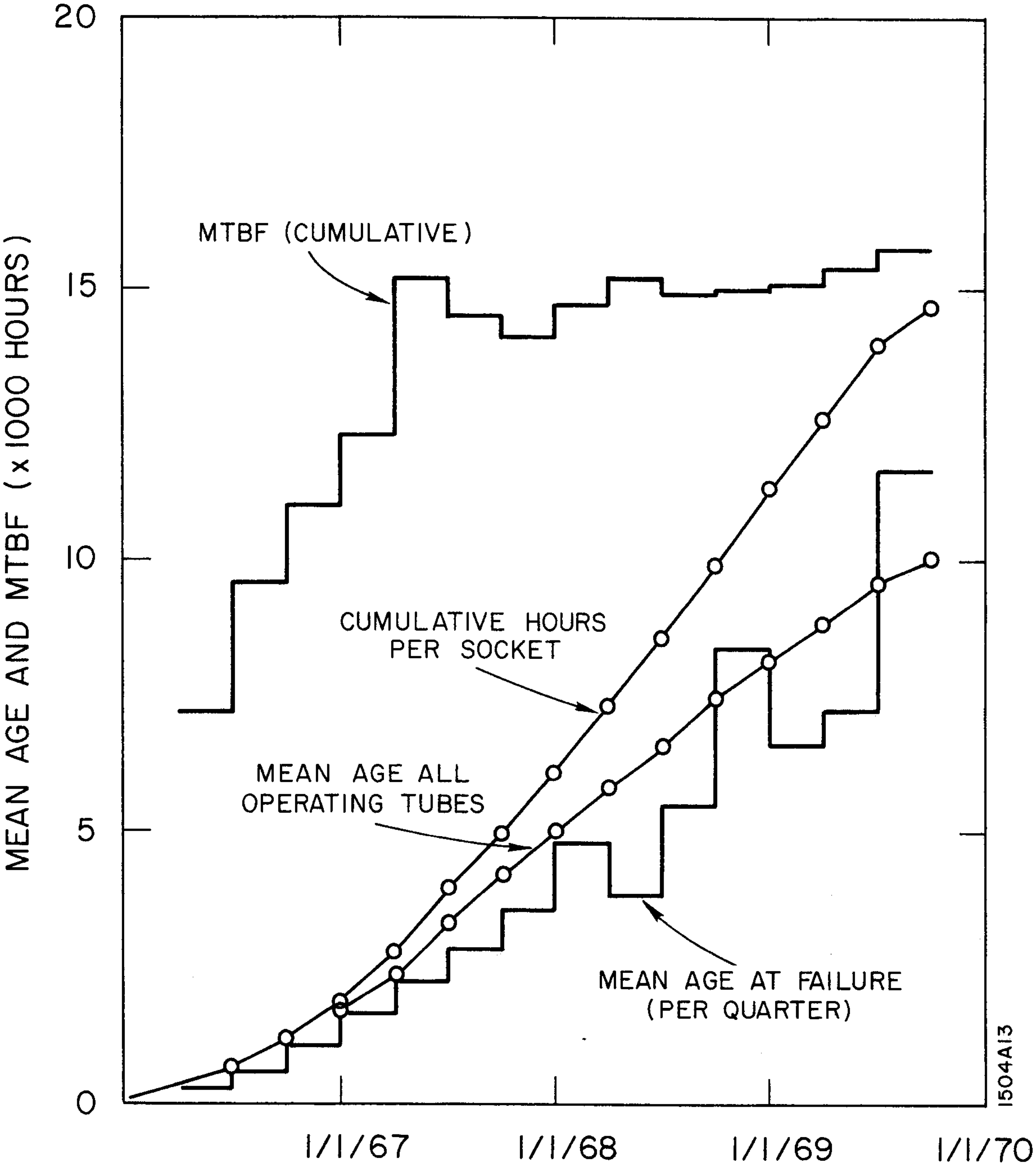

Fig. 7--High-power tubes: cumulative MTBF, mean age at failure, mean age of operating tubes, and cumulative hours per socket, Oct. 1, 1969.

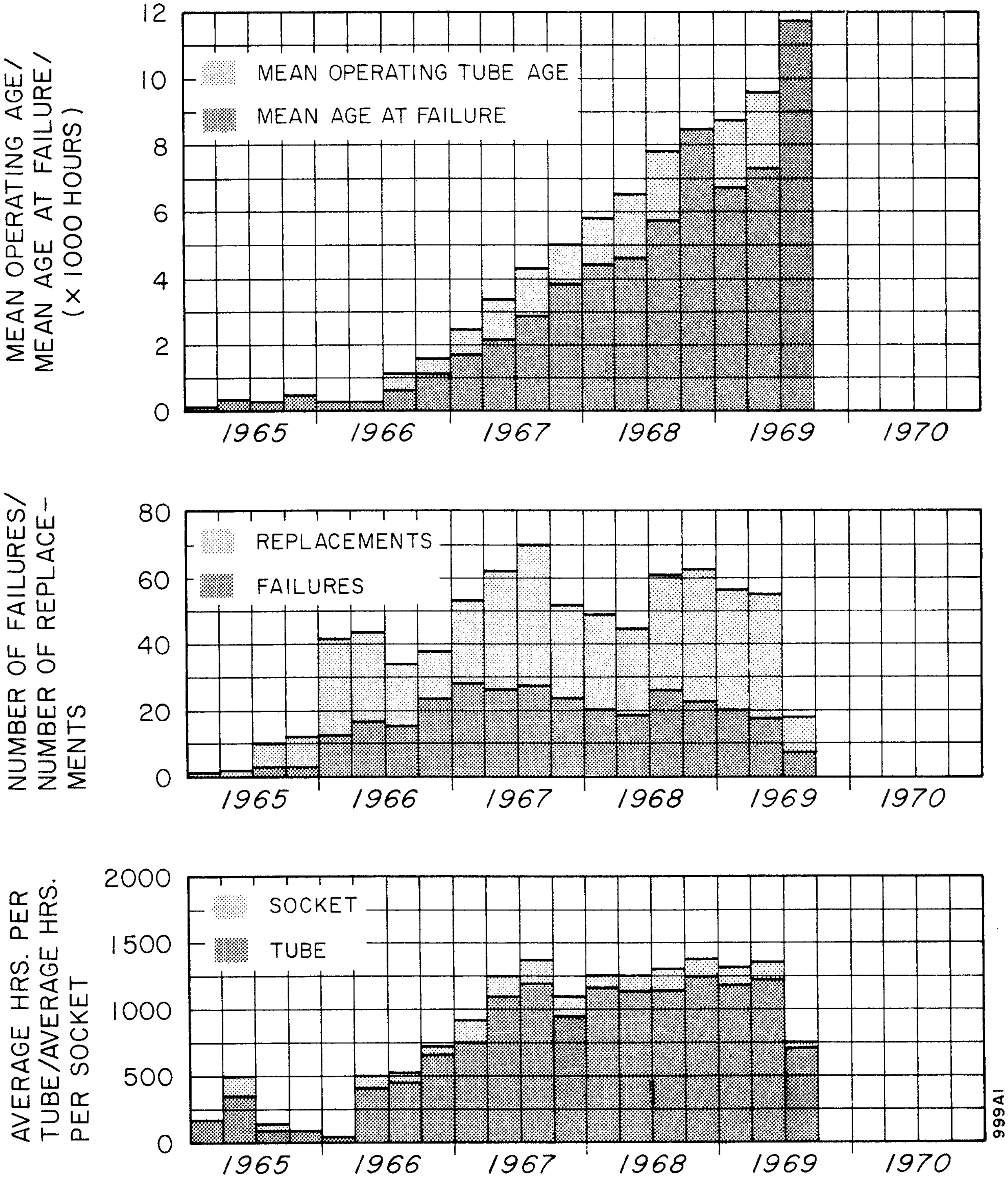

FIG. 8--Operating experience, high-power tubes, through Oct. 1, 1969.

number of failures. The replacement rate stays approximately 2-1/2 times the failure rate.

The number of trouble reports per station has increased slightly this quarter but is still less than 1 per 1,000 hours of operation. However, the stations operating at 265 kV have a trouble report rate of close to 3 per 1,000 hours of operation.

We were unable to continue the preventive maintenance checks with the frequency which has been our goal. We believe the reason is the schedule of operation and inability to obtain stations for preventive maintenance during difficult beam combinations. We hope that the decrease in the preventive maintenance operation will not result in an increase in failures in the near future.

3. Driver Amplifier Klystrons

The operation and maintenance of driver amplifier klystrons has continued satisfactorily. However, the number of replacements and failures per operating hour increased considerably. This may be caused by the fact that at least one-half of the Eimac tubes remaining in use have now accumulated more than 20,000 hours. The tube age distribution is shown in Fig. 9 and the age distribution of failed driver amplifiers is shown in Fig. 10.

4. Main Booster Klystrons

No difficulties were experienced with the main booster klystrons during the quarter; there were no replacements and no failures.

5. Vacuum System

No major changes occurred in the performance of the accelerator vacuum system. Average pressure at the main manifold gauges was about 1.5×10^{-8} torr with klystrons operating.

The 10-foot refrigerated baffle between Sector 30 and the beam switchyard was accidentally warmed up and let up to air. As a result, maintenance procedures, interlock operation and equipment responsibilities were checked and redefined where necessary. A residual gas analysis was run to determine if there was any oil contamination on the ion-pumped side of the baffle. No significant contamination was observed.

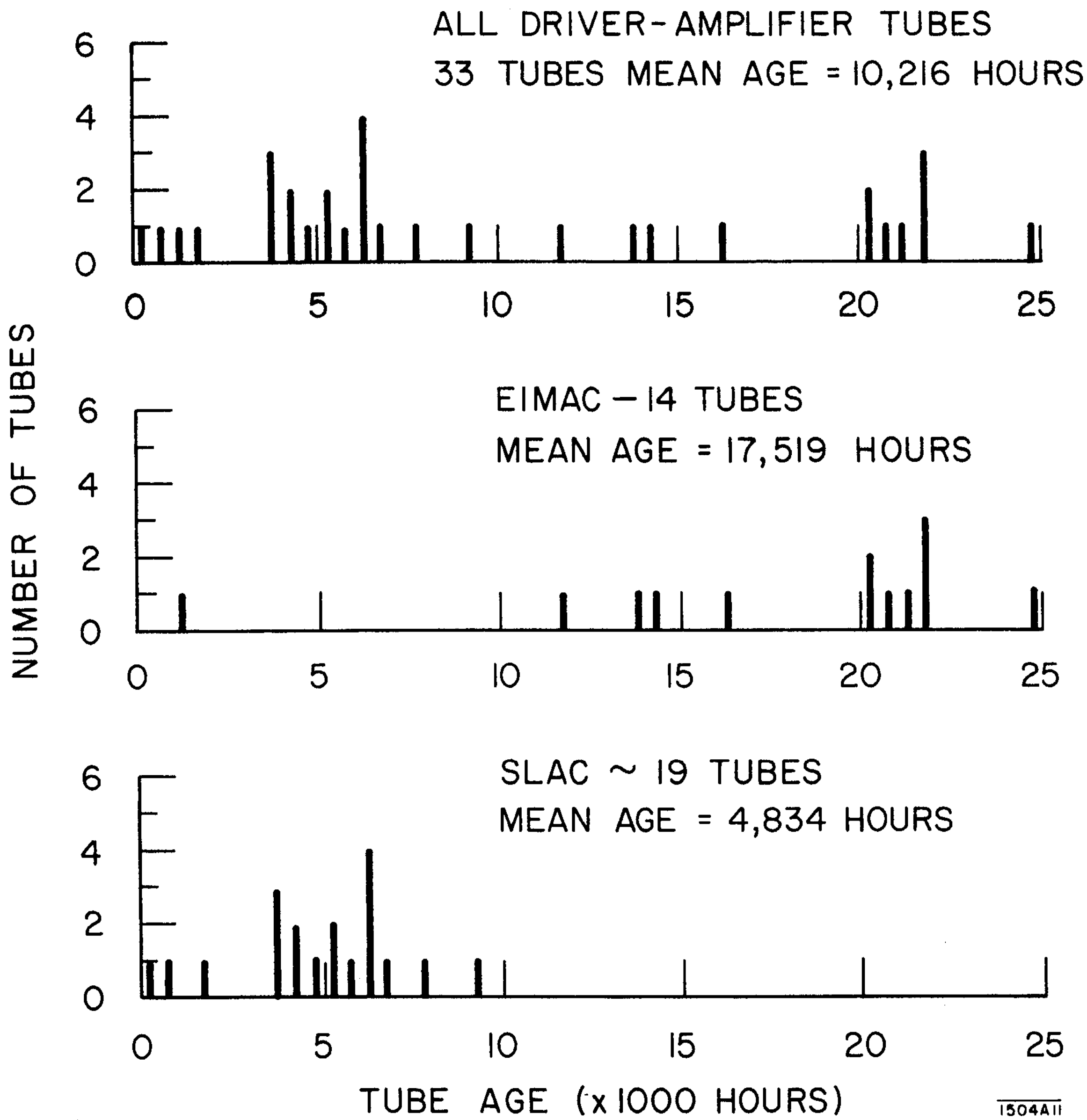

FIG. 9--Age distribution, all operating driver-amplifier tubes, Oct. 1, 1969.

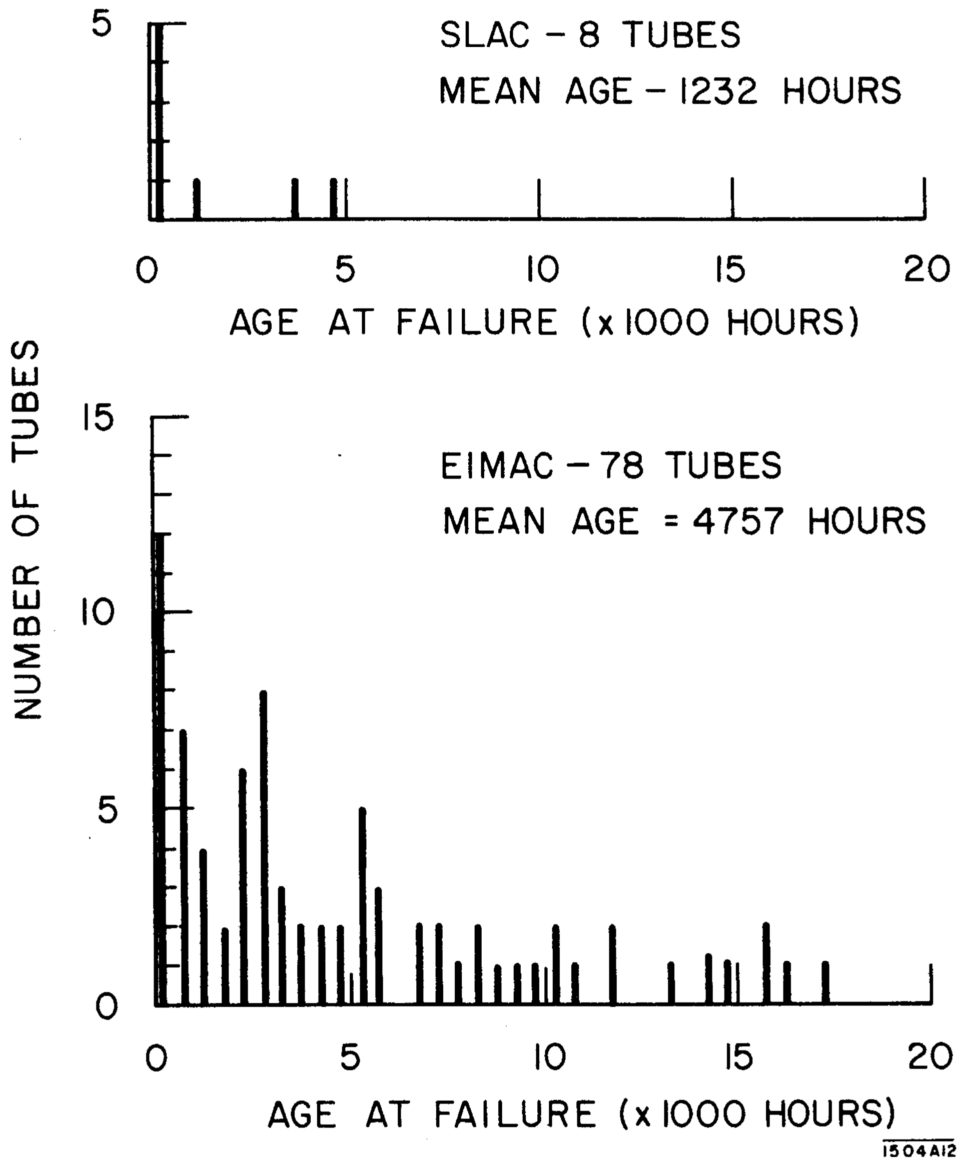

FIG. 10--Age-at-failure distribution, driver-amplifier tubes, Oct. 1, 1969.

VII. ACCELERATOR PHYSICS
(October 1968 - September 1969)

Introduction

Fairly comprehensive summaries of many Accelerator Physics activities during this report period can be found in the following papers.

1. "Recent Beam Performance and Developments at SLAC" by R. H. Helm, H. A. Hogg, R. F. Koontz, G. A. Loew, R. H. Miller, and R. B. Neal, SLAC-PUB-563, presented at the 1969 National Particle Accelerator Conference, Washington, D.C., March 1969.

2. "Feasibility Study of a Two-Mile Superconducting Linac" by W. B. Herrmannsfeldt, H. A. Hogg, G. A. Loew, and R. B. Neal, SLAC-PUB-560, presented at the 1969 Particle Accelerator Conference, Washington, D.C., March 1969.

3. "Two-Mile Superconducting Accelerator Study" by W. B. Herrmannsfeldt, G. A. Loew, and R. B. Neal, SLAC-PUB-626, presented at the 7th International Conference on High Energy Accelerators, Yerevan, Armenia, USSR, August 1969.

4. "Microwave Studies at the Stanford Linear Accelerator Center" by H. A. Hogg, SLAC-PUB-663, presented at the 1969 European Microwave Conference, London, England, September 1969.

5. "Linac Beam Interactions and Instabilities" by R. H. Helm, H. A. Hogg, R. F. Koontz, G. A. Loew, and R. H. Miller, SLAC-PUB-659, presented at the 7th International Conference on High Energy Accelerators, Yerevan, Armenia, USSR, August 1969.

6. "Rf Superconducting Materials Research at SLAC" by M. A. Allen, J. K. Cobb, N. Dean, Z. D. Farkas, E. L. Garwin, H. A. Hogg, E. W. Hoyt, R. A. McConnell, M. Rabinowitz, and A. Roder, SLAC-PUB-562, presented at the 1969 Particle Accelerator Conference, Washington, D.C., March 1969.

Further details are found below.

A. Injection System

1. Electron Gun

The gun presently in use on the accelerator was installed on February 18, 1968 when the original gun failed with a heater short. The gun now has operated in excess of 11,000 hours.

During July 1969, a small cathode (4 mm dia.) gun was constructed and installed on the accelerator to observe the effect of its presumed lower noise on the beam breakup threshold. This gun was operated for one shift on July 9, 1969, during which the beam breakup (BBU) threshold was measured under two operating conditions: (1) normal quadrupole focusing and, (2) maximum quadrupole focusing (approximately 20% stronger focusing). Then the small cathode gun was removed, and the standard gun with a 19 mm diameter cathode reinstalled. The BBU thresholds were then remeasured under each focusing condition. The results were puzzling and inconclusive: with the strong focusing, no difference was measured; with normal focusing, about a 10% increase in the BBU threshold current was seen with the small cathode. The test will be repeated after installation of a magnetic inflection system which will allow both guns to be installed on the accelerator at the same time, and hence permit a rapid comparison of the BBU threshold with each gun.

2. Two-Gun Assembly

The design of the magnetic inflection and two-gun assembly mentioned above is complete and fabrication is underway. Installation is planned for the November shutdown. Figure 11 is a simplified plan view of the installation. As can be seen from the figure, one gun is mounted on the accelerator axis in essentially the same manner as before, except that the gun is moved west 50 cm and two new gun lenses are added to permit the addition of a fast valve and the inflection magnet. The fast valve will protect the gun in case of a vacuum failure in the accelerator, and permit a gun to be replaced without letting down the vacuum in the rest of the injector.

The inflection magnet has been named the "α-bending magnet" since the beam from the off-axis gun follows a trajectory resembling the Greek letter α, crossing through itself at the intersection of the axis of the gun and the accelerator as shown in the figure. This design was chosen since it is nearly achromatic and has very similar optics in the horizontal and vertical planes.

The original installation will have a dc inflection magnet. Later, this will be replaced with a pulsed magnet to permit interlacing the beams from the two guns on a pulse-to-pulse basis. The two-gun assembly will provide an immediately available standby gun or, alternatively, special purpose guns such as the small cathode gun mentioned above, or a high current (5 A) gun required for certain experiments.

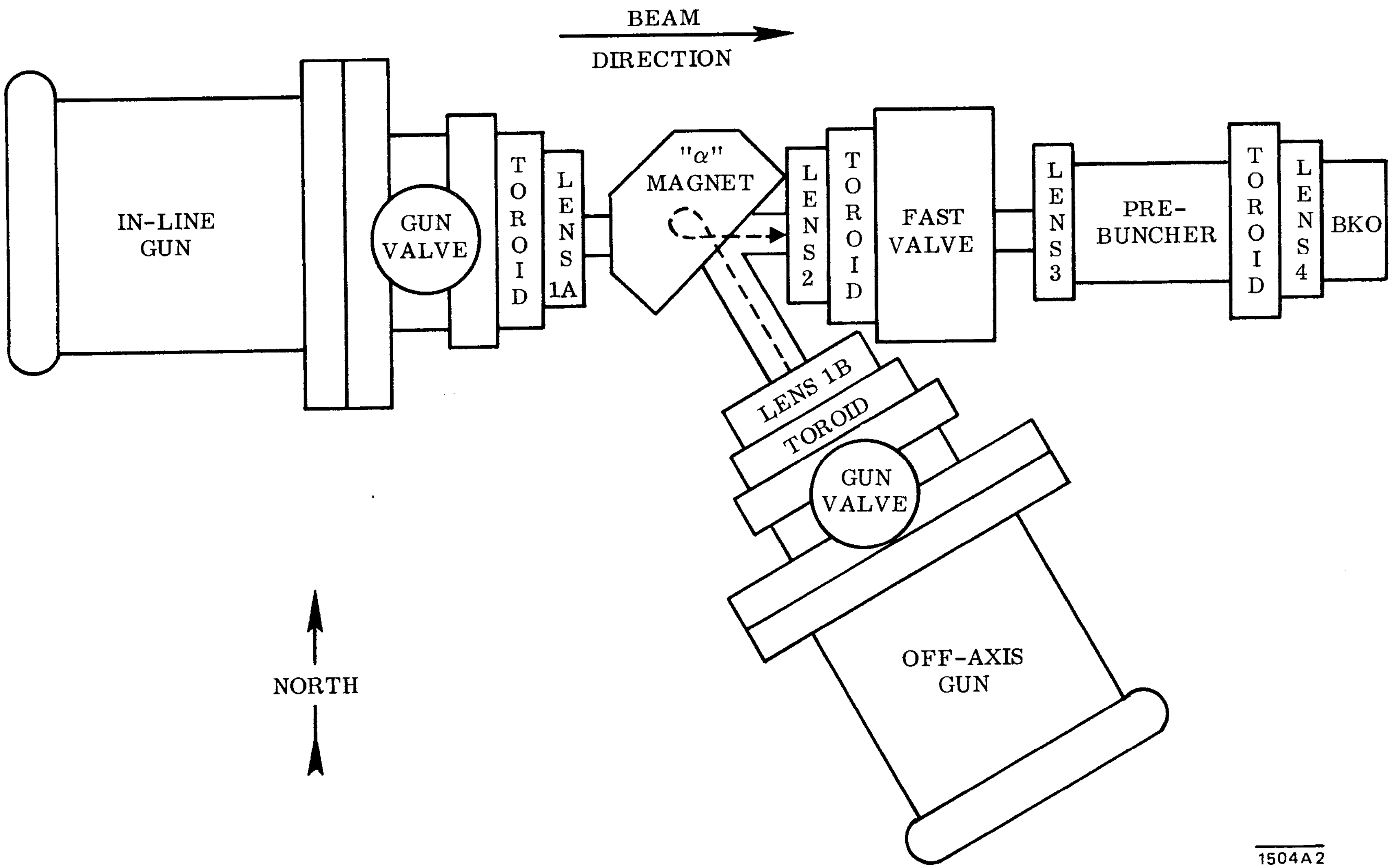

FIG. 11--Two-gun assembly.

B. Drive System

1. Master Oscillators

The master oscillators have continued to function well and only routine maintenance has been required.

2. Main Boosters

Main booster No. 2 has been completely overhauled and major improvements have been made in almost every circuit. The two most significant improvements have been made in the high voltage regulation and in the maintainability. In the near future, main booster No. 1 will be modified to be identical to unit No. 2. Completion of these modifications should greatly improve the reliability of the entire system.

3. Sub-Boosters

The sub-booster klystron and modulator system has been performing satisfactorily. Routine maintenance and tests during shutdown periods have considerably decreased the number of major failures during beam operation. When failures do occur during beam time, operating experience and adequate availability of spare parts have all but eliminated lost beam time.

4. Main and Subdrive Lines

In August 1968, Sectors 1 through 10 of the main drive line were overhauled and reinsulated. The results of this operation were excellent and as a result, plans were made to overhaul the rest of the sectors (11 - 30) during the next long shutdown period. The most appropriate time was from December 23, 1968 to January 15, 1969. During this period, Sectors 11 through 30 flanges were refaced, straightened, bullets plated and reassembled. Tests showed definite degradation before repair and subsequent improvement after completion. The assumption is that after this repair cycle, the main drive line will require only minor maintenance for several years. Tests will be performed periodically to determine the rate of deterioration, if any.

During the main drive line repair cycle, there was no attempt to repair the expansion sections between each sector. A repair program is now under way wherein the units, in batches of four, are returned to the vendor for reconditioning. With this program, four expansion sections can be repaired, exchanged with units in the line, and the old units returned for repair during each shutdown period. So far, two such exchanges have taken place. This program will take approximately two years to complete.

On December 20, 1968, the 7th directional coupler in the Sector 28 subdrive line began to breakdown and arc, causing the rf to be jittery at the corresponding station. The coupler was replaced with a spare and operation of the sector continued. A check of the other sectors in the accelerator pointed to the need for maintenance on the subdrive lines. Hence, when the main drive line work was completed in January 1969, plans were made to systematically recondition the subdrive lines of the accelerator. An auxiliary line was constructed and mounted on a rolling carriage. This carriage used train-like wheels and the high voltage cable tray for a continuous track throughout the length of the accelerator. This arrangement allowed the auxiliary line to be moved from sector to sector without disassembly and to be used, as a replacement, when a permanent subdrive line was being repaired.

This program progressed methodically until July 1969. At this time, the operating schedule and the shutdown periods for the accelerator were changed to provide longer than usual shutdowns during August, September and November. On this basis, the plan to complete the entire repair program by December 1969 was formulated. To ensure completion, a work force was developed and trained during July 28 to August 4 and August 18 to September 30. By this time, Sectors 14 through 30 had been reconditioned and returned to use. During the scheduled shutdown in November, the remaining 13 sectors will be reconditioned.

In the process of testing the subdrive lines, a new problem was observed in the solder joints of the center conductors. The construction is such that each dielectric support wafer has an undercut portion which matches the line for the increased dielectric constant of the wafer. This undercut portion is made out of a solid bar and is soft soldered to the tubing of the center conductor. Some of these solder joints seem to be deteriorating. As a result, the voltage standing wave ratios (VSWR's) of some of the lines are undergoing degradation. Resoldering appears to remedy the problem. How widespread this deterioration is has yet to be determined.

A new drive line insulation is being installed as the final part of the drive line reconditioning program. The new insulation will replace the worn out and cumbersome fiberglass insulation. It will consist of two "L" shaped pieces, approximately 10 feet long, spanning the space between each pipe support in the klystron gallery. Access and replacement when further repair becomes necessary should be much easier and more economical. The new insulation should be completed by early January 1970.

5. Varactor Frequency Multipliers

During November 1968, problems with the testing and alignment procedure of the varactor frequency multipliers were encountered. A new comprehensive procedure was developed, and since that time, operation of the multipliers has been improved considerably. In the process of revising the test procedure, the varactor output filter and coupler assembly were found to be out of specification. Tests on the filters showed that there were sizable variations from unit to unit and that specifications were not being met. Replacement with units that did meet specifications then allowed the varactors to be tuned easily and to remain stable. Final repair or replacement of the filter units is anticipated in the near future.

6. Rf Separator

The planned installation of the sub-booster type of rf driver for the rf separator is nearing completion. Final checkout and tests should occur before the end of 1969. The new 476 MHz rf amplifier has been received and installation is scheduled for early 1970.

7. Pulsed Phase Closure

The pulsed phase closure system has been working well. Plans are under way to increase the number of independent phase closures from 3 to 6. A rearrangement of the phase shifters in the rf circuit is planned. It should decrease the effect of differing attenuations in different phase shifters on the driven 24 MW klystrons.

8. Isolator-Phase Shifter-Attenuators

In June 1969, an instability was discovered in the output of some of the 24 MW klystrons. This instability was traced to the attenuator portion of the isolator-phase shifter-attenuator units which showed signs of internal breakdown and arcing. At least 23 stations are involved. The cause was traced to overheating of the epoxy and powdered iron power-absorbing vanes. Apparently, overheating causes the vanes to warp and either contact the center conductor and/or come close enough to the center conductor in a high field area to cause rf arcing. The exact cause for the overheating is not known but it is suspected that the powdered iron-to-epoxy ratio is not optimized and too much heat is dissipated in too small an area; overheating ensues. The immediate course of action was to lower the input power as much as practicable and to initiate a procurement for a sample quantity of 3 different iron-to-epoxy ratios for test purposes. The program to repair all or part of the attenuators remains undecided.

9. Injector Drive Line Switches

The main drive coaxial transfer switch has been operating satisfactorily. It is now interchangeable with coaxial links in the event of failure or harmonic crosstalk from the standby main booster amplifier. Both the coaxial links and the transfer switch are mounted on a permanent 4-port patch panel located on main booster No. 1.

Just downstream from the main drive line switch, one failure occurred in the gas barrier. Electrical breakdown was localized in the gas barrier and damaged it severely. Replacement of the gas barrier as well as local cleaning of the coaxial line were necessary. A similar failure occurred in main booster No. 2, in the portion where the klystron is isolated from the rest of the main drive line and switch. The exact cause of these two failures is unknown. The problem will be studied in the future. The first effort will be to open and inspect the line in that area on a periodic, preventive basis.

The final version of the waveguide transfer switch for the injector sub-boosters was installed and, following several minor modifications, has operated satisfactorily. A waveguide type of switch was preferred because the coaxial type failed several times. This change required 4 coax-to-waveguide adapters which were obtained and installed.

10. Research Area Main Drive Line Distribution

The program for installing diplexers to separate and distribute 476, 40, 20, 10, and 5 MHz at each of the end stations is continuing. In the past, 476 MHz power was delivered to each of the the three end stations. The need for additional beam knockout signals has continued to increase. A plan has now been formulated which will supply the beam knockout signals and the 476 MHz main drive line signal to all three end-station areas as well as to the Data Assembly Building (DAB).

11. Energy Transient Compensation

When the SLAC machine is operated at high currents, first order compensation for the energy spread due to transient beam loading is achieved by delaying the klystron turn-on time in one or more sectors of the accelerator. The compensation, however, is imperfect for several reasons, one of them being that the leading edges of the beam-loading waveform and the delayed accelerating voltage waveform do not follow the same law. Thus, when the beam is analyzed and transmitted through narrow slits, a depression or "gulch" is often observed near the middle of the current pulse.

It has been possible to fill the "gulch" by gating the rf drive to the klystrons in stations 27-7 and 27-8 using high-power PIN diode switches. Trigger controls in Central Control Room (CCR) permit separate adjustment of the delay and width of each gate. The rf pulse from one klystron is timed and phased to compensate for the "gulch." However, because of the relatively long filling-time of the accelerator section, the compensation persists when it is no longer needed, resulting in current loss at the end of the beam pulse. This difficulty is overcome by adjusting the timing and phasing the rf pulse from the second klystron to cancel the effect of the pulse from the first klystron, after the "gulch" has been filled.

C. Phasing System

The automatic phasing system has performed satisfactorily during the past year. Routine maintenance has been carried out at the beginning of each accelerator operating cycle.

Beam detector circuits are now installed in each sector phasing system. These circuits inhibit all phasing actions when the beam current through an accelerator section which is in the process of being phased falls below 1 mA, or the number of beam pulses per second in the first time slot is less than 60. The new system thus guards against the possibility of mis-phasing due to an inadequate beam, and relieves the CCR operator of the responsibility for following the phasing action, station by station and sector by sector. It is therefore feasible to speed up the process of re-phasing the whole machine by initiating phasing action in many sectors in quick succession.

An improved wobbler-driver circuit having greater noise-immunity and less current drain has been built onto the same card as the beam detector circuit.

D. Beam Position Monitors

The in-line beam position monitoring system on the accelerator continues to function satisfactorily and no engineering changes have been made this year. In the beam switchyard, however, the requirements of Experiment E-29 (Search for T-Violation in Inelastic e-p Scattering) made it necessary to install a very sensitive position monitor in the A-line just downstream of protection collimator 16. This position monitor, designated P13, utilizes a spare microwave cavity assembly, identical to the others installed in the switchyard, but employs a 2886 MHz local oscillator and high-gain 30 MHz receivers. The beam position information is not normalized with respect to current, and the sense of the transverse displacement is not given. These limitations are not important, however, as the monitor is used only in guiding the beam back onto the machine axis. The current-displacement product sensitivity achieved is better than 1 μA-mm.

The tunnel diodes in monitor P12 were also replaced by a receiver system, giving the DAB operator a choice between normal thermionic diode operation and sensitive receiver operation.

E. Beam Breakup (BBU)

The program of BBU improvement by "dimpling" was introduced in the previous report.* By the end of 1968, the first two sectors had been dimpled by 4 MHz and the BBU threshold was improved from about 40 mA to about 54 mA. Computer results had predicted a somewhat larger improvement factor; however, when the computer simulation was refined by using the actual BBU resonant frequencies in each 10-foot section of Sectors 1 and 2, before and after dimpling, there was much better agreement.

Subsequent computer experiments indicated that the random scatter of resonant frequencies could be represented quite well by using a mean frequency and an effective Q on the order of 4000 to 5000 (rather than the actual Q which is on the order of 10,000). This model greatly simplified the data input into the computer program, and improved the level of confidence in further computer predictions even though exact data on resonant frequencies were not available.

Experience had shown that the BBU frequency shift which could be obtained by detuning cavities 3, 4 and 5 in a ten-foot accelerator section was in practice limited to about 4 MHz. S-band phase-shift and VSWR deterioration became excessive when more detuning was attempted. However, computer results indicated that a greater BBU threshold improvement factor could be obtained by dividing the machine into three groups (not-detuned, 2 MHz-detuned, and 4 MHz-detuned) instead of two groups (not-detuned and 4 MHz-detuned). It was therefore decided to run a series of computer experiments to find the optimum distribution of sectors detuned by 0, 2 and 4 MHz, taking account of the fact that Sectors 1 and 2 had already been detuned by 4 MHz. Figure 12 shows the predicted results of several possible distributions. A schedule very similar to that for curve C was adopted (the only difference being that Sector 10 was detuned by 2 MHz and Sector 19 was not detuned).

*SLAC-93, December 1968.

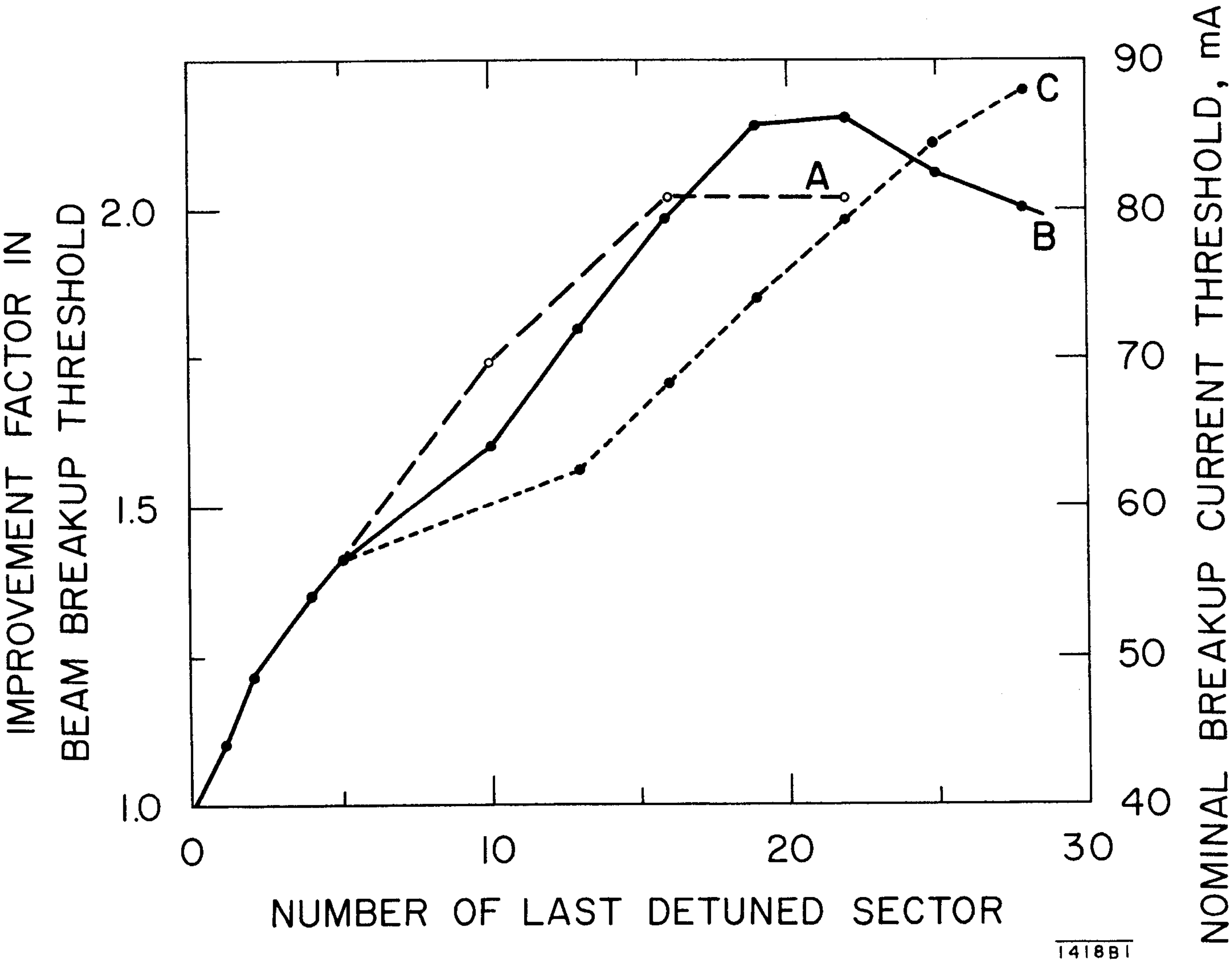

FIG. 12--Computed beam breakup improvement factors for two-mile accelerator with several possible detuning schedules.

The schedules for curves A, B, and C are as follows:

Curve A: + 4 MHz, Sectors 1, 2, 7, 8, 13, 14, 19, 20, ...
+ 2 MHz, Sectors 3, 4, 9, 10, 15, 16, ...
0 MHz, Sectors 5, 6, 11, 12, 17, 18, ...
(i.e., 442200, 442200, ...)

Curve B: + 4 MHz, Sectors 1, 2, 9, 12, 15, 18, ...
+ 2 MHz, Sectors 3, 4, 5, 10, 13, 16, ...
0 MHz, Sectors 6, 7, 8, 11, 14, 17, ...
(i.e., 4422200, 042, 042, ...)

Curve C: + 4 MHz, Sectors 1, 2, 12, 15, 18, ...
+ 2 MHz, Sectors 3, 4, 5, 13, 16, 19, ...
0 MHz, Sectors 6, 7, 8, 9, 10, 11, 14, 17, 20, ...
(i.e., 4422200000, 042, 042, ...)

Implementation of the detuning schedule has been greatly accelerated by the construction of a hydraulic dimpling tool. Four hydraulically-activated tuning plungers are mounted at 90-degree intervals around a double-ring support structure, which is made in two semi-circular sections, so that it may be fitted around the accelerator cavity to be tuned. The two sections are securely linked with tapered dowel pins. The tuning plungers are screwed in by hand until they contact the copper cavity wall. Application of hydraulic pressure then forces the plungers into the cavity wall by a preset amount, determined by adjustable stops built into the tool.

The hydraulic tool was initially used to tune three spare accelerator sections in the laboratory and seven sections in Sector 3. Microwave measurements indicated that the 2 MHz tuning was sufficiently uniform to justify proceeding without making any further measurements of frequency shift, phase-shift and VSWR. Thus the remainder of Sector 3 and Sectors 4, 5, 10, 13, 16, 22, 25, and 28 have been tuned "blind," without breaking into the accelerator vacuum system. Further tests on Sector 15 have shown that it is safe to accomplish the 4 MHz detuning in the same way.

Table III summarizes the work done to date on increasing the BBU threshold, and indicates the further improvement expected when the program is completed. The present threshold current stands at about 72 mA.

F. Magnetic Measurements

The new rapid magnet mapper was used for many jobs during the past year and proved its worth as a highly versatile, useful tool for users of large magnets. The mapper can take data at the rate of one 3-component point per second. For each point, it can log on magnetic tape the three-field components, the coordinate position in the grid and a normalizing parameter such as magnet current, magnetic induction at some point or the output from any other magnetic field transducer that can be displayed on an electronic counter or voltmeter. The grid size can be varied from 1" × 1" × 1" to 4" × 4" × 4" by hardware switches. The software to process the data logged on magnetic tape is highly versatile. The final reduced data can be graphed on the Calcomp plotter and a full repertory of contour plotting and curve graphing routines is available in the software package.

One of the major magnets mapped during the year was the 100D40 magnet. This magnet was measured first at 2400 amperes with a 20-inch gap setting. The reference induction was about 14.5 kilogauss. After this map was taken, the

TABLE III

SUMMARY OF BEAM BREAKUP THRESHOLD IMPROVEMENTS AT SLAC

Date	Comment	Beam Breakup Threshold	
		Computed	Observed
May, 1966	Original		20 mA
June, 1967	Quadrupole improvement completed	50 mA[a]	40 mA
October, 1968	Sector 1 detuned by 4 MHz	44 mA[b]	46 mA
January, 1969	Sector 2 detuned by 4 MHz	49 mA[b]	54 mA
July, 1969	Sectors 3, 4, 5 detuned by 2 MHz	57 mA[b]	60 mA
August, 1969	Sectors 10, 13, 16 detuned by 2 MHz	64 mA[b]	65 mA
October, 1969	Sectors 22, 25, 28 detuned by 2 MHz, Sector 15 detuned by 4 MHz	74 mA[b]	72 mA
Future	Sectors 12, 18, 21, 24, 27, 30 detuned by 4 MHz	84 mA[b]	
Future	Additional focusing added in Sectors 24 to 30	86 mA[b]	

(a) Normalized to May, 1966 conditions
(b) Normalized to June, 1967 conditions; recomputed using present best data on rf properties.

magnet was modified so that its gap setting was 40 inches and magnetic field maps were made at the three currents: 2400, 3200 and 4000 amperes. The reference induction for these maps was 8.7, 11.0 and 12.7 kilogauss respectively. These magnetic maps were made using a 4" × 4" × 1" grid and the final data was written on a magnetic tape for a permanent record.

The 72D36 was mapped at a current of 1535 amperes in July. The grid used was a 2" × 2" × 1" and that data is now also available on magnetic tape. The reference induction at this current is 9.1 kilogauss.

The 2-meter streamer chamber magnet was mapped during July after it was moved to its new location in the C beam. A 4" × 4" × 1" grid was mapped at two currents: 6000 amperes and 10,650 amperes. At 10,650 A the reference induction is about 16.1 kilogauss. All data is on magnetic tape.

In September, the 54" spark chamber was mapped at two induction levels: 13.5 kilogauss and 7.2 kilogauss. In addition, several planes were remapped at the previously measured value of 15 kilogauss. Twenty-one planes were mapped at each value of induction on a 4" × 2" × 1" grid. All data is now on magnetic tape.

Considering all of the above measurements, about 400-500 hours of operation were logged by the rapid magnet mapper while recording millions of data points. Its performance was usually very good and it is now being overhauled in preparation for other future mappings.

During the past year, a number of other measurements were made both in the research yard and in the laboratory. These include long coil and NMR measurements on deflection magnets and quadrupole harmonic analysis. Some of these are: seven 9D12's with various gap dimensions, pole dimensions and coil configurations, several 18D72's with aluminum coils, and several 5D36's. A series of 8Q32's in the C beam were measured and one was replaced because of detected poor quality. Others measured were A400, 12D36, and several conventional 18D72's.

BR-1 was moved to a new location and a series of long coil measurements were made on it. Agreement with previous measurements was good.

A prototype pulsed machine quadrupole doublet was built and measured extensively in June and six production models were measured; one doublet has already been installed in the machine.

A prototype 6Q20 laminated SPEAR quadrupole was measured extensively. After these measurements, a solid core quadrupole was fabricated for similar tests and the decision to use the solid core was made.

At the present time, work is also being done on the preparations for measuring a large number of storage ring magnets and associated transport system magnets. A proposal is being prepared to combine the harmonic analysis techniques used on quadrupoles in the past with the rapid magnet plotter described earlier.

G. Positron Source

A new mode of operation of the positron source was successfully developed in February, 1969, and used for physics runs during the July and October cycles. This mode permits interlacing high repetition rate positron beams with high current-high repetition rate electron beams. The former method of producing interlaced electron and positron beams utilized a periodically moving "wand" target which moved rapidly across the accelerator aperture when a positron beam was desired. This operating mode was limited to about 10 pulses of positrons per second. The new method uses a fixed target which only partially fills the beam aperture. The beam is allowed to hit the target when positrons are desired, as shown in Fig. 13. The target is inserted so that it occludes slightly more than half the aperture, extending 1.5 mm beyond center. The beam aperture in the vicinity of the positron target is 17 mm in diameter and the beam is normally focused to about a 2 mm diameter at the target. Thus it is not difficult to steer one beam so that it hits the target at the center of the aperture, and to steer a second beam so that it misses the target.

The method was successfully tested in February. A 25 mA, 6 GeV electron beam and a 1 mA, 8.5 GeV positron beam were satisfactorily interlaced with this configuration and transmitted to the Beam Switchyard. In July and October, positron beams were interlaced with a wider variety of electron beams.

Since failure of a steering supply, or an inadvertent missteering could cause all beams to hit the positron target, and thus destroy it, a protective ion chamber has been installed near the target. This ion chamber, with the acronym MIST, is set to turn off the beams when the total of all intercepted beam power near the target is about 30 kW.

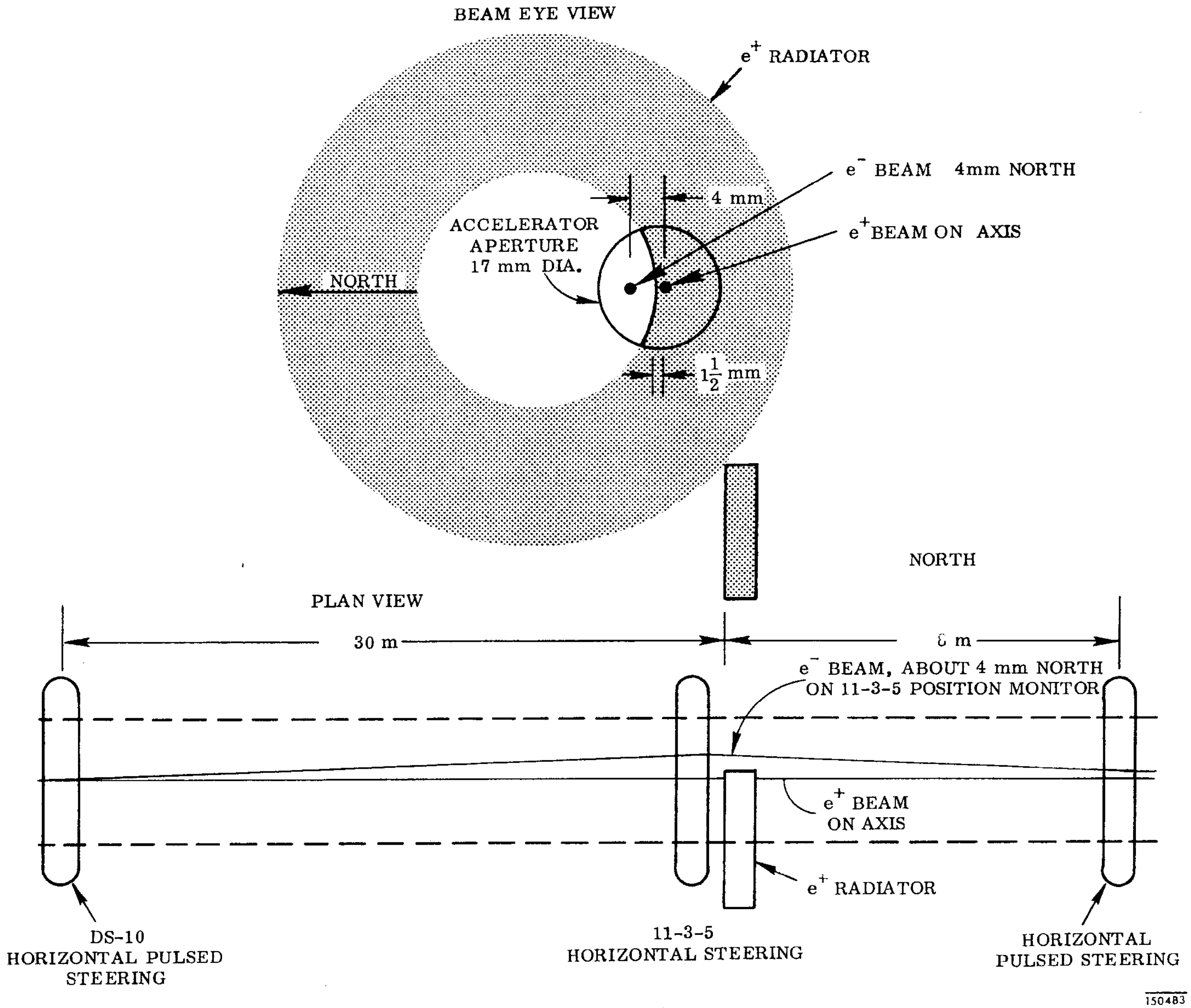

FIG. 13--Flicking beam, $e^+ - e^-$ operation.

H. SAD Committee

The SLAC Advanced Design (SAD) Committee was formed in 1968 to develop criteria and plans for future accelerator design at SLAC. During the past year, the work of this committee has been almost exclusively directed toward a feasibility study for the conversion of the existing SLAC accelerator to a two-mile superconducting linac. The first edition of this feasibility study is now complete. It consists of 35 sections devoted to various aspects of the physics applications, basic parameters, systems design and fiscal implications of a two-mile superconducting study. Papers based on this study were presented at the 1969 National Particle Accelerator Conference and at the 7th International Accelerator Conference, as noted at the beginning of this section. The copies of the report are bound in loose leaf notebooks so that sections can be rewritten and distributed as the design concepts are changed. Thus it is hoped that the study report will always be reasonably up-to-date with the latest thinking in each subject area.

With the completion of the study report, the main task of the committee is to consider the feasibility of schemes such as the electron ring accelerator or other ideas which may complement the superconducting accelerator.

I. Superconducting Accelerator Studies

Many of the anticipated problems involved in constructing a very large superconducting accelerator have been studied during the past year.

1. Cavity Fabrication and Measurements

In the microwave superconducting materials program, interest has shifted from lead to niobium. This is because, in common with other laboratories, great difficulty has been experienced in consistently producing good electroplated lead surfaces. Furthermore, these surfaces are soft, easily oxidized, and have poor field-emission properties.

Present indications are that solid niobium will be the best material for the accelerator structure. Interest in electrodeposition or chemical vapor deposition of niobium onto copper or other substrates has declined because of the complexity of the processes and the acknowledged necessity to vacuum-furnace the niobium at very high temperatures. Various processes for making accelerator cavities, such as hydroforming, circular roll-forming and electroforming, are being investigated. X-band TE_{011} cavities machined from solid niobium are being used for evaluating processing techniques. Q-values up to 5×10^9 at 2^oK

have been obtained so far, using niobium cavities which have been etched and vacuum-furnaced at 2000^{o}C. The stability and match of the microwave source used in these measurements are inadequate, and are being improved.

As a possible alternative to niobium, a copper TE_{011} cavity has been plated with the reactor-produced element, technetium. A method of electroplating this radioactive metal onto copper from an aqueous solution of ammonium pertechnetate has been developed at SLAC. It has been possible to obtain a mirror-finish on the inner walls of the cavity. The TE_{011} resonance could not be detected during the first microwave test on this cavity at temperatures down to 1.8^{o}K, presumably because the cavity Q was too low for the very light coupling employed. It is possible that the surface resistance was degraded by the presence of technetium oxide, as the deposition of oxide is known to be very dependent upon the pH value of the electrolyte. It is planned to make further tests with a technetium-plated copper end-plate sealed to a niobium cavity.

Experiments are being designed to test various tuning and matching devices, which will ultimately be incorporated into servo-systems for automatically controlling the phase and match of the proposed traveling-wave resonator accelerator structure. Tentative designs for the microwave and electronics systems to be used in these phasing and matching loops have been worked out.

Cavities assembled with electron-beam welds and vanadium brazes will be tested, to evaluate the deleterious effects of such vacuum-joints.

High power measurements will be made in TE_{011} cavities to determine critical magnetic field limitations. Cavities resonant in the TM_{010} mode will be tested before proceeding to test short accelerator sections.

2. Room Temperature Field Emission and Breakdown Measurements

Experiments which measure β, the electric field enhancement factor, are continuing. Low β values have been achieved with surfaces that are microscopically smooth. However, a surface with initially low enhancement factor may, under the stress of high electric fields, grow whiskers which increase β. Methods for reducing β by sputtering are being investigated. Surfaces are evaluated for breakdown and field emission properties at dc levels in an apparatus developed for this purpose. Provision is made to vary the separation between two electrodes and establish high fields by applying voltages up to 150 kV. The resulting current passing between the two electrodes is measured. Ultrahigh vacuum is maintained in the apparatus. It is hoped to correlate these room temperature measurements with microwave measurements on the surfaces at superconducting temperatures.

3. Measurement of Magnetic Susceptibility

Sensitive measurements of magnetic susceptibility at low frequency are made on samples in the form of rods a few inches long and about 1/8 inch in diameter. The physical variable observed is the mutual inductance between a pair of coaxial ac (100 kHz) coils wound over the superconducting sample. This mutual inductance is measured as a function of an externally applied magnetic field. A magnetic field is swept from zero to some high value and the change in susceptibility of the sample which is the central core of the coil pair is observed as a signal to a phase-locked detector. The departure from the perfect diamagnetic state is observed as a change in the mutual inductance and a consequent unbalancing indicated on the phase-locked detector. This apparatus is being utilized to observe the effect on the critical magnetic field of various processing techniques. The usefulness of this approach is that many materials can be investigated in a short time. Properties of niobium and lead have been investigated.

4. Radiation

Since the superconducting properties of materials are very structure-sensitive, it is important that the effect of lattice defects which may be caused by radiation during accelerator operation be considered. Experiments are being prepared to irradiate samples of superconducting material at a suitable place in the experimental area of the two-mile accelerator and also at lower energies in a small experimental accelerator which exists at SLAC. It is hoped by these experiments to establish some criteria for the permissible dose of radiation to an accelerator surface.

J. Optical Alignment System

In November 1967, it was discovered that alignment target 12-3 had moved 0.125 inches towards the south. Further checking proved that the accelerator had indeed moved, probably resulting from hydrostatic pressure against the end of Sector 11 and the beginning of Sector 12. The area was realigned. Subsequent months indicated a continuation of the southward trend, discretely located around 12-3. The drift was on the order of 0.010 inches per month. Obviously, the first 0.125-inch motion occurred abruptly, that is, within 2 months. As a corrective measure, 8000 cubic yards of earth were moved from the hill north of Sector 12, and dropped into the valley in Sectors 13 - 14. Since the excavation, there has been no further southward drift, but, instead, a slight rebound of about 0.015 inches.

Angular level errors were frequent in 1967, and to correct this effect, several angular levels were tried. After using each for about six months, one was adopted for use. It is the same level used by the Precision Alignment team. Several careful surveys indicate that between complete realignment periods, 30% of the target stations have excessive level errors. For this reason, it was decided that a simple laser alignment survey was not adequate to determine the degree of misalignment of the accelerator.

The original encoder-counter system, used to determine the position of the scanner and, therefore, the alignment targets, developed serious problems. The problems were such that the system had to be returned to the factory several times. Finally, the manufacturer stated that no more repair could be made for a reasonable cost, and advised SLAC to buy a new system. The new encoder-counter was accepted in September 1969. It is very satisfactory.

While the old positional readout system was being repaired and the new one was on order, six months went by without a realignment. A survey made in October 1969 indicates that, excluding angular level errors, the accelerator alignment was very stable, with a mean error of 0.015 inches. The worst errors were found in Sector 13, where three stations were found to be down by 0.030 inches and northward by more than 0.030 inches but less that 0.055 inches.

Research has continued to determine the feasibility of building a long path length optical interferometer in the SLAC alignment pipe. Recently, a prototype has operated, without counting electronics, over a path length of 1200 feet.

VIII. MECHANICAL ENGINEERING DEPARTMENT

(October 1968 - September 1969)

Accelerator Engineering and Maintenance

1. Accelerator Physics Support

Accelerator Physics personnel were assisted with detuning Sector 2. A hydraulic tool for quick repeatable tuning was designed and built. Frequency shift vs. tuning depth was determined and ten additional sectors were tuned "blind," i.e., without making microwave measurements. The tool proved to work extremely well, allowing two sectors to be detuned per day.

Pulsed quadrupole magnets were designed and fabrication of eight magnets was completed. A drift section was modified to accept a pulsed quad doubled and installed at Sector 28. A second drift section is presently being modified.

A fast beam monitor was designed, built and installed at Sector 10. New beam knockout plates were installed at the injector. Rework of the keybanks, to improve their reliability, was completed. Target and shutter assemblies were designed and installed in the drift sections at Sectors 17 and 18 for Experiment 43.

2. Accelerator Maintenance

Alignment of accelerator sections on their support girders (quarter point alignment) was checked. The effect of temperature variations on alignment was found to be greater than previously believed. Alignment checks and adjustments have therefore been made with the hatches to the accelerator housing closed. Approximately one-half of the accelerator was checked during the last year. Most accelerator sections were found to be within $\pm$ 0.015 inch. Those that were out of alignment more than $\pm$ 0.010 inch were re-aligned. Re-alignment of more than 0.015 was required at only twelve stations, the maximum observed misalignment being 0.033 inch.

Protective covers over the vacuum bellows in the accelerator housing have been replaced in areas where the plastic covers have deteriorated. The new covers are all metal and will therefore not be subject to radiation damage. This activity is continuing as required.

Some minor repairs and adjustments to the thin in-line vacuum valves were required. A small vacuum leak developed in one of the injector waveguide sections and was repaired.

3. Positron Source

Redesign of the wand target and drive system was completed and the system was fabricated and installed. Lead shielding was placed over the Panofsky long ion chamber (PLIC) cable in the positron source area. The shielding allowed the PLIC sensitivity to be increased throughout Sector 11 thereby offering greater machine protection in that sector.

4. Magnets

This period was one of considerable magnet production and one of even greater demand. One large spark chamber magnet (100D40) was completed and another (72D36) was designed and built. These two magnets are the second and third generation of such large magnets using aluminum coils and considerable empirical data was obtained on magnet mirror design as well as cost and fabrication techniques for aluminum coil construction.

Four sweeping magnets (5D36) were procured and one (12D36C) was fabricated. The latter was to be used close to another beam which made the C configuration mandatory. The former are standard H magnets with a bending capacity of 16 to 18 kilogauss meters. It was hoped that these magnets could be used to sweep charged particles out of neutral beams thus liberating some bending magnets with better field shape and/or more bending capacity for use as regular beam transport bending magnets.

Our standard beam transport bending magnet (18D72) was redesigned to use aluminum coils. Four magnets were fabricated to the new design and it was found that a 25% reduction in cost could be realized by sacrificing only 1.5 to 3% in performance.

Four small C magnets (9D12) were designed and constructed. These were originally conceived as steering magnets but only one is being used for steering. The others have been strengthened in one way or another so that they can be used as small beam transport bending magnets.

Four small quadrupoles (1.5Q26) were procured to be used as general beam transport lenses. Procurement of three larger quadrupoles (8Q48) was initiated and a contract was awarded for the repair of three more quadrupoles (8Q32). Upon the completion of these contracts the quadrupole supply situation will be much brighter although the demand for bending magnets both large and small still far exceeds supply.

IX. PUBLICATIONS ISSUED

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SLAC-PUB-590
ELECTRONIC INSTRUMENTATION FOR A NON-INTERCEPTING GAMMA-BEAM MONITOR. A. Barna, E. L. Cisneros, C. Dale, A. Johnson. Submitted to Nuclear Instruments and Methods.

SLAC-PUB-601
A NON-RELATIVISTIC STRONG-COUPLING MODEL WITH A RECOILING SOURCE. A. Krass (UC-Santa Barbara). Submitted to Physical Review.

SLAC-PUB-604
π^0 PHOTOPRODUCTION FROM HYDROGEN AT BACKWARD ANGLES. R. Anderson, B. Gittelman, J. Litt, B. H. Wiik, D. Yount; D. Tompkins (Penn); A. Minten (CERN). Physical Review Letters 23:725-728, 1969.

SLAC-PUB-605
A BEAM MONITOR SYSTEM FOR HIGH-INTENSITY PHOTON BEAMS IN THE MULTI-BEV RANGE. G. E. Fischer, Y. Murata. Submitted to Nuclear Instruments and Methods.

SLAC-PUB-606
A THEORY OF DEEP INELASTIC LEPTON-NUCLEON SCATTERING AND LEPTON PAIR ANNIHILATION PROCESSES, I. S. D. Drell, D. J. Levy, T-M. Yan. Submitted to Physical Review.

SLAC-PUB-608
A SURFACE-WAVE DESCRIPTION OF π^+p BACKWARD SCATTERING. H. C. Bryant. Submitted to Physical Review.

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INTEGRATED-CIRCUIT DISCRIMINATOR WITH 10-NSEC PULSE PAIR RESOLUTION. A. Barna, E. L. Cisneros. Submitted to Nuclear Instruments and Methods.

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SLAC-PUB-619
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SLAC-PUB-623
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SLAC-PUB-625
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SLAC-PUB-627
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SLAC-PUB-628
THE DESIGN FOR A NONINTERCEPTING PHOTON-BEAM MONITORS. R. A. Gearhart, P. R. Klein, J. J. Murray; W. J. Podolsky, M. S. Rabin (UCLRL-B); C. K. Sinclair (Tufts). Submitted to Nuclear Instruments and Methods.

SLAC-PUB-631
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SLAC-PUB-632
A PHENOMENOLOGICAL ANALYSIS OF π^+ AND π^0 PHOTOPRODUCTION AT BACKWARD ANGLES. J. V. Beaupre, E. A. Paschos. Submitted to Physical Review Letters.

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SLAC-PUB-634
DETERMINATION OF THE REAL PART OF THE COMPTON AMPLITUDE AT A NUCLEON RESONANCE. S. J. Brodsky; A. C. Hearn (Stanford ITP); R. G. Parsons (Texas). Submitted to Physical Review.

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SLAC-PUB-641
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MUON-PROTON INELASTIC SCATTERING q^2 LESS THAN 1.2 $(GeV/c)^2$. B. D. Dieterle, T. Braunstein, J. Cox, F. Martin, W. T. Toner, M. L. Perl, T. F. Zipf; W. L. Lakin (Stanford HEPL); H. C. Bryant (New Mexico). Physical Review Letters 23:1187-1190, 1969.

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THE EXTERIOR THREE-PARTICLE WAVE FUNCTION. H. P. Noyes. Physical Review Letters 23:1201-1204, 1969.

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Conference on $\pi\pi$ and $K\pi$ Interactions, Argonne National Laboratory, May 1969.

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Birmingham Conference on the Three-Body Problem in Nuclear and Particle Physics, England, July 1969.

INTRODUCTORY TALK. H. P. Noyes (SLAC-PUB-667)

International Conference on High Energy Accelerators, 7th, Yerevan, Armenia, USSR, August 1969.

SLAC: STATUS, RECENT PROGRESS, AND FUTURE PLANS. R. B. Neal (SLAC-PUB-624)

TWO-MILE SUPERCONDUCTING ACCELERATOR STUDY. W. B. Herrmannsfeldt, G. A. Loew, R. B. Neal. (SLAC-PUB-626)

THE STANFORD POSITRON-ELECTRON ASYMMETRIC RINGS (SPEAR). SLAC Storage Ring Group, presented by B. Richter. (SLAC-PUB-630)

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DETERMINATION OF THE TOTAL PHOTON-PROTON CROSS SECTION FROM HIGH ENERGY INELASTIC SCATTERING. E. D. Bloom, R. L. Cottrell, D. H. Coward, H. DeStaebler, J. Drees, G. Miller, L. W. Mo, R. E. Taylor; J. I. Friedman, G. C. Hartmann, H. W. Kendall (MIT LNS). (SLAC-PUB-653)

COMPARISON OF u-CHANNEL ρ^0 PION-PRODUCTION WITH THE ISOVECTOR PART OF π^+ PHOTOPRODUCTION. Z. G. T. Guiragossián. (SLAC-PUB-657)

STUDY OF THE REACTION $\gamma p \rightarrow \pi^+\pi^-\pi^+\pi^- p$ ABOVE 4.5 GeV AND EVIDENCE FOR A πA_1 ENHANCEMENT. M. Davier, I. Derado, D. C. Fries, F. F. Liu, R. F. Mozley, A. Odian, J. Park, W. P. Swanson, F. Villa, D. Yount. (SLAC-PUB-666)

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National Symposium of American Vacuum Society, 16th, Seattle, Wash., October 1969.

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SWITCHING PROPERTIES OF THE EMITTER-COUPLED TRANSISTOR-PAIR. A. Barna. (SLAC-PUB-578)

A SIMPLE DIODE MODEL INCLUDING CONDUCTIVITY MODULATION. A. Barna, D. Horelick. (SLAC-PUB-617)

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SLAC-96
THE USE OF MAN-MACHINE INTERACTION IN DATA-FITTING PROBLEMS. L. B. Smith.

SLAC-99
CIRCE - A GENERAL MULTI-PRONG FITTING COMPUTER PROGRAM FOR SPATIAL COORDINATES IN A NON-UNIFORM MAGNETIC FIELD. D. E. Fries.

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