SLAC-90
UC-28, Particle Accelerators
and High-Voltage Machines
(SR)

TWO-MILE ACCELERATOR PROJECT

Quarterly Status Report
1 April to 30 June 1968

August 1968

Technical Report
Prepared Under
Contract AT(04-3)-400 and
Contract AT(04-3)-515
for the USAEC
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INTRODUCTION

This is the twenty-fourth Quarterly Status Report of work under AEC Contract AT(04-3)-400 and the eighteenth 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 April 1, 1968 to June 30, 1968. 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. In January 1967, a beam energy of 20.16 GeV was achieved. Beam currents up to 45 miliamperes peak have been obtained.

The terms of Contract AT(04-3)-400 provided for a fully operable accelerator and for sufficient equipment to measure and control the principal parameters of the electron beam; in addition, provision was 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 on January 1, 1964, provides 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. Among the principal activities covered in the scope of Contract AT(04-3)-515 are theoretical physics studies, experiments performed by the SLAC staff at other accelerators, research-equipment development programs (such as particle separators, specialized magnets, bubble chambers, etc.), and research into advanced accelerator technology. Contract AT(04-3)-515 also provided for the initial stages of operation of the Center after completion of construction.

I. ACCELERATOR OPERATIONS

A. OPERATING HOURS

	April	May	June	Quarter
Manned Hours				
Physics Beam Hours*				
Machine Physics	21	38	83	142
Particle Physics	236	297	346	879
Total Physics Beam Hours	257	335	429	1,021
Non-Physics Hours				
Scheduled Accelerator Maintenance	100	20	17	137
Accelerator Failure	116	35	35	186
Search or Shut-Down	2	1	--	3
Accelerator Tune-Up	29	28	13	70
Beam Off - Accelerator Physics Request	3	1	2	6
Beam Off - Research Area Request	25	28	24	77
BSY or End Station Malfunction	10	15	19	44
Tune-Up and Adjust. of BSY and End Station	10	16	20	46
Search and Clearance of Radiation Areas	--	--	--	--
Other	--	9	1	10
Total Non-Physics Hours	295	153	131	579
TOTAL MANNED HOURS	552	488	560	1,600
Experimental Hours**				
Machine Physics	28	38	128	194
Particle Physics				
End Station A	186	252	281	719
End Station B	122	186	297	605
End Station C	214	242	176	632
Total Particle Physics	522	680	754	1,956
TOTAL EXPERIMENTAL HOURS	550	718	882	2,150

B. BEAM INTENSITY

	April	May	June	Quarter
Peak	37.5 mA	37.0 mA	38.0 mA	38.0 mA
Average	11.0 μA	13.0 μA	4.0 μA	9.3 μA

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

**Number of hours an experiment is run including actual beam hours and beam downtime "normal to the experiment." Additionally, experiments run simultaneously are acknowledged.

C. KLYSTRON EXPERIENCE

	April	May	June	Quarter
Total Klystron Hours	73,597	109,897	124,051	307,545
Number of Klystron Failures	4	6	8	18

D. BUBBLE CHAMBERS

	April	May	June	Quarter
Number of Pictures Taken - 82" HBC	154,538	430,482	89,975	674,995
Number of Pictures Taken - 40" HBC	--	17,000	--	17,000

E. DATA ANALYSIS

	April	May	June	Quarter
Spark Chamber Events Measured	2,942	7,879	4,691	15,512
Bubble Chamber Events Measured	14,151	9,412	11,856	35,419

F. COMPUTER OPERATIONS

	April	May	June	Quarter
Manned Hours				
Computation Hours				
SLAC Facility Group	147	114	131	392
User Groups	461	494	369	1,324
Total Computation Hours	608	608	500	1,716
Non-Computation Hours				
Scheduled Maintenance	45	43	38	126
Scheduled Modifications	27	44	35	106
Unscheduled Down Time	12	7	34	53
Idle Time	12	23	9	44
Utility Failure	--	--	10	10
Total Non-Computation Hours	96	117	126	339
TOTAL MANNED HOURS	704	725	626	2,055

G. SPECIAL OPERATING FEATURES

1. Positrons

Using the "wheel" target, positrons were delivered to all beams for a total of 58 hours during May. There were no experiments requiring the "wand" scheduled during the quarter.

2. Beam Knockout

The beam knockout was run for about 20 hours in April and 3 hours in June for experiment E-32 and for about 14 hours in June for machine physics runs.

3. Power Supplies

The 3.4 MW power supply was run for 228 hours during April and for 100 hours during June. It was down during the month of May for rebuilding.

The 5.8 MW power supply was inoperable all quarter.

Installation of the motor-generator facility was completed in May and ran for about 48 hours of miscellaneous testing and for 312 hours of experimental time in June in conjunction with the 2 meter spark chamber.

4. Scheduled Shut-Down

The accelerator was off for one week in May for a scheduled shut-down.

5. The accelerator was inoperable for approximately one week in April due to failure of the main drive line. Partial repair permitted low energy operation for an additional week after which high energy operation was resumed. Additional permanent repairs are continuing.

H. SEMI-ANNUAL SUMMARY OF ACTIVITIES

Recognizing the desirability of longer periods of uninterrupted operation, yet limited by the budget in the number of operating shifts a week, a revised schedule was put into effect early this year. The first week of January was the last week of the old schedule, where operation commenced on Monday at 1600 hours, and ended at 1600 hours Saturday. This was followed by two periods of a two-week-on, one-week-off cycle, with thirty shifts of high-energy physics runs scheduled for the two-week-on period (giving an overall average of 10 shifts per week of operation). A revision in the operating budget afforded somewhat expanded operation, and the present schedule of two weeks "back-to-back" was inaugurated early in March. A two-week operating cycle is generally scheduled as follows. The accelerator housing is open throughout day and swing shift on the first Monday. Early shift 1 on Tuesday, the housing is searched and secured, klystrons are turned on and, hopefully, a beam is set up to the low energy (3 GeV) beam analyzing station at Sector 20 (BAS II). The succeeding four shifts are scheduled for machine physics tests and experiments, following which high energy physics runs commence and continue through the weekend and on to 1500 hours Friday of the second week. (A total of 26 or 27 shifts.) Shift 3 Friday is devoted to hot maintenance, reserved for tuning and maintenance on those modulator/klystron stations that cannot be released for this purpose during beam runs.

For major equipment installation, there were two scheduled down periods, one starting at 0000 hours Wednesday, the second week of Cycle 19* (March 18 through 31)

*The Cycle numbers were chosen so that Cycle 26 would fall at the end of the fiscal year.

and the other starting at 0800 hours Monday, the second week of Cycle 23 (May 13 through 26). This was in addition to the two down weeks occurring in January and February as part of the "two-week-on, one-week-off" operation.

Cycle 21, April 16-26, featured very abbreviated operation, when the main drive line failed, requiring nearly twenty shifts of repair time.

During the first quarter of calendar 1968, with a total of 175 manned shifts, there were 140 shifts scheduled for high energy physics runs and 20 for machine physics. (An additional 7 shifts of machine physics time was scheduled to run concurrently with one or more particle physics runs.) During the second quarter of calendar 1968 the respective figures were 220 manned shifts, 174 particle physics shifts and 21 machine physics shifts, with one additional concurrent shift. Figure 1 shows the comparison of scheduled time with previous quarters.

It is quite evident that the new mode of operation, featuring longer uninterrupted running periods, is beneficial. It almost invaribly takes several shifts after a start up for the accelerator to "settle down", following which operation is generally quite smooth until the end of the cycle. With only half the number of start-ups, there is a significant improvement in operation.

Figure 2 compares the first two quarters of calendar 1968 with previous quarters, where the terminology used is the same as used in previous quarterly reports. The improvement in operation during the first quarter of calendar 1968 is obvious. The sharp drop in delivered beam in the second quarter can be attributed largely to the main drive line failure which occurred during Cycle 21, accounting for 160 hours of accelerator failure. (If Cycle 21 were omitted from the calculations, the total percentage of delivered beam for this quarter would increase to 76.7%.) Beginning with the Cycle scheduling, it is difficult to make an exact comparison with previous quarters. An additional two shifts (16 hours) have been added to each cycle. This is included in the "Manned Hours" figure, yet little of it contributed directly to the delivered beam hours. Eight of these additional 16 hours have been charged to search/shut down, expanding the category to search/ start-up/shut down. The other eight hours appears on the short-term schedule as operator beam tests. Those hours where a useful beam has been achieved, have gone to machine physics, the rest where troubles have been encountered in starting up, are included in accelerator failure.

It should be realized that, when using these figures to estimate the "efficiency" of operation, that the method of calculation would not allow greater than 91% delivered beam, even if there were no time charged to accelerator failure, tune-up or RAD/AP

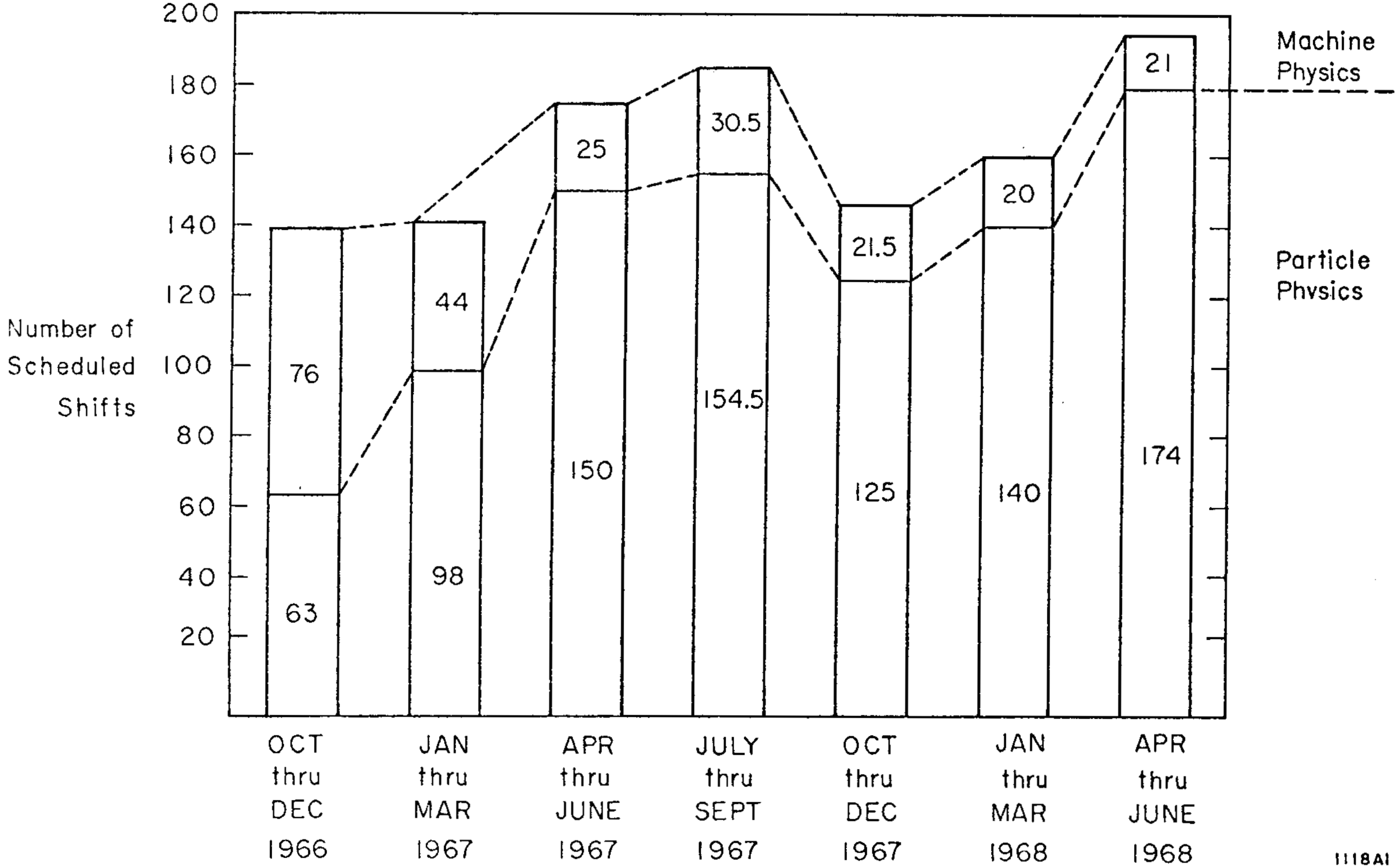

FIG. 1--Beam time, shifts per quarter

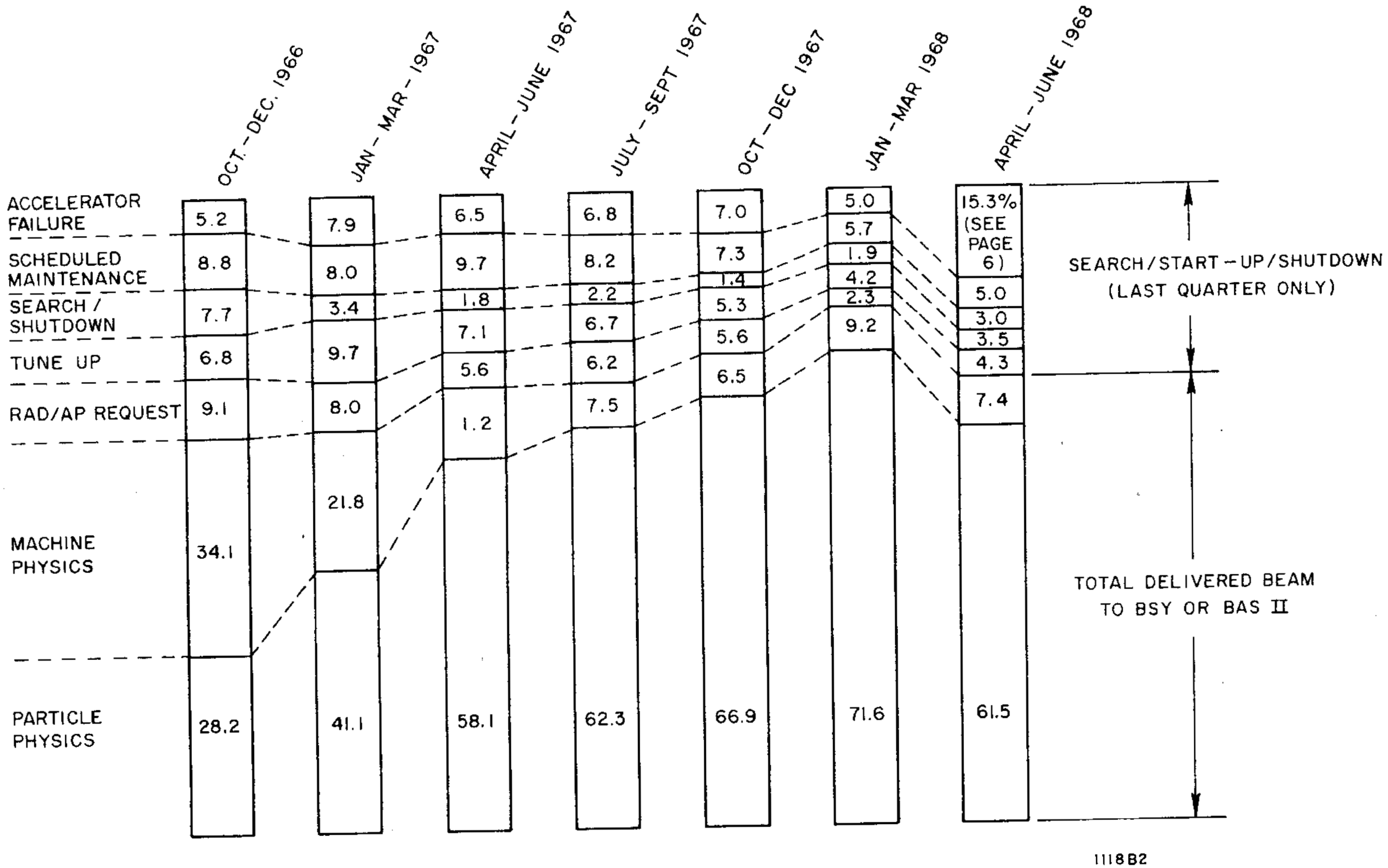

FIG. 2--Beam time in percentages per quarter.

request. This follows because, of the 272 manned hours in a normal cycle, 25 are charged to scheduled maintenance and "search and shutdown."

I. POSITRON OPERATION

(The major portion of the positron operation took place during the first quarter of calendar 1968, with only 11 shifts of positron runs since April 1st. The schedule calls for a large share of positron operation during the next quarter.) Of the 83 shifts scheduled for positron operation, there were actually 75 shifts of experimental runs. Of these, 33 were with the wand, running interlaced e^+ and e^- beams, and 42 with the wheel. During part of the latter runs, there were also wheel-generated electrons in use. The discrepancy in scheduled and actual shifts can be explained by the fact that the latter figure does not include the time scheduled for experimental operation that was actually used for positron set up. Also, three shifts scheduled for wand generated positrons during the first week of the period were cancelled because of failure of the experimenter's equipment.

While the positron operation can be called quite successful, with long periods of uninterrupted e^+ beam, and excellent yield (up to 4%), a great many problems have been encountered. The high current power supplies for the three solenoids at the positron source have been a continual source of trouble. The positron water system has failed several times, largely because of leaky seals on the two main water pumps. Other troubles included an intermittent short in a vital quadrupole, e^+ triggering, wand timing, and deterioration of a main water hose to the wand. However, these problems are all yielding to persistent efforts at cure, and the positron operation continues to improve.

J. ACCELERATOR FAILURES

The major accelerator problem during the period was, of course, the failure of the main drive line. Briefly, the problem was one of joint corrosion. This took place at the connections between twenty foot lengths of the inner conductors, and at the expansion joints between each sector. The increase in VSWR led to arcing, resulting in actual puncture of the line. The final cure was complete dismantling, cleaning, replacement of connectors and reinstallation. The electrical breakdown in the line, before actual collapse of the system, affected operation during the weeks before Cycle 21. Following repair, it was several weeks before installation of the water lines and insulation for temperature control could be completed; during this period operation was much more unstable than normal.

In February the gun failed. This gun had been in operation since October 1965 and had logged 17,000 heater and 14,000 high voltage hours; a fantastic record. Installation of the replacement gun was rapid, and operation was delayed little more than 8 hours by the event.

The gas burst problem discussed in this section of previous quarterly reports has apparently been solved. An account of the phenomenon appears in the Klystron section of the Quarterly Report for the period 1 January to 31 March 1968.

With the exception of the problems encountered in the positron source area, other accelerator failures have tended to be minor. The down time charged to accelerator failure is in general the accumulation of a large number of short outages, and cannot be attributed to any one system or area of the machine.

K. ACCELERATOR IMPROVEMENTS

Because of economic considerations only two video cables running the length of the accelerator were installed during the initial construction. By use of video repeaters and amplifiers, information can be patched into these cables at any sector but the number of signals in the control room is limited to two at any one time. During this period, the use of the system has been greatly expanded by the installation of a remote (from CCR) switching system, which allows the operator to easily switch not only several signals at any one sector, but also from any sector to another. Among other uses, this has simplified the search for the cause of energy instabilities along the machine.

Toward the end of the period a new and greatly improved gun modulator was installed. The major feature is the ability now to get six independent beams; however, the design is based on the experiences gained with the previous modulator and it is expected to be a much more satisfactory piece of equipment. Installation was rapid and the debugging period was remarkable short and trouble free.

There have also been a number of relatively minor changes and improvements that have contributed to ease and reliability of operation.

II. ACCELERATOR DEVELOPMENTS

Klystron life performance to date continues to exceed previous expectations. The mean age of all klystrons on the machine as of July 1, 1968 was 6,570 hours compared with 5,820 hours as of April 1, 1968 and 5,200 hours as of February 1, 1968. There are currently 62 tubes which have operated between 9,000 and 10,000 hours and 15 tubes which have operated over 10,000 hours.

A modification to the RCA contract was negotiated by which the total number of magnets will be increased by ten. Twelve Sperry magnets were modified to accept RCA tubes and some of these tubes have been installed on the line.

A modification of the Litton contract for sub-booster klystrons has been negotiated reducing the quantity from 100 to 12. SLAC built sub-booster klystrons have been performing satisfactorily. Five tubes were installed during the quarter and have accumulated operating hours ranging from 900 to 2,830 hours. The mean age of Eimac tubes in operation is 9,500 hours and the oldest Eimac tube has been operating 17,878 hours.

Failure of the main drive line in April was responsible for approximately a week's down time and a week's limited operation of the machine. The initial failure occurred at the end of sector 6 so the drive line in sectors 6 and 7 was removed and cleaned and two damaged sections were replaced. These initial repairs permitted limited operation of the accelerator, but beam stability was clearly unsatisfactory, leading to the decision to disassemble and clean the first 15 sectors. This work was accomplished and operations resumed.

During the scheduled down week of May 21 - 28 a major modification was made in the RF drive system in order to reduce the probability of future drive line failures. The modifications consisted of reducing the operating power output of the main booster amplifier at the beginning of the accelerator from 17 to 8 kW. Since the input power to the 30 individual sectors of the machine could not be changed accordingly, the coupling ratios of the 30 main drive line couplers had to be decreased by approximately 3 dB. This was accomplished by moving all couplers four sectors upstream. Four new couplers were procured to fill the last four coupler positions made vacant by the move, but upon delivery they were found to be inadequate. It has not yet been determined whether they can be reworked or whether new ones must be ordered.

Beam break-up studies continued during the quarter. Tests to determine the optimum dimpling pattern, which must give at least 3 MHz detuning on both the horizontally and vertically polarized HEM_{11} modes with minimum phase-shift and VSWR deterioration at 2856 MHz continued. Because of variations in dimpling technique used during the initial tuning of accelerator sections, there was some doubt as to whether the frequencies of HEM_{11} resonances in the first eleven cavities were the same in machine installed accelerator sections as had been measured on test sections in the laboratory. Four sections were disconnected and tested: two in sector 1, one in sector 2 and one in sector 14. The frequencies of corresponding resonances were found to agree within 2 MHz. Tests indicated that dimpling cavities 3, 4, and 5 at the 45^{o} points to produce a phase shift of 9^{o} per cavity at 2856 MHz would produce sufficient detuning around 4140 MHz. A dimpling tool, consisting of a steel cylinder split along a diametral plane and hinged along one side so that it could be clamped around the accelerator pipe, was made. The cylinder has rows of 4 tapped holes in the 45^{o} planes through which dimpling screws are inserted. Once the tool is clamped in place, it can be used to dimple three cavities. The tool was used on 3 reject accelerator sections in the laboratory to confirm earlier experimental results and then, during the machine shut-down week of May 20, accelerator section 1-1C was dimpled. Transmission phase-shift and input VSWR were monitored as the dimpling proceeded in small steps. The total phase shift introduced in cavities 3, 4 and 5 was -29^{o}. The input VSWR was 1.06 before dimpling and 1.07 afterwards. The shift of BBU resonant frequency was +4.28 MHz. After the dimpling was completed, the energy contribution of section 1-1C was measured by several methods, one of which showed a decrease in energy of about 5% whereas the expected decrease was only of the order of 1%. It was not clear that this effect was attributable to the dimpling operation, so it is planned to essentially repeat the experiment by dimpling 1-1B, taking very careful "before and after" measurements of energy contribution as a function of klystron power and phase.

A satisfactory 3-inch positron "wheel" bellows has been secured, but not in time for the May experimental run. A replacement 2-inch "wheel" was installed for this run and operated satisfactorily.

The air actuated drive system for the positron "wand" has been replaced by an electric motor driven system. Initial tests have been satisfactorily concluded and the system will be used for experiments during the month of July. The smoother action of the motor driven system is expected to result in longer life expectancy for the "wand" and a lower incidence of failure in operation.

III. RESEARCH AREA DEVELOPMENTS

A. GENERAL BEAM SWITCHYARD (BSY) AND RESEARCH AREA ACTIVITIES

Installation of a thick concrete shielding wall in the B-Beam of the BSY which isolates the B-target room from the remainder of the BSY is now complete. A radiation safety check has been made. The B-target room can now be made accessible during operation of the beam to End Station A and the Central Beam. This will greatly facilitate beam construction in this area. Various beam line valves and beam position and current monitors have been installed in the three beam lines in the B-target room. In the A-Beam, improvements in high power beam handling capability continue. As an example, in the past difficulty has been encountered in centering the electron beam in the A-Beam dump due to insufficient beam monitoring. Because of a target placed in the beam upstream from the dump it is desirable to have a visual profile; also, a continuous display is desirable. A prototype air Cerenkov cell is being tested and is operating satisfactorily as a beam monitor in that location. At the beam power levels involved a ZnS screen monitor fails in just a few minutes of operation.

The B-Beam switching facility was given a check-out and operates satisfactorily. This facility allows programmed pulse-to-pulse switching of the accelerator beam to three experimenters in End Station B. In principle, use of the system allows the accelerator to operate with six useful independent beams; e.g., a beam of arbitrary rep rate, energy and current including beam knockout to End Station A, End Station C, and the tune-up dump, and three beams of the same energy but different rep rates and current including beam knockout to the End Station B. In practice, this is presently difficult to achieve operationally because of inadequate instrumentation and certain limitations which result from accelerator beam optics. Presently planned additions will greatly improve the situation and routine operation with six beams should be possible. The present capability for switching is limited to about 19 GeV by the maximum output of the pulsed power supplies.

Design studies are in progress for the resolution of various problems having to do with thermal damage of equipment in the primary beam lines and radiation resulting from the high power electron beams produced by the accelerator. Hardware modifications are being made as rapidly as possible: (1) Several beam outages have resulted from damage to vacuum flanges near the downstream end of the BSY divergent chamber. A study of what protection devices can be placed in this area to prevent future damage is in progress. (2) High radiation levels in the research yard near End Station A result when experimenters require thick targets and/or high intensity beams. Although much improvement has been made in this situation, further improvement is required to meet experimental requirements, in particular if access to the streamer chamber is required during spectrometer operation. (3) In End Stations B and C high reliability dumps and collimators are required for locations where failure of these devices could allow the primary beam to escape and result in extremely high personnel radiation exposures.

The high-Z momentum defining slit SL-31 in the BSY B-Beam developed a water-to-vacuum leak on June 5. This required that accelerator operations scheduled for the remainder of the week be terminated. During this down period SL-31 was removed from the BSY and the A-Beam high-Z slit SL-11 was substituted. A-Beam can operate temporarily using only the high power slit SL-10 until SL-31 can be repaired and returned to the BSY.

A pressure test with water indicated a leak in both jaws of slit SL-31 located in the area of the shower maximum and on the front or collimating faces. A detailed examination of the copper modules is not yet possible due to high radiation. However, preliminary observations indicate deformations (due to yielding) in the area of the shower maximum. The texture of the copper surface shows typical signs of thermal fatigue failure (as for example at the positron source). It is thought that the failure occurred due to a combination of factors, such as crystal growth, embrittlement due to radiation damage of the copper, and permanent deformation due to excessive thermal stresses, and thermal fatigue due to the pulsing nature of the beam. Once the radiation level of the modules is lower, they will be sectioned and analyzed.

A decision has been made to repair the slit by substitution of new modules of the same design. The two new modules are in fabrication and SL-31 is expected to be ready for installation about August 1, 1968.

As a part of the program of obtaining general purpose equipment for construction of experiments a small number of beam transport magnets and one large volume magnet are being constructed this year. These consist of two 8Q48, two 18D72, and one 100D40 magnets. The progress of construction of these magnets is as follows: Both the coils and iron machine work on the 8Q48 magnet is complete. Assembly remains to be completed. One of the 18D72 will be complete in July. The second will be complete in August. All coils for the 100D40 magnet are complete and have passed electrical checks. The coils for this magnet are constructed from aluminum conductor. Final machining of the 160 tons of iron for the magnet is in progress.

B. LIQUID HYDROGEN TARGETS

The following are the principal activities of the liquid hydrogen target program during the quarter: Results of Experiment E-4a, e^- p elastic scattering, indicated significant density changes in the liquid hydrogen target due to beam heating. Because it is necessary to know the density of the target material in order to perform parts of the experiment, a means of control had to be found. It appeared necessary to flow the hydrogen through the beam at a velocity such that the density seen by any one pulse was uniform to 2%. Two solutions were proposed: The first was to attempt to increase the natural convection currents in the target cell; the second was to redesign the cell incorporating a means of forced convection. It was decided to use the former solution in the Experiment E-4b, e^- p inelastic scattering, scheduled for the end of July. To this end a model with water as a working fluid was designed and fabricated. The preliminary test results show the heat losses in the model high; however, fluid velocities of 18 inches per second were obtained. It was felt that these velocities were high enough to warrant the inclusion of three 70 watt heaters in the E-4b target, scheduled for July 29, 1968.

The redesign of the End Station A reservoir was completed in this period. The major parts were released for fabrication.

The condensing target cell fabricated for Experiment E-11b was assembled, tested, and placed in operation during June. The target for experiment E-32 was 70% completed during June.

C. POWER SUPPLIES

Primary activities with research area power supplies and ac distribution were as follows: Installation work required for operation of eight new 400 kW power supplies which arrived in May progressed. Two ac substations were procured and installed. The dc distribution cable and control wiring for the new 400 kW power supplies were also installed. At the conclusion of this installation work it will be possible to power all three of the present beam lines in the End Station B simultaneously. However, when the 100D40 is installed for Experiment E-31, power supply sharing will again be required until new 1.6 MW power supplies become available.

The 5.8 MW power supply was repaired to operate at 3/4 rating using three of its original four transformers. This power supply failed again during operation of the streamer chamber on June 6 due to another transformer failure. The revision of the 5.8 MW power supply for use with Askarel-filled transformers is under way. An order for new transformers for the supply has been placed.

The transformers in the 3.4 MW power supply had been operating at an internal temperature considerably above the rating of the insulation. Early in May these transformers failed, shutting down the power supply. Fortunately, the new Askarel-filled transformers for this supply were delivered to SLAC during the month. The power supply was back in operation in June.

During the quarter the installation and checkout of the two 1.6 MW motor generator units was completed. These units are now in operation.

D. INSTRUMENTATION AND CONTROL

Instrumentation and control work in the Data Assembly Building (DAB) continued in two areas: System improvement of the present control area, and DAB Expansion System Design. The beam monitoring system was improved by the addition of a new oscilloscope providing a high brightness trace under all operating conditions. The temperature monitoring improvements started several months ago became partially operational during April; the new system allows direct digital readout of the temperature of any of the platinum resistance thermometers in the BSY. Spectrum display in the accelerator control room has been improved by addition of spectrum drift indication for the B-side of the BSY. Design of all major system changes required by the expansion was completed during April. Chassis rework and new chassis for the profile monitor, position monitor, spectrum control, personnel protection and target control systems were either completed or in fabrication during the quarter.

Changeover from the original interlock circuits to the new system was made during June. This entailed moving all of the signals from the BSY and Research Area interlock sensors from one summary circuit to the other, modifying many of the sensor chassis and interlock controls, and installing new control panels at the operation console. This was accomplished without loss of beam time by installing as much of the cabling as possible in parallel with existing cables and making the necessary change in wiring during a long shutdown weekend.

The new system, when fully implemented, will allow operators to establish multiple beams in all beam lines, selecting six out of nineteen destinations for the primary beams (the present CCR controls allow a maximum of 6 beams to be set up). Each of the beams can be interlocked separately at the final destination but are interlocked in common where they coincide.

Each of the three major channels (A, B, C) can be operated in a "half-beam" mode, such that if the appropriate slit or stopper is closed the interlocks downstream of the slits or stopper are ignored and the beam can be turned on for accelerator check-out.

If beam is detected in the entrance toroid to a beam channel when there should be no beam there, all beams are tripped off (the "errant beam detector"). Addition of this feature allowed us to provide a "tune-up" beam pattern which is interlocked only by signals upstream of the tune-up dump. This allows operation of the accelerator into the tune-up dump (D-10) even if interlock problems arise later in the switchyard. Final implementation awaits changes in the trigger system (at present only five of the nineteen destinations are available for this reason) and additions to the current monitoring system to allow operation of the errant beam detector circuits and the tune-up beam.

E. DESCRIPTION OF APPROVED EXPERIMENTS

Table I is a list of presently approved high-energy physics experiments. The Reaearch Area Plan Drawing, Fig. 3,shows the location of the various experiments. A summary description of each experiment follows:

E-1 Proposal For a Survey of the μ-p Elastic Interactions at High Energy

J. Brown, J. Cox, F. Martin, M. L. Perl, T. H. Tan, W. T. Toner, T. F. Zipf, (SLAC).

This experiment is a spark chamber experiment using large optical spark chambers. A monochromatic muon beam of 2 to 13 GeV/c passes through a 2 meter long liquid hydrogen target. The scattered muon has its angle, momentum, and identity measured by two sets of spark chambers on either side of a large magnet. For an elastic event the angle of the recoil proton is also measured via a spark chamber. The spark chambers are triggered by a system of counters before and after the magnet.

The objectives of the experiment are:

1. To survey the $\mu + p$ inelastic interaction for muon scattering angles of 20 to 30 milliradians and muon energy losses up to 10 GeV.

2. To measure the $\mu + p$ total inelastic cross section as a function of incident muon energy and minimum q^2.

3. A particular aspect of 2 is the study of the small q^2 (down to .01 $(GeV/c)^2$) inelastic cross section, where there are relatively small radiative corrections for the muon compared to the electron.

4. The extrapolation of the small q^2 inelastic cross section to $q^2 = 0$ to obtain the photoproduction inelastic cross section.

5. To compare intermediate q^2 muon inelastic scattering with the electron case to examine the validity of the single virtual photon exchange concept and of the radiative correction calculations.

6. To compare large q^2 (up to 4.0 $(GeV/c)^2$) muon inelastic scattering with the electron case to look for muon-electron differences.

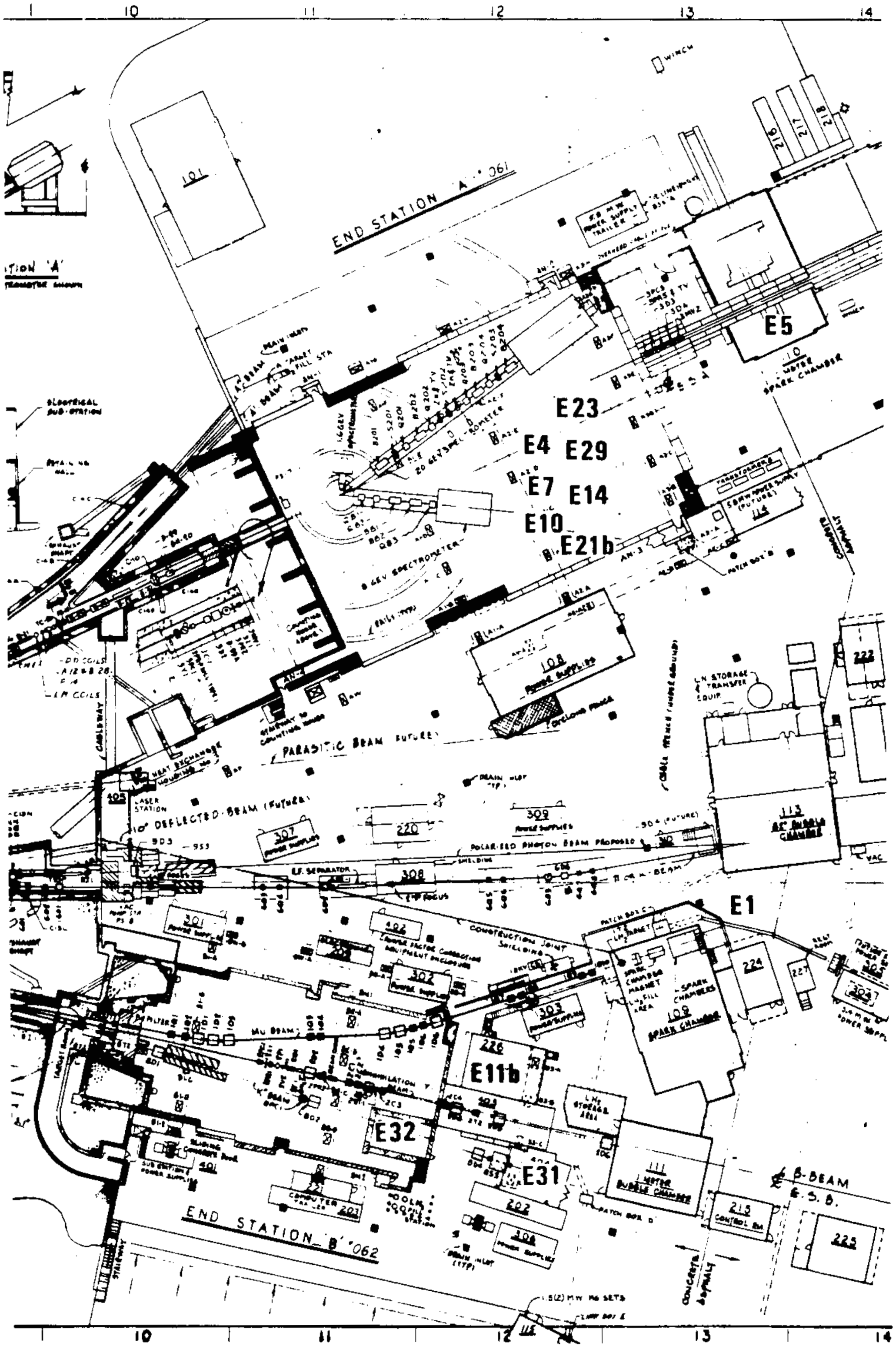

FIG. 3--Experiment locations.

7. Elastic events are obtained concurrently with inelastic events. We expect useful numbers of elastic events up to $q^2 = 2.0$ (GeV/c)^2.

8. Low q^2 elastic events will be obtained in abundance and will provide a check on the normalization for the inelastic data and the high q^2 elastic data.

9. Sometimes the recoil proton and the produced pions are recorded in the spark chambers in the inelastic events. Thus, the experiment provides an introduction to the study of muon inelastic interactions by detection of all the outgoing charged particles. This would be "full event analysis" as in a bubble chamber.

10. This experiment supplements one now being carried out at the A.G.S. by Blanpied, Wilson, Drickey and their colleagues with enough overlap to provide normalization checks.

E-4 Proposals for Initial Electron Scattering Experiments Using the SLAC Spectrometer Facilities

W. K. H. Panofsky, D. H. Coward, H. DeStaebler, J. Litt, L. W. Mo and R. E. Taylor, (SLAC), J. I. Friedman, H. W. Kendall and L. Van Speybroeck, (MIT), C. Peck and J. Pine, (CIT).

Proposal No. 4 actually comprises three separate but related experiments. These experiments acted as a shakedown of the spectrometers for scattering experiments and provide a general survey of the basic cross sections which will be useful for future proposals. They also furnished a relatively straightforward way to check out and debug the rather complex data recording system.

4a. Electron-Proton Elastic Scattering. Studies of electron-proton scattering[1] have been previously carried out at linear accelerators and electron synchrotrons in order to obtain information about the structure of the proton. Because of limitations in energy and beam intensities these measurements were able to determine separately the electric and magnetic form factors of the proton, G_E and G_M, only up to squared four-momentum transfers, q^2, of about 2 (BeV/c)^2. CEA experiments at higher q^2 values have placed a limit of about 0.04 on G_E, and G_M has been determined to an accuracy of about 0.02. Utilizing the higher intensities and energies available at SLAC, we expect to extend considerably the measurements of the form factors to higher four-momentum transfers. The maximum value of four-momentum transfer available at SLAC is about 37 (BeV/c)^2 corresponding to an incident energy of 20 BeV. Since the form factors decrease rapidly as q^2 increases, the range over which these measurements can be extended depends critically on the detailed behavior of the form factors. It is useful to list some of the questions of interest that can be investigated by extending the measurements to higher q^2:

(1) Existence of a nucleon core.

(2) Validity of the pole description of nucleon form factors.

(3) Validity of the Wu and Yang form factor, that $G \sim e^{-|q|/0.6}$.

(4) Hypothesis of Drell that $G > e^{-|q|/2M}$.

(5) Hypothesis of Sachs that $G_E = G_M$ at large q^2.

(6) Hypothesis that $F_2(q^2)$ and $F_1(q^2)/q^2$ asymptotically approach zero as q^2 becomes large.

Aside from shedding light on the validity of the above hypotheses, determinations of the detailed behavior of the proton form factors at large q^2 will provide very valuable constraints and guide posts to any future theory of the nucleon and its interactions with other particles.

4b. The Electron-Proton Inelastic Scattering Experiment. It was desired to conduct a survey of inelastic electron-scattering from the proton. The method of investigation consists of measuring the spectra of inelastically scattered electrons as a function of the four-momentum transfer and energy transfer to the target system. Such studies have been previously carried out at the Mark III accelerator and at the CEA. In the Stanford work the (3, 3) resonance was excited and studied as a function of four-momentum transfer up to about 0.79 (BeV/c). The CEA experiment observed, in addition, evidence for the excitation of the 1.512- and 1.688-BeV resonances at four-momentum transfers up to about 1.97 (BeV/c); however, the measurements at the higher momentum transfers are limited by poor statistics. Because the inelastic cross section contains q^2 dependences which are similar to that of the form factors describing elastic scattering, the counting rates drop rapidly as a function of four-momentum transfer. The higher energies and intensities available at SLAC will enable both the scope and the precision of the measurements of e-p inelastic scattering to be greatly enlarged.

4c. Comparison of Positron-Proton and Electron-Proton Elastic Scattering. The data from Experiment 4a. will separate the electric and magnetic form factors of the proton through analysis assuming the validity of the first order Born approximation (one-photon exchange). Two-photon exchange processes can be directly investigated in electron-proton elastic scattering by measuring the ratio of positron-proton to electron-proton scattering. Such results will not only be interesting in themselves but will provide useful information to assist the analysis of the data from Experiment 4a.

E-5 Multibody Photoproduction

I. Derado (Univ. of Notre Dame), D. Drickey, D. Fried, R. Mozley, A. Odian, F. Villa, D. Yount (SLAC).

Photoproduction will be measured between 1 GeV and the peak beam energy of 10 to 20 GeV. Of primary interest is the energy region above 4 GeV in which photoproduction of multibody final states has not been studied.

A large streamer chamber $2\text{ m} \times 1.5\text{ m} \times 0.6\text{ m}$ has been mounted in a large volume magnetic field and will be used to view photoproduction interactions in a manner similar to a hydrogen bubble chamber. The solid angle is essentially 4π.

Analysis of the August run is in process and from it the type of result from that run can be described and prediction of what should be expected from the additional running time can be made. A total of 5,700 events was obtained in the August run, with 527 3-prong 3C's and 131 5-prong 3 C's. This reflects that a large fraction of the events have missing π^0's. It is expected to obtain about three to four times as many events in the present run. This implies an operational efficiency about one and one-half times greater than in August.

With this data the following types of information will be obtained: ρ^0 production above and below 4 GeV, ρ mass $\pm$ 15 MeV, ρ width $\pm$ 50 MeV, ρ production as a function of momentum transfer, and ρ decay angular distribution.

There are a total of about 100 ρ's over 4 GeV. With the additional data it will be possible to obtain substantially more accurate measurements and also be possible to make meaningful cuts in energy, mass, and momentum transfer.

At present the indications of f^0 production are statistically inadequate. There is some information on ϕ production (approximately 6 ϕ's with a background of 2).

In the 5-prong 3C's there is an apparent ρ peak in the events over 5 GeV. This is a much clearer indication than that obtained in the lower energy data of DESY. A cut of these to study A1 and A2 production has been made but the resultant peaks are not statistically very meaningful.

In addition, use of a Pb plate spark chamber should enhance our data rate by allowing analysis of otherwise unavailable neutral decay modes of all photoproduced reactions.

E-7 Proposal for a Survey Experiment on Photomeson Production Processes at Backward Center of Mass Angles

D. Ritson, R. Anderson, D. Gustavson, R. Prepost (SLAC).

We propose to measure p, $\pi^{\pm}$, and $K^{\pm}$ photoproduction yields at backward C. of M. angles in order to study the following processes:

1.	$\gamma + p \rightarrow \pi^{+} + n$	particle detected π^{+}
2.	$\gamma + p \rightarrow \pi^{-} + N^{*}$	particle detected π^{-}
3.	$\gamma + p \rightarrow K^{+} + \Lambda^{0}$	particle detected K^{+}
4.	$\gamma + p \rightarrow K^{+} + Y^{*}$	particle detected K^{-}
5.	$\gamma + p \rightarrow K^{-} + (K^{+} p)$	particle detected K^{-}
6.	$\gamma + p \rightarrow p + \pi^{0}$	particle detected p

These are all two-body or quasi-two-body processes so that measurements of momentum and angle of one particle can serve to uniquely determine the kinematics, and identify the process.

These processes are of particular interest at backward angles. Contributions to the cross section arising from nucleon and isobar exchange lend to enhancements in the backward direction since they should give rise to contributions to the cross section which are of the form

$$\frac{d\sigma}{d\Omega^{*}} \sim \frac{P_n(\cos\theta^{*})}{(1+\beta_N \cos\theta^{*})^2}$$

where

$P_n(\cos\theta^{*})$ is a polynomial in $\cos\theta^{*}$ of power n and β is the C.M. velocity of the recoil nucleon or isobar. θ^{*} is the pion C.M. angle. Thus there are poles in the angle variable for $\cos\theta^{*} = 1/\beta_n$. Thus the largest cross section enhancement is at θ^{*} and $\theta_{lab} = 180^{o}$. However, the characteristic angular half-width of this enhancement corresponds to the laboratory angular range of $180^{o} - 90^{o}$, and this range is well covered by the 100-inch spectrometer. Also, the backward pion momenta typically have a value of $M_p c$ or less so the detected momenta are also well within the range covered by the 100-inch spectrometer. In addition, these processes permit one to search for the existence of resonances through the observation of missing masses.

E-10 A Proposal to Study Photoproduction at Forward Angles Using the SLAC 20 GeV/c Spectrometer

A. Boyarski, F. Bulos, R. Diebold and B. Richter (SLAC).

When the SLAC accelerator began operation a new region of energy was opened up for the study of photon induced reactions. This is a proposal for two experiments to begin the exploration of this new energy region. Both experiments require the use of the 20 GeV/c spectrometer in End Station A.

The first experiment is a general survey of photoproduction from hydrogen covering the angular region in the laboratory from approximately 1^o to 10^o (about 90^o in the center-of-mass system), and a range of photon energies from about 7 GeV to the maximum energy at which the accelerator will operate conveniently (16 to 20 GeV). The second experiment involves a detailed study of small angle processes (diffraction production, virtual one particle exchange, etc.) in the region from about $1/2^o$ out to an angle of about 5M/E (M and E are, respectively, the mass and energy of the detected particles).

The reactions leading to the final states π^+N, $K^+\Lambda$, and $K^+\Sigma$ for momentum transfer squared from 10^{-4} to 2 $(GeV/c)^2$ and photon energies from 5 - 16 GeV have been studied.

Preliminary studies of Y* and N* photoproduction have been made. The results of these measurements showed that the existing setup was adequate for the measurement of the cross section for π^-N^{*++}, but the precision of the beam monitoring needs improvement for measurement of Y* or N^{*o} production. Modifications to the beam to correct this deficiency are in progress. Preliminary measurements of π^-N^{*++} show that the cross section is considerably larger and has a different slope vs momentum transfer than the π^+N reaction.

In the second round of photoproduction it is planned to improve the accuracy of the forward K^+ measurements. The energy dependence of the forward π^+ cross section will also be checked.

Finally, a cross section measurement for π^-N^{*++} over the same range of momentum transfer and energy as has been covered in the π^+N measurements is planned.

E-11b A Proposal to Investigate CP Violations in Electromagnetic Interactions Through Diffractive f^o Photoproduction

A. Boyarski, A. Brody, F. Bulos, W. Busza, R. Diebold, S. Ecklund, R. R. Larsen, D. W. G. S. Leith, B. Richter (SLAC), L. Kaufman, V. Perez-Mendez, A. Stetz, S. Williams (LRL, Berkeley).

The two proposals E-11 and E-24 are now combined. The experiment is designated Experiment 11b to denote a new phase, i.e., the use of hydrogen and deuterium targets to study photoproduction of the ρ^{o}. There is also interest in measuring the ϕ photoproduction cross sections at the highest available energy.

Experiment E-11 proposed to use the wire-spark-chamber spectrometer being assembled for the ρ experiment to measure the diffractive cross section for f^{o} photoproduction from complex nuclei. To do this we plan to measure the effective mass and momenta of di-pion systems photoproduced at small momentum transfers by the monochromatic photon beam. By choosing the correct geometry we will detect $\pi^{+}\pi^{-}$ decays in the f^{o} mass region. Since this process involves a γ-f Pomeronchon vertex it is C violating and can be used to test the hypothesis that the electromagnetic interactions have a large CP violating component (as suggested to explain $K_{L}^{o} \rightarrow \pi\pi$). The diffractive contribution to f^{o} production will be separated from the other contributions by finding the nuclear coherent part of the production from the momentum transfer distribution, and by observing the dependence of the cross section with incident energy. A check of this separation procedure will be made by changing A, the atomic number of the target. We plan to use Be, $A\ell$, and Cu targets and photon momenta of 4, 7, and 10 BeV. By running this experiment consecutively with the ρ experiment (summer, 1967) a great saving of set-up time can be made and it is estimated that with the 95 hours requested we should be able to observe a signal 10% of that expected for maximal violation.

E-13 A Proposal to Measure Wide Angle Electron Pairs

R. B. Blumenthal, G. Feldman, F. M. Pipkin and J. Tenenbaum (Harvard),
R. Mozley, I. Derado, D. Drickey, D. Fries, A. Odian, F. Villa (SLAC).

It is proposed to measure the photoproduction of wide angle electron-positron pairs at energies and angles such that the virtual fermion momentum is in the range from 300 MeV to 1200 MeV. In particular it is planned to study electron-positron pairs in the region where the mass of the electron-positron system is greater than the rho mass and one is free from the troublesome correction due to rho mesons decaying into electron-positron pairs. The beam would be the SLAC high-energy Bremsstrahlung beam. The apparatus would consist of two large total absorption shower counters, two counter hodoscopes, two threshold gas Cerenkov counters, and a two-meter bending magnet.

E-14 Proposal for Testing of Quantum Electrodynamics by Photoproduction of Asymmetric Muon Pairs

W. K. H. Panofsky, D. H. Coward, H. DeStaebler, J. Litt, A. Minten, L. Mo, R. E. Taylor (SLAC), J. I. Friedman, H. W. Kendall, L. Van Speybroeck (MIT).

The essence of the experiment is to detect μ^- from $\gamma p \longrightarrow p \mu^+ \mu^-$ near 0^o with $p \approx k_{max}$, and to compare the muon yield with the electron yield under the same conditions of target, γ beam and magnets and with similar detectors. The "good" Feynman diagram has for the lepton propagator $t \approx -2$ km which at 20 BeV is $(2\ \text{BeV/c})^2$ for the muon and $(0.14\ \text{BeV/c})^2$ for the electron. We would measure the relative yields at several energies (say 10, 15, 20 BeV) and look for a deviation from QED. Very roughly, for a 5% experiment that showed no deviation the limit on the usual Λ would be $\Lambda^{-1} \lesssim 3 \times 10^{-15}$ cm (67% confidence).

The experiment would be done with the 20-BeV spectrometer set at 0^o. The normal p and θ hodoscopes would be spread away from the spectrometer axis to let the blast of electrons through. A special p hodoscope would measure the electron spectrum. Muons are identified by a coincidence telescope after 6.5 feet of steel. The muon rate is about 100 counts per hours.

E-21b Proposal for Measurements on the Photoproduction of π^o, η, ρ^o, ω and ϕ Mesons at Small Momentum Transfer t and Photon Energies up to 18 GeV and a Search for Mesons of Other Masses

D. Ritson, R. Prepost, R. Anderson, D. Gustavson, J. Johnson (Stanford); R. L. Walker, G. Jones, D. Kreinick, A. V. Tollestrup (CalTech); R. Weinstein, M. Gettner (Northeastern U.)

As planned, the originally approved time has been used observing the recoil protons associated with, $\gamma + p \longrightarrow X^o + p$ where X^o is any boson system. The data gives information on the production of π^o, η^o, $(\rho + \omega)$'s, η' (?), ϕ's and other particles. The $(\rho + \omega)$'s were rather completely covered, and the limitation to obtaining further information by this method is limited by systematics and not by statistics. The π^o running was relatively complete at lower energies, but could be considerably extended in precision at higher energies. The η^o's are only well resolved from ρ-meson production at lower energies. The main data in ϕ^o-mesons was taken in the last two days of running and will be considerably extended. A clear structure due to one or more particles in the 1300-1450 MeV mass region has been observed.

To extend this work, the following are planned for the next run:

(a) Extend the π^0, and η^0 production measurements as far as can be done with this present technique.

(b) To look for $\eta'(958)$ production at low energies at a number of t values.

(c) To extend the ϕ^0 data over a wider range and to higher precision.

(d) To considerably extend our data in the mass range 1300-1450 MeV and to more clearly delineate the phenomena in this region.

(e) To extend high precision sweeps over the high mass region from 1450 MeV to 2000 MeV.

E-23 Backward π^0 Photoproduction

B. Gittleman, A. Minten, R. Anderson, J. Litt, D. Yount (SLAC), B. Wiik (HEPL).

A class of high energy interactions which are being treated with peripheral models are those involving large t and small u. Several recent experiments on elastic pion-proton scattering around 180° have shown the cross sections to have interesting structure. At 180° for laboratory energies of 2 to 5 BeV,[1] there are a number of bumps and dips in the cross section of both $\pi^+ + p$ and $\pi^- + p$. Data on the angular distribution 4, 6.5, and 8,[1] show a narrow backward peak whose width decreased with increasing energy. An explanation of this data has been given by Barger and Cline.

We expect similar structure in photo-pion production and would like to compare it with the elastic pion scattering data. Very little is known about the coupling of γNN^* for N^* mass above 1688 MeV and one immediate result of such a comparison will be information on the γNN^* vertex for higher energy resonances. We would also like to trace out the s and u dependence of the cross section up to 15 or 20 BeV where the process should be completely dominated by "Fermion exchange." There are two pertinent photoproduction experiments one might do.

$$\gamma + p \rightarrow p + \pi^0$$
$$\qquad\qquad N + \pi^+$$

The π^0 photoproduction angular distribution at 12.0 GeV has been obtained for $-1.2 < u < +0.03$ (GeV/c), and at the two angles 1.20° and 3.85° the momentum spectrum of the recoil proton for the missing mass squared range of -0.3 to $2.0\ GeV^2$ has been measured. At 8 other angles between $.75^\circ$ and 5.5° data has been taken at a single spectrometer setting which covered the missing mass square range from 0.0 to

0.5 GeV^2 in order to obtain the π^o differential cross section. At 5 of these angles data was also taken on the π^+ spectra in order to determine the resolution function (shape and threshold).

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

Owen Chamberlain, Gilbert Shapiro, Herbert Steiner, Howard Weisberg (U. C. Berkeley), Elliot Bloom, John Litt, Luke Mo, Richard Taylor (SLAC), Jerome Friedman, Henry Kendall, (MIT).

The experiment consists in inelastically scattering electrons from a target containing polarized protons. Only the scattered electron is detected and its momentum is measured. It will use the spectrometer facility including the SDS 9300 computer, as presently used in elastic and inelastic e-p scattering experiments. Either the 8 BeV or 20 BeV Spectrometer will be used. The polarized target will be furnished by U. C. Berkeley. In the one-photon approximation, any difference in the rate of the scattering reaction when the sense of the target polarization normal to the scattering plane is reversed would be evidence for T-violation in electromagnetic interactions. This type of experiment was first suggested by Christ and Lee.

E-31 Measurement of the Magnitude of η_{oo} and its Phase Relative to η_{+-}*

D. Dorfan, M. Schwartz, S. Wojcicki, (SLAC)

An accurate determination of the magnitude of η_{oo} and its phase relative to η_{+-} is essential to a complete understanding of the parameters characterizing CP violation in the K_2^o decay. Although the magnitude of η_{oo} has been measured by several groups, there is still considerable question as to the experimental validity of the existing results. In particular, only the measurement of Cronin appears relatively free of background and statistically valid. Hence on general principles it would seem appropriate to accurately redetermine this parameter. No direct determination of the relative phase of η_{oo} and η_{+-} has yet been pursued, none are easy and all suffer from substantial background difficulties.

Phase I of the experiment consists of a measurement of the magnitude of η_{oo}. In Phase II we will then place a thin regenerator at the beginning of the decay region, regenerating K_1^o and observing the characteristic interference-induced oscillatory behavior of the $\pi^o\,\pi^o$ decay intensity as a function of distance from the regenerator.

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* $$\eta_{oo} = \frac{\text{Ampl. } (K_2 \to \pi^o \pi^o)}{\text{Ampl. } (K_1 \to \pi^o \pi^o)}$$

In Phase III the interference in the $\pi^+ \pi^-$ decay mode will be detected, measuring the phase of η_{+-} in the same beam, and with the same regenerator.

E-32 A Proposed Study of K_1^0 Mesons Regenerated From a K_2^0 Beam Incident on Hydrogen

D. J. Drickey, E. Seppi, P. G. Innocenti, R. Zdanis (SLAC), E. Dally (Stanford), L. Ettlinger (Johns-Hopkins), H. Ticho, J. Helland (UCLA).

A proposal to study $K_2 p \longrightarrow K_1 p$ at medium and high energies using wire spark chambers and a 1-meter long hydrogen target. Specifically we wish to observe:

(a) The energy dependence of the magnitude and slope of the forward differential cross section in the region where ϕ exchange is expected to dominate the t channel.

(b) The large angle regeneration above 2 GeV where exchange of $S = -1$, $T = 1$ baryon resonances (Σ, Y_1^*) might be expected in the u channel. We wish to compare this cross section with the recent measurements of $K^{\pm} p$ backward scattering.

It has been possible to use the identical experimental geometry for (a) and (b) above; however, the counter trigger and treatment of the analysis are different for forward and backward regeneration.

It should be possible to obtain ≈ 1000 forward regeneration events and ≈ 100 backward regeneration events in 150 hours of running at 500 K_2/sec (180 cycles).

E-37 Measurement of the Total Photoabsorption Cross Section for Hadron Final States

D. Caldwell, V. Elings, W. Hesse, R. Morrison, F. Murphy, (UCSB), D. Yount, (SLAC).

Tagged photons from 5 to 15 GeV will be produced in a parasitic weak positron beam at SLAC. Hadronic final states from a long, liquid hydrogen target are detected by a large counter sensitive to electromagnetic and strong showers. Pairs and surviving photons continue through a hole into a small-angle shower counter; lack of a shower here is an independent measurement of the hydronic final state signal. The cross section will be measured in 5% energy bins with 3% statistics and, we expect, smaller systematic errors. We set the present upper energy limit to require minimum modification to present beam facilities; extension of the measurement to higher energy would be straightforward.

BC-3 A Proposal for a Photoproduction Experiment in the SLAC 40-Inch Bubble Chamber Exposed to Monochromatic-Ray Beams (4 GeV annihilation photons)

Y. Eisenberg, E. Ronat, A. Shapira, G. Yekutieli (Weizmann Institute)

This experiment is a part of a study of several physics problems in the 2-6 GeV region using the monochromatic photon beam in the SLAC 40-inch bubble chamber. The physics of interest include:

A. 3-prong events
   1. Photoproduction of the N* (1238)
   2. Photoproduction of ω^o mesons
   3. Associated photoproduction of resonance, $N^{*++} + \rho^-$
   4. $\gamma + p \rightarrow p + \rho^o \rightarrow p\, \pi^+ \pi^-$
   5. $\gamma + p \rightarrow p + f^o$
   6. $\gamma + p \rightarrow N^{**} + \pi$
   7. $\gamma + p \rightarrow N + A$

B. 5 prong events, preliminary survey

C. Strange particle productions

Since it is known that other experiments cover the upper and lower part of the energy range of interest, this experiment concentrated on $E\gamma = 4$ GeV. A total of approximately 180K pictures have already been obtained in this program.

BC-4 K^+p, π^+p, and π^-p Interactions near 12 GeV/c

M. Abolins, O. Dahl, P. Dauber, P. Eberhard, S. Flatté, L. Galtieri, M. Alston-Garnjost, J. Kirz, G. Lynch, M. Pripstein, A. Rosenfeld, R. Ross, G. Smith, F. Solmitz, and L. Stevenson, (LRL, Berkeley), J. Murray, (SLAC).

A beam for the 82-inch bubble chamber at SLAC has been designed and built under the direction of Stanley Flatté and Joe Murray. The beam provides $\pi^\pm$ mesons from 5 to somewhat over 12 GeV/c with a full momentum bite of 5 percent and a momentum resolution for each beam track, utilizing correlations in the chamber, of ~0.3 percent full-width. The purity of the π beams is assured by Cerenkov-counter trigger system. The beam also provides K^+ mesons at 11.7 GeV/c with a momentum resolution of 0.5 percent using an RF separator. The K^+ became available in late 1967.

It was proposed to use this beam to gather 3,000,000 pictures of the following type: 1,000,000 K^+ pictures at 11.7 GeV/c; 200,000 π^+ pictures and 200,000 π^- pictures at each of the following momenta; 10.0, 10.5, 11.0, 11.5 and 12.0 GeV/c.

The primary objective of the K^+ portion is to obtain high statistics data for the study of low yield reactions (~ 10 μb). A search for higher lying baryon and meson resonances with S = 0, +1 is possible. Similarly, the $\pi^\pm$ data should enable a study of resonances with S = 0, -1.

BC-10 A Proposal to Investigate K_2^o p Interactions with the 40-Inch HBC

A. D. Brody, W. B. Johnson, R. R. Larsen, D. W. G. S. Leith, G. A. Loew, R. Miller, B. C. Shen, W. M. Smart.

A detailed systematic study of $K_2^o p$ interactions leading to the formation of direct channel $S = \pm 1$ baryon resonances and the production of meson and baryon resonances via exchange processes will be carried out over the extended energy region (1.5 - 12 BeV/c) using the SLAC 40-inch HBC as the main detector. In addition, the momentum of the incident K_2^o which interacted in the chamber will be measured by using time-of-flight techniques with scintillation counters mounted within the bubble chamber surrounding the hydrogen flask. It is noteworthy that the relatively neutron free K_2^o beam, together with the momentum information obtainable from time-of-flight techniques, are the unique features of SLAC which make this experiment possible.

BC-11 A Bubble Chamber Experiment with the Polarized Laser Induced Photon Beam

J. Ballam, G. B. Chadwick, Z. G. T. Guiragossián, P. Klein, A. Levy, M. Menke, J. Murray, G. Wolf, (SLAC), C. Sinclair, (Tufts), H. Bingham, B. Equer, K. Moffeit, (UC-B), M. Radin, W. Podolsky, A. Rosenfeld, (UC-LRL).

The 82-inch LRL hydrogen bubble chamber will be exposed to the polarized laser induced photon beam at photon energies E_γ above 3 GeV. With a photon flux of 250 quanta per picture, there will be roughly 1 event on 1000 frames per μb cross section. We plan to start with an exposure of 0.5 million pictures at photon energies between 3 GeV and 5 GeV which will yield 500 events per μb cross section, or 60,000 events with three or more charged outgoing particles, and in particular 10,000 $\gamma p \rightarrow p\rho^o$, 2000 $\gamma p \rightarrow p\omega$ and 130 $\gamma p \rightarrow p\phi$ events, about six times as many events as the DESY bubble chamber collaboration had in this energy region. In addition, the value of the total γp cross section will be obtained with an accuracy of approximately 5%. A detailed study of photoproduction at these energies is therefore possible. In a second step we want to make a first exploratory exposure of 0.5 million pictures for photon energies in the region from 7 GeV to 10 GeV. This exposure will result in $\sim$ 400 events per μb cross section; among many other reactions there will be 4500 $\gamma p \rightarrow p\rho^o$, 600 $\gamma p \rightarrow p\omega$ and 60 $\gamma p \rightarrow p\phi$ events.

TABLE I

TABLE OF PROGRAMMED EXPERIMENTS

Number	Title	Authors	Date Approved
1	Proposal for a Survey of the $\mu - p$ Inelastic Interaction at High Energy	J. Brown, J. Cos, F. Martin, M. Perl, T. Tan, W. Toner, T. Zipf (Group E)	2/13/66
4	Proposals for Initial Electron Scattering Experiments Using the SLAC Spectrometer Facilities: 4a Electron-Proton Elastic Scattering 4b The Electron-Proton Inelastic Scattering Experiment 4c Comparison of Positron-Proton and Electron-Proton Elastic Scattering	SLAC-MIT-CIT SLAC (Group A) W. Panofsky, D. Coward, H. DeStaebler, J. Litt, L. Mo, R. Taylor MIT J. Friedman, J. Kendall, L. Van Speybroeck CIT C. Peck, J. Pine	2/13/66
5	A Proposal for a Photoproduction Experiment Using the Two Meter Streamer Chamber and Magnet	I. Derado, D. Drickey, D. Fries, R. Mozley, A. Odian, F. Villa, D. Yount (Group D)	2/13/66
7	Proposal for a Survey Experiment on Photo-meson Production Processes at Backward Center-of-Mass Angles	(Group F) D. Ritson, R. Anderson, D. Gustavson, R. Prepost	2/13/66
10	A Proposal to Study Photoproduction at Forward Angles Using the SLAC 20 GeV/c Spectrometer	A. Boyarski, F. Bulos, R. Diebold, B. Richter	2/13/66
11B	A Proposal to Investigate CP Violations in Electromagnetic Interactions through Diffractive f^0 Photoproduction	STANFORD A. Boyarski, A. Brody, F. Bulos, W. Busza, R. Diebold, S. Ecklund, R. R. Larsen, D. W. G. S. Leith, B. Richter LRL L. Kaufman, V. Perez-Mendez, A. Stetz, S. Williams	8/23/66

Table of Programmed Experiments (cont'd)

Number	Title	Authors	Date Approved
13	A Proposal to Measure Wide Angle Electron Pairs	CYCLOTRON LAB, HARVARD R. F. Blumenthal, G. Feldman, F.M. Pipkin, J. Tenenbaum STANFORD R. Mozley, I. Derado, D. Drickey, D. Fries, A. Odian, F. Villa, D. Yount	8/23/66
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
21B	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
23	Backward π^0 Photoproduction	STANFORD B. Gittelman, A. Minten, B. Wiik, R. Anderson, J. Litt, D. Yount	6/22/67
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

Table of Programmed Experiments (cont'd)

Number	Title	Authors	Date Approved
31	Measurement of the Magnitude of η_{oo} and its Phase Relative to η_{+-}	STANFORD D. Dorfan, M. Schwartz, W. Wojcicki	11/6/67
32	A Proposed Study of K_1^o Mesons Regenerated from A K_2^o Beam Incident on Hydrogen	STANFORD E. B. Dally, D. J. Drickey, E. Seppi, R. Zdanis CORNELL L. N. Hand HARVARD P. G. Innocenti	12/16/67
37	Measurement of the Total Photoabsorption Cross Section for Hadron Final States	UCSB D. Caldwell, V. Elings W. Hesse (Student), R. Morrison, F. Murphy STANFORD D. Yount	5/11/68
BC-3	A Proposal for a Photoproduction Experiment in the SLAC 40-Inch Bubble Chamber Exposed to Monochromatic -Ray Beams (4 GeV annihilation photons)	WEIZMANN INSTITUTE Y. Eisenberg, E. Ronat A. Shapira, G. Yekutieli	8/12/67
BC-4	K^+p, π^+p, and π^-p Interactions Near 12 GeV/c (82-Inch HBC)	LRL M. Abolins, O. Dahl, P. Dauber, P. Eberhard, S. Flatté, L. Galtieri, M. Alston-Garnjost, J. Kirz, G. Lynch, J. Murray, F. Solmitz, L. Stevenson	12/16/67
BC-10	A Proposal to Investigate K_2^0p 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
BC-11	A Proposal for a Bubble Chamber Experiment with the Polarized Laser Induced Photon Beam	Spokesman: Gunter Wolf	5/11/68

F. SUMMARY OF A-BEAM ACTIVITY (May-June)

The following is a summary of use of A-Beam facilities:

May 1 - 10	E-4a, e^- elastic scattering.
May 15-20	E-4c, e^+/e^- scattering.
May 20-26	Installation and set-up of Experiment E-5 and E-21b.
May 27-31	E-5 Multiple Photoproduction. Start of data taking run preliminary beam set-up and preliminary data taken.
June 1-5	E-5, Study of photoproduction using two meter streamer chamber and magnet.
June 6-11	Accelerator off, replacement of SL-31 (see text), preliminary preparation for E-21b, measurement of photoproduction of π^o, η, ρ^o, ω, ϕ, and other mesons, and E4 electron scattering from hydrogen.
June 11-12	Accelerator and BSY tests.
June 12-21	E-5.
June 22-25	Accelerator off, continued preparation for E-21b and E-4.
June 25-30	E-5.

G. SUMMARY OF PRIMARY B-BEAM ACTIVITIES (May-June)

May 1 - 9	E-32, Counter check-outs, spark chamber check-out, and Beam Knockout studies.
May 9-10	E-1, Counter and spark chamber checkout.
May 15-17	BC-2, Gamma p (5,7,0) 17,000 pictures taken before 3.4 failure.
May 20-26	Accelerator scheduled down week. Various beam construction was performed.
May 27-31	E-1, μ^-p Inelastic Scattering.
June 1-5	E-1, μp scattering experiment. Terminated June 5 by failure of 5.8 MW power supply.
June 6-11	Failure of SL-31. Accelerator Physics runs; BSY and End Stations open.
June 11-12	Exposure of Emulsion in μ beam. (P. McNutly, Clarkson College, and P. Jain, New York State University, Buffalo.) E-1 counter check-out.
June 12-21	E-11b.
June 22-25	Accelerator off, continued preparation for E-31, E-32.
June 25-30	E-11b.

H. SUMMARY OF C-BEAM ACTIVITY (April-May-June)

April 3-10	12 GeV/c K^+ rf separated for S. M. Flatté. *et al.*, LRL. 110 K pictures taken.
April 10-12	13.6 GeV/c π^+ rf separated for R. B. Willman, *et al.*, Purdue. 46 K pictures taken.
April 23-26	1-3 GeV/c e^- time resolution tests of scintillation counters for use in K^0 experiment (No. 31) for S. Wojicicki, *et al.*, SLAC.
April 30	13.6 GeV/c π^+ rf separated--continuation of Purdue run noted above.
May 1-5	F. Loeffler *et al.*, Purdue University, BC-8, 13.6 GeV/c π^+ exposure in 82-inch HBC. 235 10^3 pictures taken.
May 5-9	M. Peters, *et al.*, University of Hawaii, BC-5. 12.0 GeV/c π^- exposure in 82-inch HBC. 175 10^3 pictures taken.
May 9-10	SLAC-RAD, feasibility study for (a) Production of high purity rf separated e^- beams in 2-5 GeV/c region for emulsion exposures (Lord) and (b) Production of rf separated K^+ beam for HBC use in lower pass band centered at 6.85 GeV/c. Results were favorable in both cases.
May 15-20	R. Hofstadter, B. Hughes, W. Lakin, E. Dally, Stanford University. Tests of enlarged NaI and PbF total absorption.
May 29-30	SLAC-RAD, first tests of electron beam transport system for Compton scattered laser beam. Beam pipe alignment problems were encountered.
June 4-15	Emulsions for several experimenters were exposed to e^- beams at energies of 2.3, 5 and 13.6 GeV. In all cases the emulsions were located at a point 20 feet ahead of the center of the 82-inch bubble chamber. Pure e^- beams ($\pi^-/e^- \sim 10^{-5}$) were obtained at 2.3 and 5 GeV by rf separation. At 13.6 GeV the required purity ($\pi^-/e^- \sim 10^{-3}$) was obtained by setting the secondary beam momentum approximately equal to the incident electron energy. A total of 23 emulsion stacks were exposed with peak fluxes ranging from 10^2 to 6×10^6 e^-/cm^2. The experimenters and their institutions were: J. Lord, University of Washington J. Kirk, University of Idaho

P. Jain, New York State University, Buffalo, and

P. McNulty, Clarkson College

R. Piserchio, San Diego State College

R. Daniel, Tata Institute, Bombay

June 18 — Further tests of the scattered laser beam system (exclusive of laser itself) were carried out. Previous tests had established the basic safety of the system. On this occasion the beam line was completed up to a point just ahead of the 82-foot bubble chamber. With a gas target in the interaction region and using a simple shower counter at the bubble chamber it was established that the bremsstrahlung signal from a radiator of 10^{-8} radiation lengths was at least two orders of magnitude greater than background (in numbers of quanta $\gtrsim$ 6 MeV). The laser light will be equivalent to a radiator of 10^{-7} to 10^{-6} radiation lengths. It is reasonably certain then that backgrounds will be negligible. A definitive test with the bubble chamber as detector is planned for late July or early August.

June 19-21 — Further test of NaI total absorption counters, B. Hughes, et. al., Stanford University.

June 24-27 — 82-inch bubble chamber run (BC-4) 12 GeV/c rf separated K^+, 90 10^3 pictures taken for Flatté et al., LRL. This run ended prematurely because of vacuum failure in the 82-inch bubble chamber. The expansion bellows developed a leak and the experiment was terminated so the bellows could be replaced. Repair time is expected to be about one month, if all goes well.

IV. RESEARCH DIVISION DEVELOPMENT

A. PHYSICAL ELECTRONICS

Stable Secondary Emission Monitor (SEM)

Disassembly of a 4-inch SEM after extensive use in the beam showed the presence of black spots randomly distributed over the surface of some foils, indicating the need for tighter process control in evaporation of silver onto the aluminum foils, as well as in subsequent assembly operations. Another 4-inch and 8-inch SEM are being assembled.

Transparent Conductive Coating for Mylar Streamer Chamber Windows

Extensive tests were carried out on the large sputtering chamber, and modifications to the discharge geometry and pumping system were accomplished. Production of coated mylar should begin early in July.

Alkali-Halide Secondary Emission Foils

A 6-stage multiplier with aluminum photocathode was assembled (5 bulk density CsI dynodes, 1 low density CsI dynode). This tube survived assembly and bakeout, but was destroyed by an arc during preliminary tests.

The report covering the studies of transmission secondary emission from alkali halides has been completed, and final printing is now scheduled for August 15, 1968. Two papers and one doctoral thesis have been written on this subject.

Initial planning has been carried out for a new series of measurements in which practically monochromatic electrons of energies between $\simeq 0$ and $\simeq 7$ eV can be injected into a thin film of alkali halide and their behavior in the film studied by retarding potential measurements. These measurements are intended to supplement and to provide more detailed information on the electrophoton interaction at low energies than the investigation of secondary emission just completed.

Separately, a new project for the study of some II-VI semiconductor compounds as extremely high gain secondary emitters has been initiated. This work is in part stimulated by the results of R. E. Simon, of RCA, who has reported gains of 100 (250 projected) using GaP. This is obtained by cesiation of the surface of the semiconductor.

The experience gained on secondary emission from alkali halides points to the desirability of other compounds for even higher yield. In particular, CdTe and Zn-HgTe appear promising and will be the subject of an investigation. The growth of crystals, the measurement of electrical characteristics, a technique for proper doping, effect of cesiation and, finally, secondary emission characteristics have to be studied with care. For optical and secondary emission studies of the semiconductors, the same system being built for measurements on alkali halides will be used, with minor modifications or additions.

Surface Physics

Final fits to electron desorption and new transient decay data were carried out, and appear in SLAC-PUB-392, "Electron Induced Resorption of Gasses from Aluminum," which was presented at the 4th International Vacuum Symposium by M. Rabinowitz.

RF Superconductivity

The experimental dewar and magnetic shield were completed as were the cryogenic rf probe assembly and the room-temperature field-emission testing device. The helium pumping and recovery system for producing 1^{o} to 2^{o} K temperatures was also completed, and the pressure control features of the system have been tested. The probe and cavity ultra-high vacuum system was assembled, baked out, and leak checked. It is now under 10^{-9} torr vacuum, awaiting attachment of a lead-plated cavity. A cryogenic run should take place in July.

B. MAGNET DEVELOPMENT

Investigation of energy dissipation of superconducting magnets in external resistances has been further pursued in order to develop a general theory of fast flux extraction from the superconductor. The 5000-ampere leads have been built and tests will start in May. The work on instabilities of composite conductors is continuing.

C. CONVENTIONAL DATA ANALYSIS

The Spiral Reader project has now completed its first step of debugging. All the electronics, except the high speed data channel, has been thoroughly checked and some changes in the electronic and mechanical designs have been initiated as a result of this effort.

MPF (NRI) machines 5 and 6 are progressing satisfactorily. Machine 5 is now being installed. Numerous changes have been made by EMR on the 6020 computer, and these seem to have improved several of the technical difficulties that we have been having in the past with the system.

Construction of the IMP's (Image Monitoring Project) is continuing; they are nearing completion. The single frame advance prototype for the SPV's is being constructed. The film drive for the streamer chamber cameras has been completed.

V. PLANT ENGINEERING

During this quarter the following construction projects were completed, or essentially so: an addition to the End-Station-A Counting House which doubled the amount of available space; additional laboratory space in the Test Laboratory; the housing of two large motor-generator sets in the target area; the addition of approximately 2,000 square feet of building space to the Temporary Computer Building; the provision of new office space in the Central Control Building; relocation of the 3.4 MW power supplies.

Construction of SLAC's two major building projects continued throughout the quarter. The Central Laboratory Addition is 63% complete and the General Services Building is 59% complete. The present status of these two facilities and several others is shown graphically in Figs. 4 through 7.

Other projects are in various stages of progress. Engineering is underway on: a relocation of the front entryway incident to the widening of Sand Hill Road along the north boundary of SLAC; improvements to the access road to Alpine Road; excavation of the hilly area north of Sector 12 to preclude lateral movement of the accelerator housing in that vicinity; rebuilding and housing of the 5.8 MW power supplies; services for the new 5.0 MW power supply installation; office and laboratory partitioning for the Central Laboratory Addition; updating of the SLAC Master Plan to accommodate future building placements and additions. Construction continued on several projects, percentage of completion being as shown: expansion of electrical and mechanical utilities for the Temporary Computer Facility (35 percent); provision of a sandblasting Facility for the craft program (1 percent); installation of two 2 MVA substations near End Station B (90 percent); extension of gas and air services to the Crafts Building (75 percent); restoration of drive line insulation in the Klystron Gallery (70 percent).

The program of plant utility operation and maintenance as an overall service to SLAC was continued. The highest peak electrical demand to date was registered on June 3, 1968 at 39.17 megawatts.

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FIG. 4--Central Laboratory Addition.

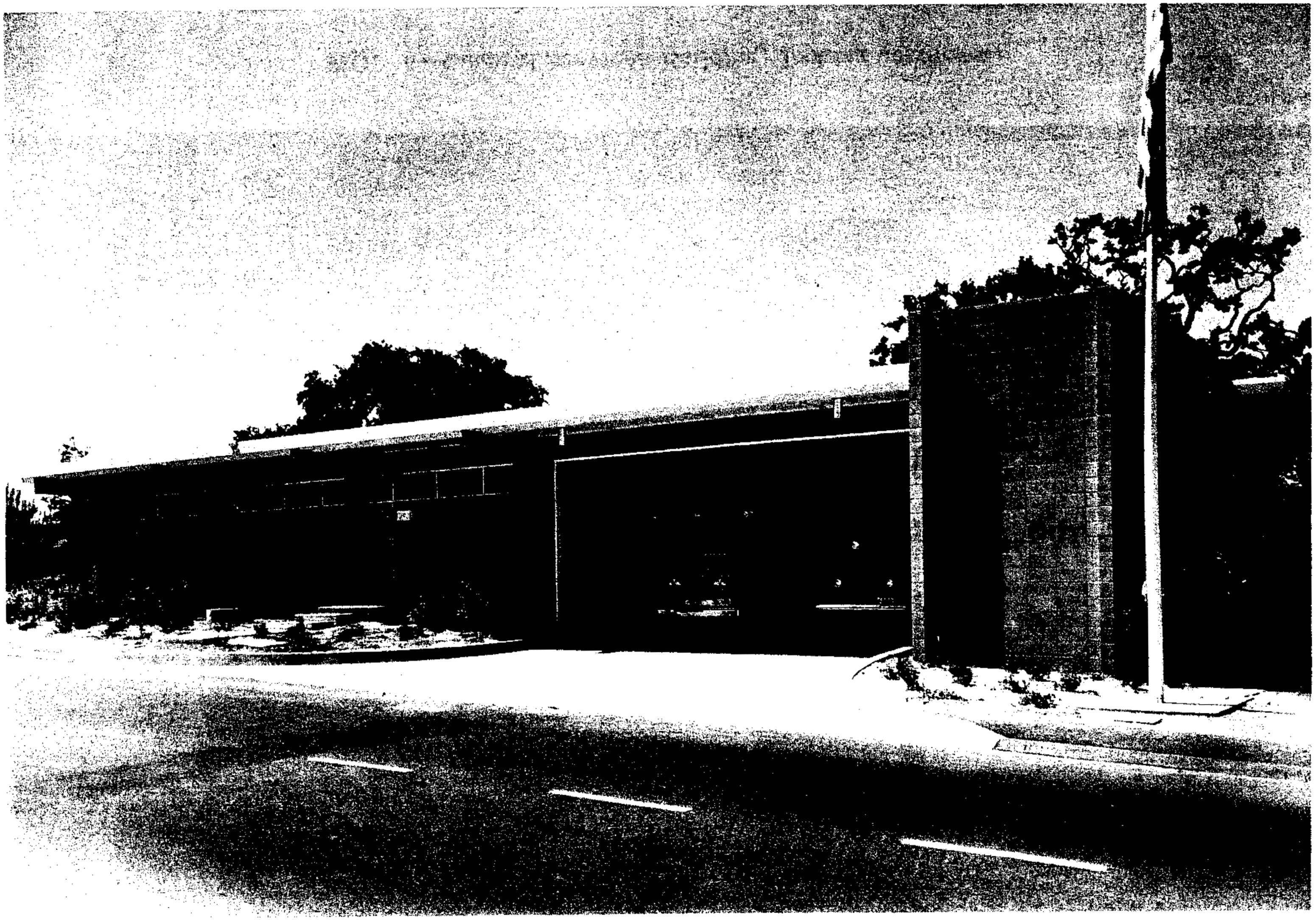

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FIG. 5--New Fire Station.

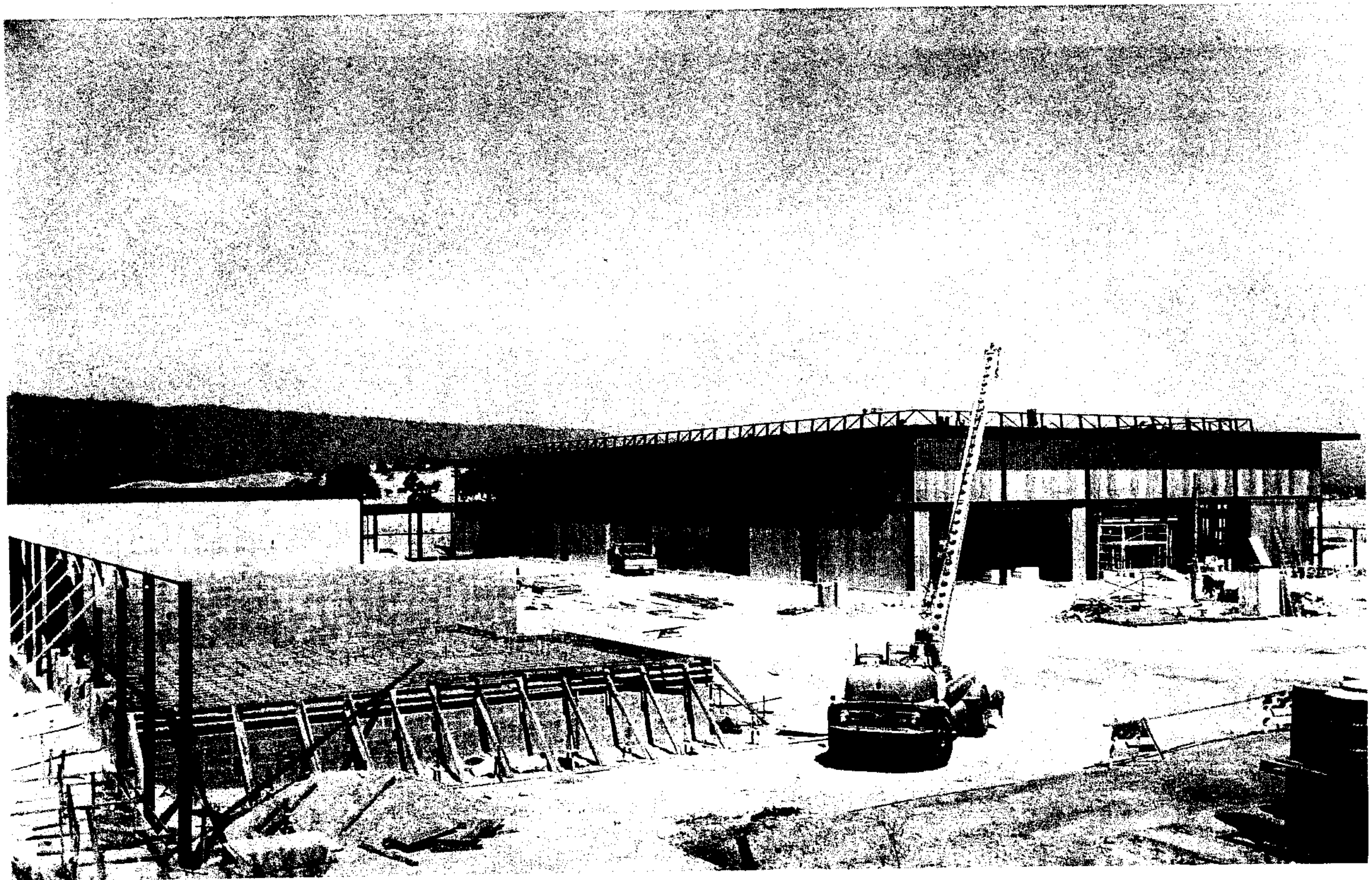

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FIG. 6--General Services Building, looking northeast.

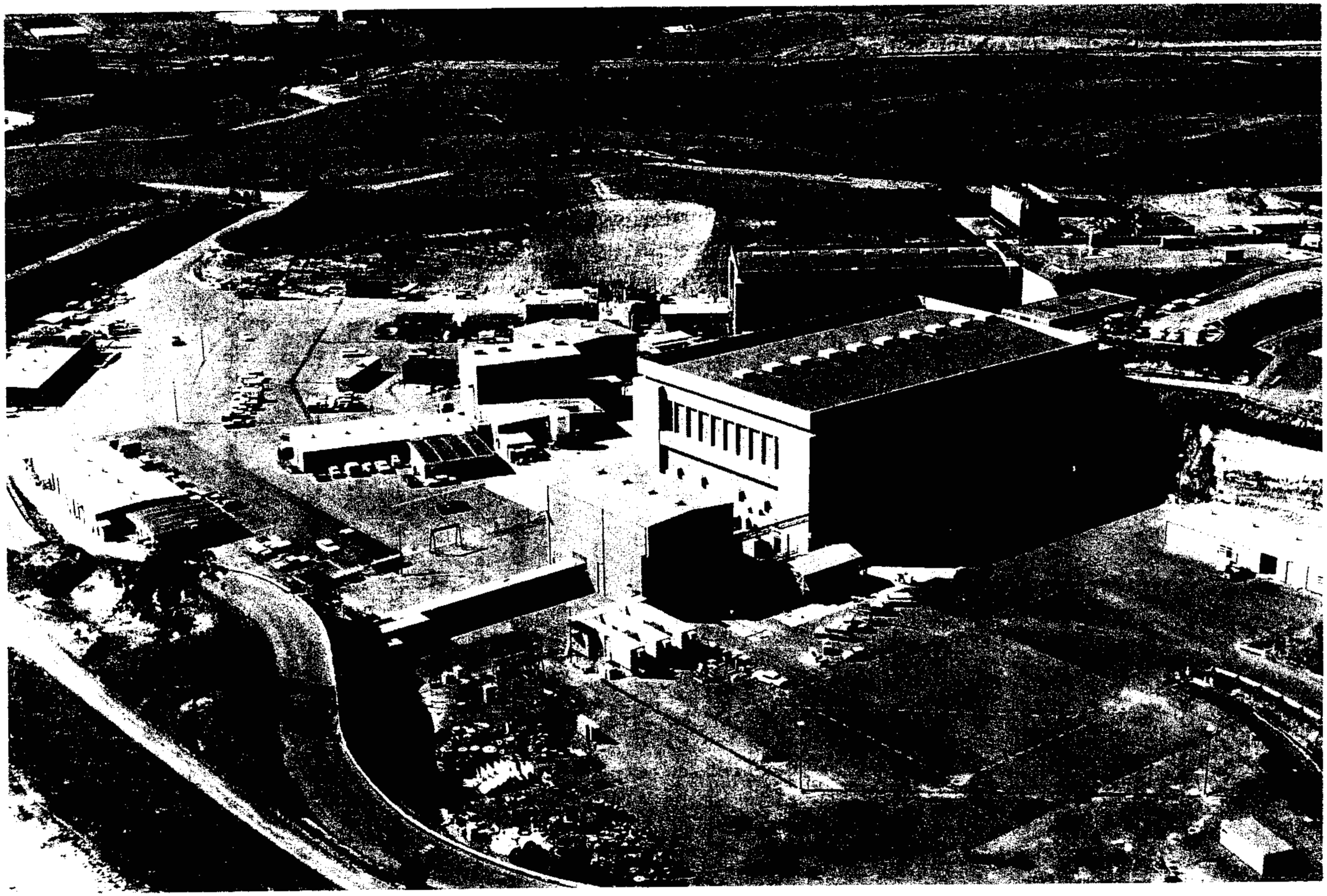

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FIG. 7--Target area, looking south.

VI. KLYSTRON STUDIES

A. DEVELOPMENT

The high power tube development work at SLAC has been limited by two factors: (1) the necessity of fabricating an adequate number of driver amplifiers, and (2) by the reappearance of gas problems in the high power tubes fabricated or reworked during the quarter.

RCA is working on both a window improvement program and a program of upgrading the present tubes for operation at a peak power output of approximately 30 MW. Litton is still plagued by arcing problems. Solutions investigated to date have not resulted in full success in eliminating the problems.

Activities in the vacuum area have been concentrated on the design, construction, and preliminary tests of equipment needed for a systematic approach to some of our problems.

1. Klystron Procurement

RCA Subcontract. Emphasis in fabrication has been on window problems, which at the present time appear to be the principle cause of failure of RCA-built tubes. Analysis of failures by date of delivery indicates that the tubes built in 1966 are particularly prone to window failure, and technical discussions have been held between RCA and SLAC to attempt to determine some possible means of prevention of this high failure rate in tubes of that vintage still in inventory.

The window coating by rf sputtering now used by RCA appears to produce much more stable coatings, but final evaluation will have to wait until a sufficient number of such windows have operated in the accelerator to ascertain the true behavior.

RCA has completed the design of a klystron capable of operation at 270 kV, with a power output of 30 MW, and expects to begin testing the first tubes built to this new design during the next quarter.

In addition, negotiations have been completed between RCA and Stanford to allow us to increase the total number of RCA tubes on the line covered by extended warranty. To enable us to achieve this goal, RCA will ship to SLAC 10 additional permanent magnets at no additional cost to us. These magnets will also be usable with 270 kV, 30 MW tubes.

Litton Subcontract. During the last two quarters Litton delivered few acceptable tubes. The low delivery rate is caused by the difficulties which Litton has been experiencing and is still experiencing in producing tubes which do not show arcing problems at the 250 kV operating level. Their processing yield is still extremely poor. They have tried many minor modifications in tube fabrication in the cathode and anode region. To date, there appears to be no significant improvement to return their yield to that of their initial production of this tube.

The low acceptance rate at the present time is caused by a different problem which has been present in Litton tubes for sometime, but which appears to be much more pronounced lately. Specifically, at some operating voltages there appears to be back conduction from the anode to the cathode resulting in inverse voltage clipping, and usually excessive heat in the anode and cathode support. The result is a change in perveance and tube performance which makes them unacceptable for use in the accelerator. Unfortunately, these phenomena are not observable at Litton because of the difference in modulators on which the tubes are processed and those on which they are tested here. The inverse voltage is much lower in the Litton modulator than in ours, the rate of change of voltage is also much lower, and Litton is not able to detect and analyze the problems prior to shipping the tubes. In addition, the phenomena also appears to be at least to some extent affected by the specific shape of the magnetic field in the anode-cathode region. In some cases, the "burning" can be stopped by either testing the tube in a different magnet or by appropriately shunting the magnet near the anode.

SLAC Klystron Development. In spite of the fact that the arcing problem appeared to be resolved at the end of the previous quarter, the total fabrication yield of high power tubes at SLAC has been very poor again. However, the cause of the low yield is evenly distributed between the reappearance of arcing problems and gassiness observed in many tubes. It is possible, although not certain, that during this quarter arcing was caused by gassiness.

In an attempt to understand the gas problems, studies have been conducted on gas evolution in the cathode package by using a new high vacuum-high temperature furnace and its associated gas analyzer. It appears that the main source of gas originates at the heater itself. Although no known changes have taken place in heater insulation, it is possible that some minor variations in insulating coating thickness is responsible for the change in gas evolution observed. However, tests using a tungsten instead of moly heater indicated a much lower gas evolution, and tubes will be built next quarter using tungsten heaters for comparison.

Prior to these findings, several tubes were processed using a cathode conversion procedure recommended by RCA. It appears that the arcing situation was somewhat improved, however, the gas problem was still present, and in addition the cathode emission seemed to be a rapid function of temperature. As a result, the perveance would shift from a low value when the beam voltage was initially turned on to a normal value after a few minutes of operation.

Other minor tube redesigns are being carried out including the modification from our present bolted-on window to a heliarced window assembly which should in principle reduce the amount of work involved in tube rework. We also are redesigning the rf input assembly to give us better reproducibility of input "Q."

Because of the manufacturing difficulties mentioned above, and the additional fabrication work involved in driver amplifier tubes, no special attempt has been directed specifically to operate tubes reliably at 270 kV, 360 pps. However, some minor redesign of the high voltage, high efficiency tubes has been carried out on paper.

2. High Power Window Development

Resonant Ring Tests. At the present time the resonant ring is used for spot checking occassional SLAC window coatings to evaluate changes in coating process. Some of the resonant ring time has been devoted to studies of RCA's rf sputtered coating. The indications are that the rf sputtered coating when applied in the right technique is more stable during bake cycles than the SLAC-type coating. Hence, it may present some advantages in enabling rebaking of a tube without having to remove and recoat the window.

Window Coating. Tests are being continued on the relative value of titanium coating by ac sputtering (our standard technique), and electron beam evaporation. Unfortunately, the thickness measurements by crystal frequency variation do not give direct comparison of the total amount of coating introduced by various methods, probably because the crystal distorts the boundaries of the plasma in the sputtering process. Hence, the necessity for ring tests whenever a new coating method is contemplated.

Window Failures. A good deal of time has been spent analyzing the failures on RCA, Litton and SLAC windows. It appears that some of the window failures (at least of Litton windows) observed in the gallery were probably caused by small copper slivers.

Examination of the waveguide flange gaskets revealed that some of the gaskets had been made by a worn die and had minute loose slivers near the inside corners. Steps are being taken to correct the problem in future tube installations.

3. Vacuum

An auxiliary vacuum system using a diffusion pump and double liquid nitrogen trapping has been built for use in ion pump stability studies, and as a general tool for high vacuum problems. This equipment, in conjunction with a gas mixing system which has been completed and a quadrupole gas analyzer which has been ordered, should provide the necessary tools required to make ion pump stability studies under various conditions of operation.

4. Driver Amplifier Klystrons

During the quarter we processed 12 new tubes and 4 reworks. The reworks were of the old mechanical design; one failed due to a leak in the input and has been scrapped, the other ones are usable although they will probably be used only in the Test Lab because of the lack of mechanical rigidity which makes their installation in the gallery difficult.

Of the 12 new tubes built, two failed in bake, one because of a shorted input, one because of operator error at the end of the bake cycle. Of the 10 tubes that reached test, one is still in test, and the other 9 were accepted with peak power outputs of between 69 and 77 kW at 60 mW drive, and up to 85 kW at 200 mW drive.

B. OPERATION AND MAINTENANCE

High power klystrons accumulated approximately 308,000 hours during the quarter with 18 failures. Twenty-eight tubes were available for immediate installation with a total of 110 klystrons in storage.

Driver amplifier klystrons operated approximately 43,000 hours in the gallery and 2600 hours in the Test Lab. There were 12 failures in the gallery. Twelve spares were available at the end of the quarter.

Main booster klystrons operated approximately 3000 hours during the quarter. Two tubes which had been removed previously have been declared failed during this quarter. The failures were caused by operating tubes with improper focusing and body current interlock. As a result, some of the cavity noses had been partially melted, and although the tubes were still operable the gain was low and the stability was questionable.

1. High Power Klystron Operation

Table II gives the summary of tube usage and failures since the beginning of operation.

The last Sperry tube failed during the quarter after approximately 8500 hours of operation. The ratio of operating tubes is approximately 35% Litton tubes, 41% RCA tubes, 24% SLAC tubes on the line. The information on tube operating experience including all tubes is given in more detail in Fig. 8. The mean tube age at the end of the quarter and the mean age at failure during the quarter, the number of replacements and the number of failures are given as well as the average per tube and average hours per socket per quarter. The mean age at failure is still increasing, and reached 4620 hours during the quarter, whereas the number of replacements and failures continues to decrease slightly.

Figure 9 gives the MTBF per quarter and cumulative, exclusive of Sperry tubes. Mean time between failure (MTBF) is defined as the number of operating hours in a given period divided by the number of failures in the same period. The MTBF is still substantially constant although there appears to be a slight increase during the last two quarters.

Figure 10 gives the tube age distribution in 500 hour increments at the end of the quarter. The mean age of all operating tubes at the end of the quarter was approximately 6570 hours; the median age approximately 7750 hours. Fifteen tubes have achieved lives in excess of 10,000 hours.

Figure 11 gives the failure probability and survival probability of all tubes with the latest information available at this time. Again it appears that the failure rate per 1000 hours is substantially constant at 5% per 1000 hours except for early failures. This trend indicates that most failures are accidental, and we have not yet reached wear-out mechanism in the tubes used in the accelerator.

Causes of Failure. Almost half of the operating failures were window failures. In addition, many of the RCA window failures were very early life failures which explains the rather low average age at failure of all tubes. As mentioned earlier, this situation has been discussed with RCA with a view of preventing the recurrence of these early failures.

Effect of Operating Levels. We are continuing to monitor the effect of operating level on such things as total number of faults, number of trouble reports, and MTBF.

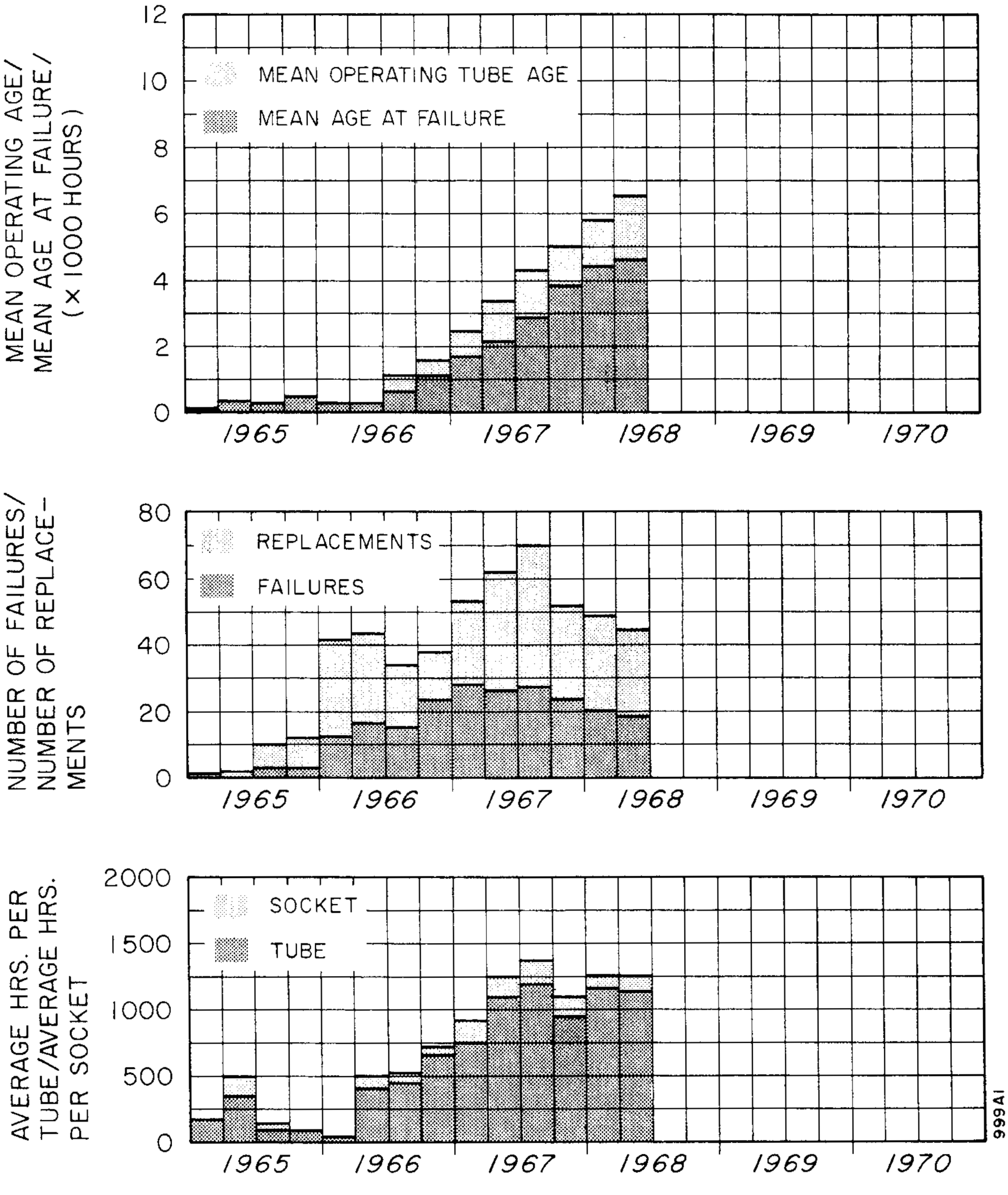

FIG. 8--High power klystron quarterly operating experience.

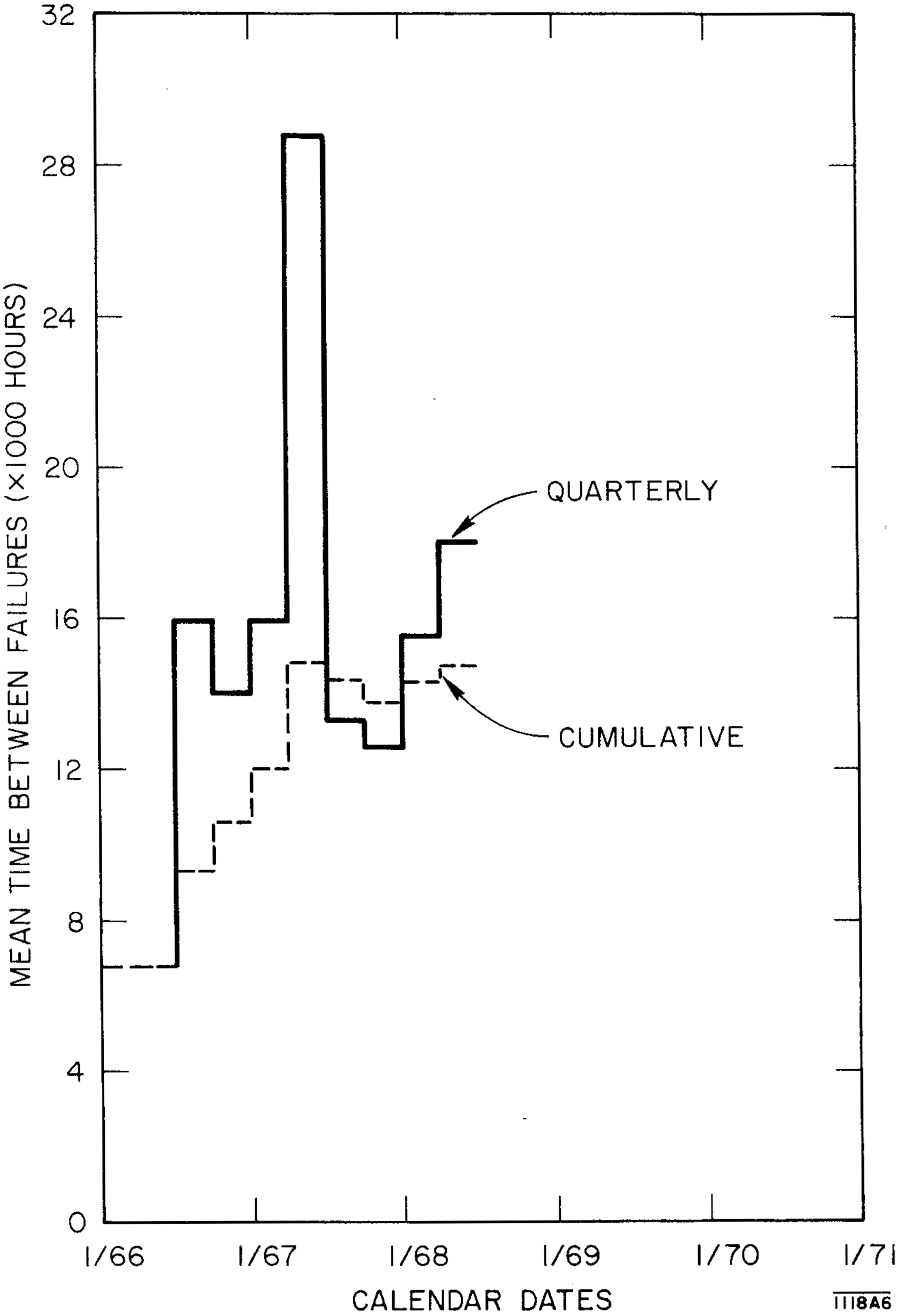

FIG. 9--Mean time between failures, excluding Sperry tubes.

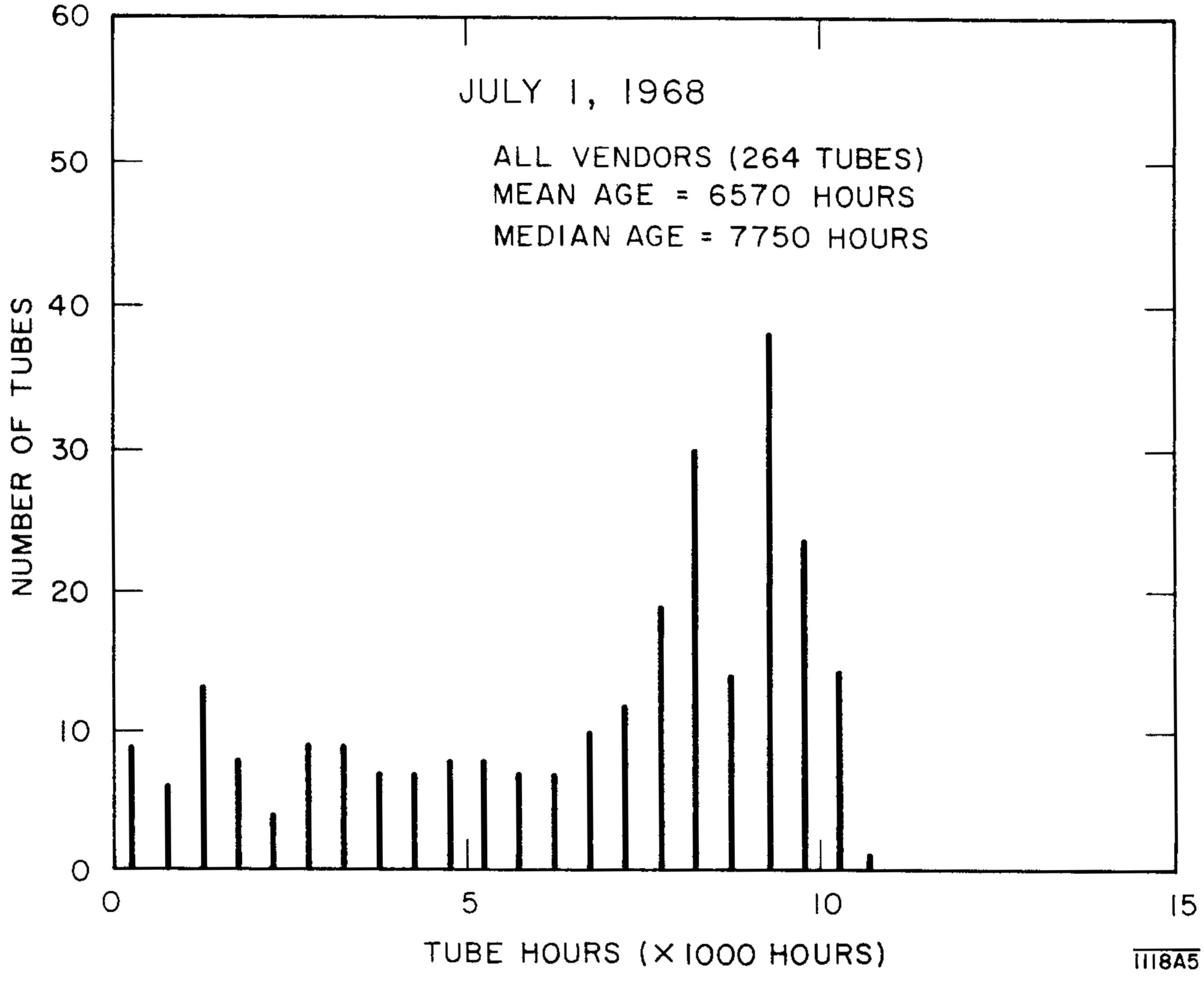

FIG. 10--Klystron age distribution (all vendors) in 500-hour increments.

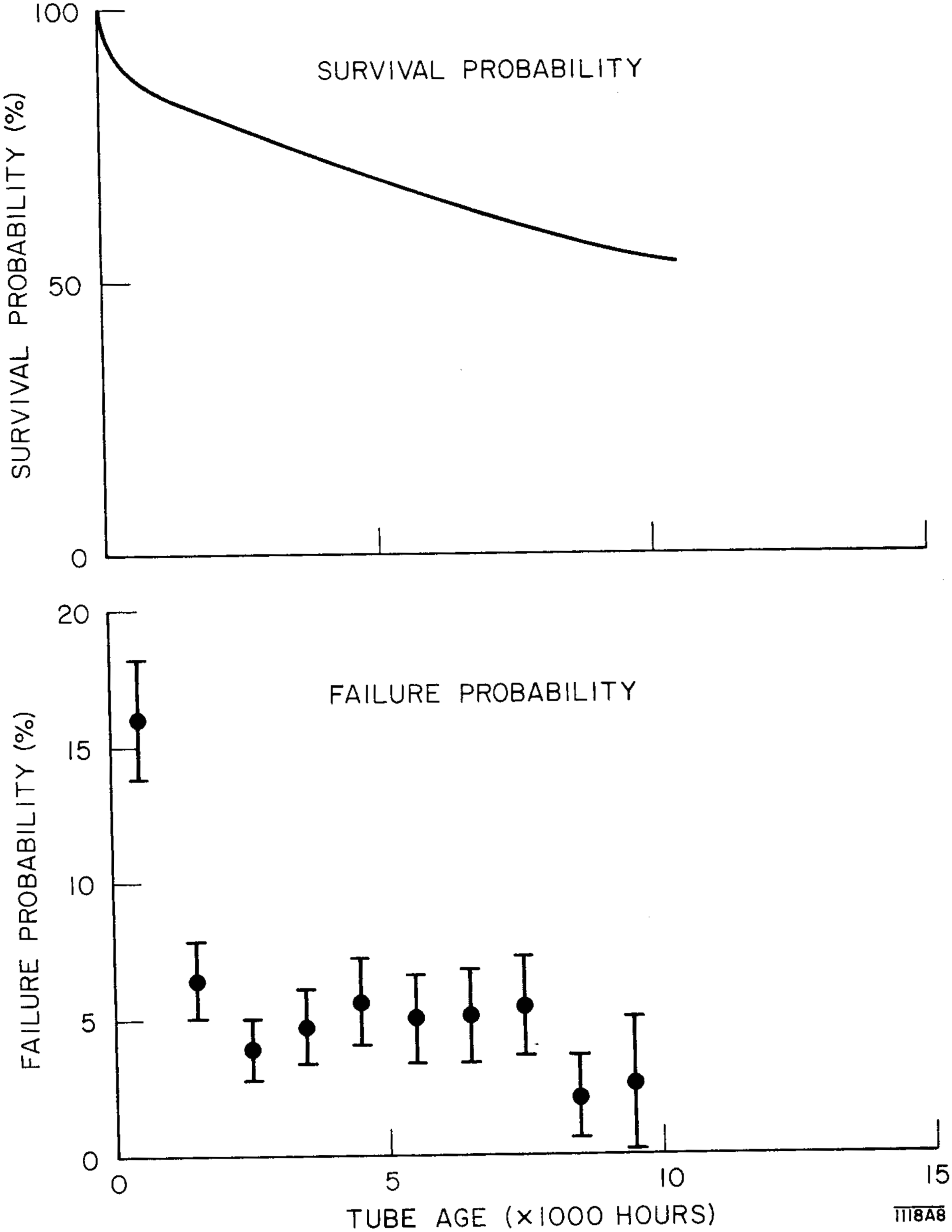

FIG. 11--Klystron survival and failure.

We have approximately 13% of the stations running at 245 kV, 7% at 215 kV, and the rest at 235 kV. During the quarter, the number of trouble reports per station was substantially the same for stations running at 215 or 235 kV. However, for the stations running at 245 kV, the number of trouble reports per station is roughly 1.6 times the average for the whole machine. Similarly, the incidence of fault counts is 1.4 times higher in the sectors operating at 245 kV than the overall average for the machine. On the other hand, the number of failures appears to be less than average for the quarter in the sectors operating at 245 kV. Although there were three failures in those sectors, two of these failures were early window failures and probably have no connection with the operating level.

2. High Power Klystron Maintenance

As shown in Fig. 8, there were 45 replacements during the quarter; ten of these were oil leaks, 5 were replacements of new vendor tubes for which operational data was desired, and the remainder were replaced for either suspected tube or pulse transformer tank problems.

Preventive maintenance is continuing at approximately the same rate, and no particular problems have been uncovered yet.

Other activities in maintenance include mechanical improvements to the handling equipment. In addition, the cadium plating on some permanent magnets has been stripped to prevent its contaminating the pulse transformer tank oil and causing transformer breakdown.

3. Driver Amplifier Klystrons

During the quarter the last two Litton driver amplifiers failed. In addition there was one early SLAC failure (144 hours), and 5 Eimac operational tube failures at an average age of 6700 hours. In addition, 4 Eimac tubes which had been held as limited use tubes were declared failed during the quarter.

The SLAC tube failure was caused by an open filament, the Eimac failures were of the usual gassiness problem indicated by large phase droops during the pulse.

Figure 12 gives the tube age distribution of all driver amplifier klystrons now on the line. The operating experience of driver amplifier is shown in Fig. 13.

4. Main Booster Klystrons

No main booster klystrons failed during the quarter, although as mentioned in the summary, two tubes which had previously been damaged in operation were declared failed and are being replaced. Since the drive line modification, the main boosters are

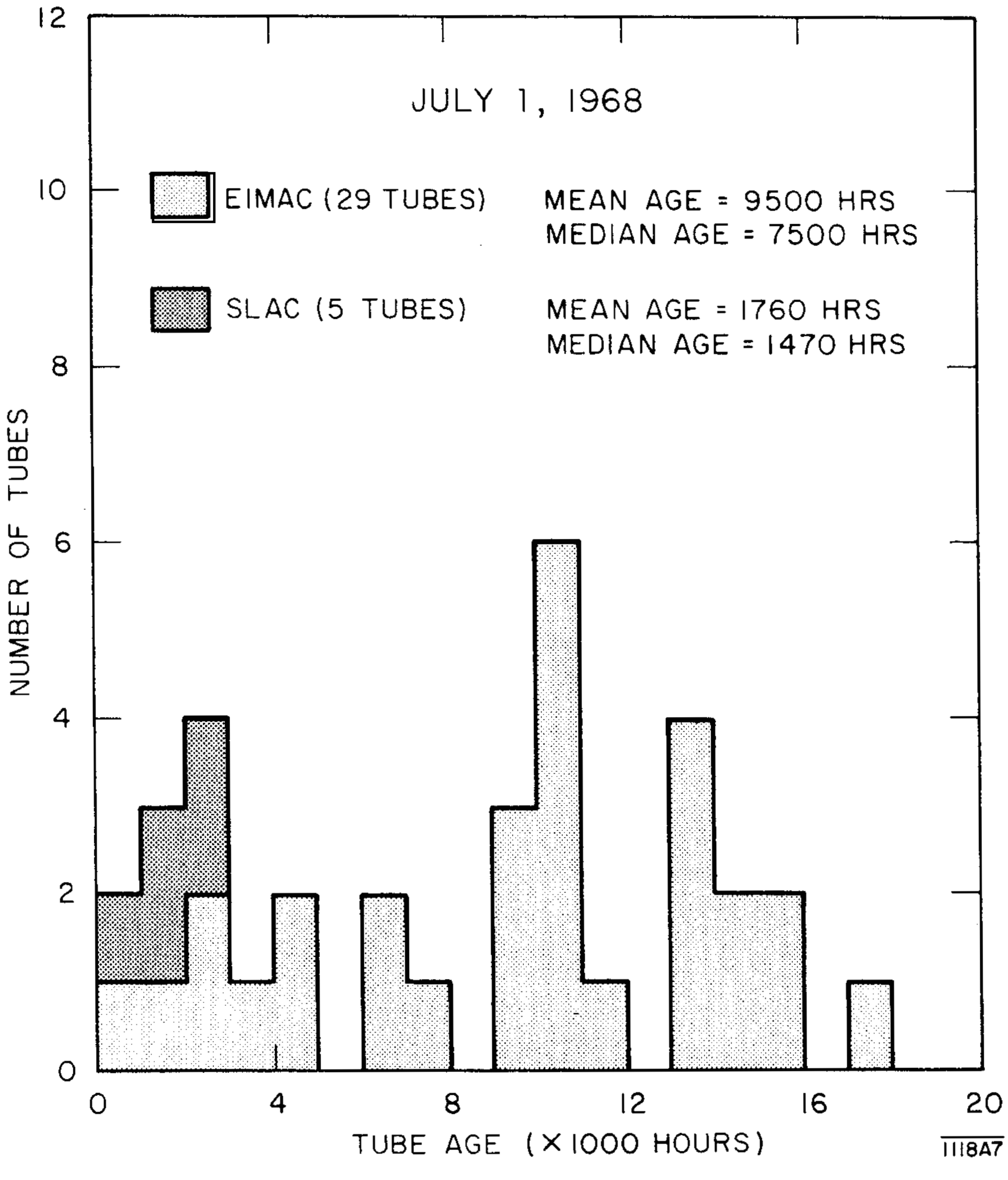

FIG. 12--Driver amplifier tube age distribution in 1000-hour increments.

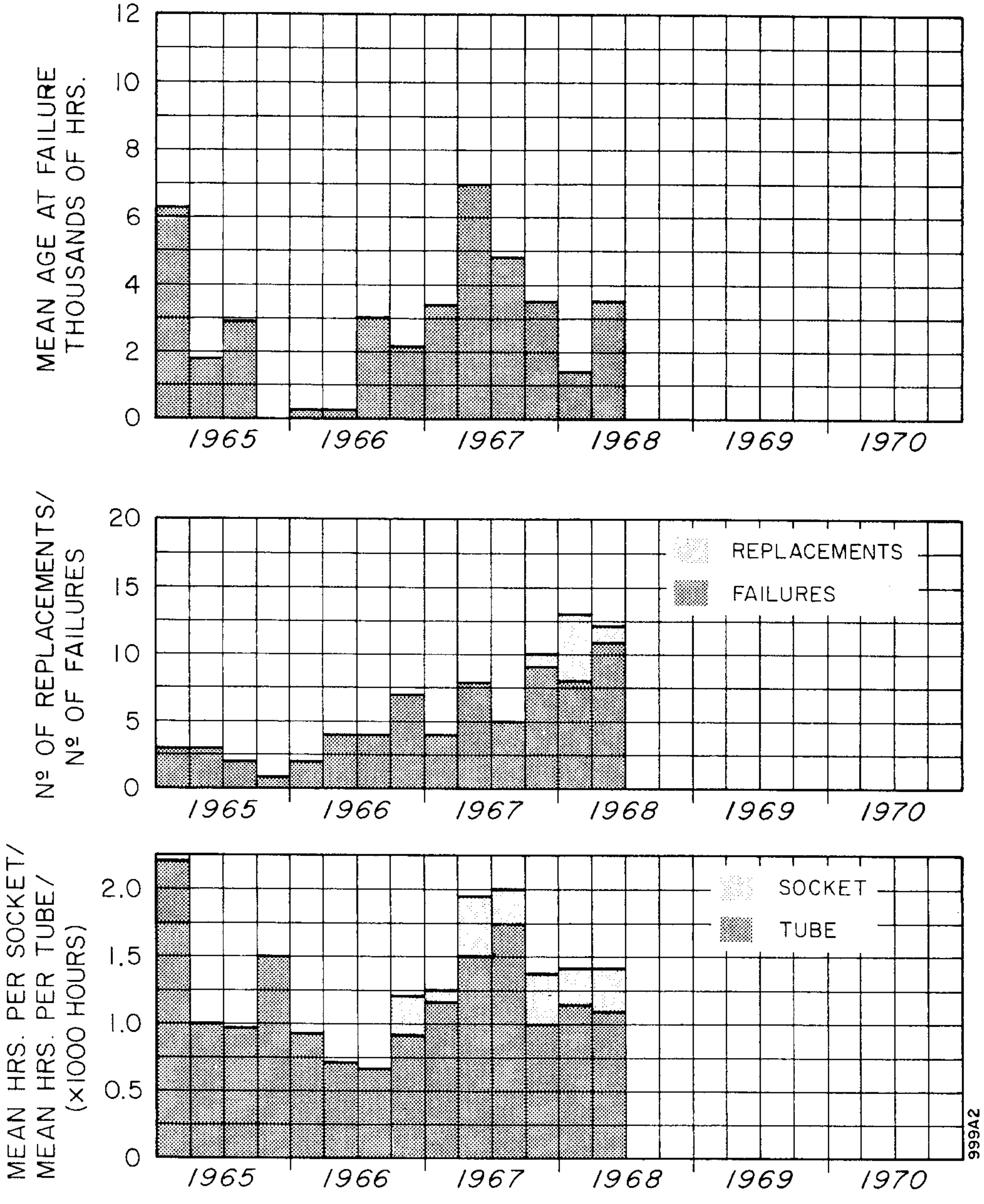

FIG. 13--Driver klystron quarterly operating experience.

now operating at approximately half the power needed prior to the modification. A more detailed study of instabilities which might be caused by the tube, the power supply regulators and the drive system has been instigated.

5. Vacuum System

Vacuum system operation continues to be very satisfactory with average manifold gauge readings of 1.3×10^{-8} Torr without rf, 1.7×10^{-8} Torr with rf. The gas burst problem appears to be under control at the present time. A new 500 L/sec DI pump was installed at station 7-1 late in the quarter, and no bursts have been observed since. Similarly, the bursting at sector 10 has been stopped by installing a modified 500 L pump in which 25% of the cells have been replaced by DI-type cells.

TABLE II

KLYSTRON USAGE AND FAILURES

Overall

Dates	Operating Hours		Failures			
			Quarter		Cumulative	
	Quarter	Cumulative	Number	Mean Age @ Failure	Number	Mean Age @ Failure
To 6/30/66	118,000	156,000	17	234	39	256
To 9/30/66	127,000	283,000	14	594	53	350
To 12/13/66	176,000	459,000	23	1070	76	575
To 3/31/67	228,000	687,000	28	1670	104	860
To 6/30/67	303,000	990,000	26	2166	130	1130
To 9/30/67	335,000	1,325,000	27	2881	157	1433
To 12/13/67	265,500	1,590,500	23	3833	180	1739
To 3/31/68	311,000	1,901,500	20	4487	200	2013
To 6/30/68	307,500	2,209,000	18	4620	218	2225

VII. MECHANICAL ENGINEERING

A. ACCELERATOR MAINTENANCE

During the first quarter of calendar year 1968, back-flushing of accelerator section water jackets where torn or broken strainer screens were found was completed. A small amount of screen material, some balls of solder, and a large amount of a copper-like sludge were found. The latter probably from the pipe thread lubricant (a colloidal copper suspension) used at initial installation. Back-flushing with hot water apparently softened the carrier and allowed the excess thread lubricant to be swept away.

Realignment of accelerator sections on their supporting girders ("quarter point alignment') was completed. The realignment was made necessary because of the change in girder deflection with ambient temperature. Since the accelerator housing temperature has now attained its equilibrium value, it is not expected that the "quarter point alignment" will have to be repeated.

A number of small vacuum leaks were located by the vacuum maintenance group. Three leaks were determined to be in brazed joints on the rectangular waveguide system. Two power dividers and one "S" assembly were replaced in the accelerator housing because those leaks could not be repaired in place. A leaky weld in the vacuum manifold was repaired in place by re-welding. Still another leak was eliminated by tightening waveguide flanges.

A new set of beam knock-out plates was designed, fabricated, and installed at the injector. Many of the instruments on the injector girder were removed or repositioned to make room for the new beam knockout. A large misalignment between the buncher and pre-buncher was discovered in the course of installing the beam knockout. Eliminating the misalignment will require let-up of the injector vacuum system, opening a weld joint, realigning, and then re-welding. It has tentatively been planned to carry out this operation during the next major shutdown in August.

The indium in the fast valve at the end of the accelerator was replaced since the valve had tripped closed during a remelt cycle. Closing the valve during the remelt cycle allowed indium to flow out of the valve seat. After replacing the indium and remelting, the valve was found to be vacuum tight.

B. POSITRON SOURCE

A positron run, using a 2-inch wheel target, was completed in January. The total incident beam energy on the target during that run was 15.8 megawatt hours. A residual radiation level of 10 roentgen/hour was recorded just downbeam of the target approximately one foot from the beam axis and through a one inch thick lead shield. Radiation levels in the vicinity of the positron source have been recorded regularly on accelerator down days. The results of observations made at the location described above as well as observations made in the aisle opposite the target (same y and z as above, but about 5 feet away from the beam axis) are shown in Fig. 14.

Late in March the 2-inch wheel target was examined and found to be badly cracked and pitted. The total beam energy incident on the target was approximately 24 megawatt hours. A new 2-inch wheel target and a new wheel drive system were fabricated and installed.

The design of a 3-inch wheel target and drive system was initiated. A novel feature allowing the target to produce positrons continuously or intermittently was incorporated into the design. A variable throw crank will allow the wheel to be trolled in a 2-inch, 2-1/2-inch, or 3-inch circle. When operated in a 2-inch circle, concentric with the target, the electron beam will miss the target, except when a bump on the inside diameter of the wheel target intercepts the beam. This operating mode will produce positrons intermittently like the wand presently does. Operating on a 3-inch circle will yield positrons continuously. By running in a 2-1/2-inch circle with its center slightly displaced from the center of the wheel target a 50-50 mix of electrons and positrons will be generated. A new 3-inch wheel target was fabricated, but was not installed because a bellows which would operate reliably at a 3-inch stroke was not available. The new two inch target was used during a week long positron run during which the target was subjected to approximately 15 megawatt-hours of incident electron beam energy.

Test of a formed Inconel 718 bellows at a 2-1/2-inch stroke was completed. The bellows was subjected to approximately 18 million cycles and was then removed from test. It was still vacuum tight. Two additional Inconel 718 bellows were tested at a 3-1/2-inch stroke. The bellows were tested to verify that the design was sufficiently conservative for use on the 3-inch drive system. Both bellows failed at about 600,000 cycles. The bellows which had successfully undergone 18 million cycles at 2-1/2-inches was then tested at 3-1/2 inches. It failed at about 600,000 cycles. A 316 stainless steel bellows was also tested at a 3-1/2-inch stroke. It failed at about 200,000 cycles.

All cooling water hoses to solenoid coil zero, the wand, and the wheel were replaced after two of the hoses failed. One of the hoses appeared to have sustained radiation damage.

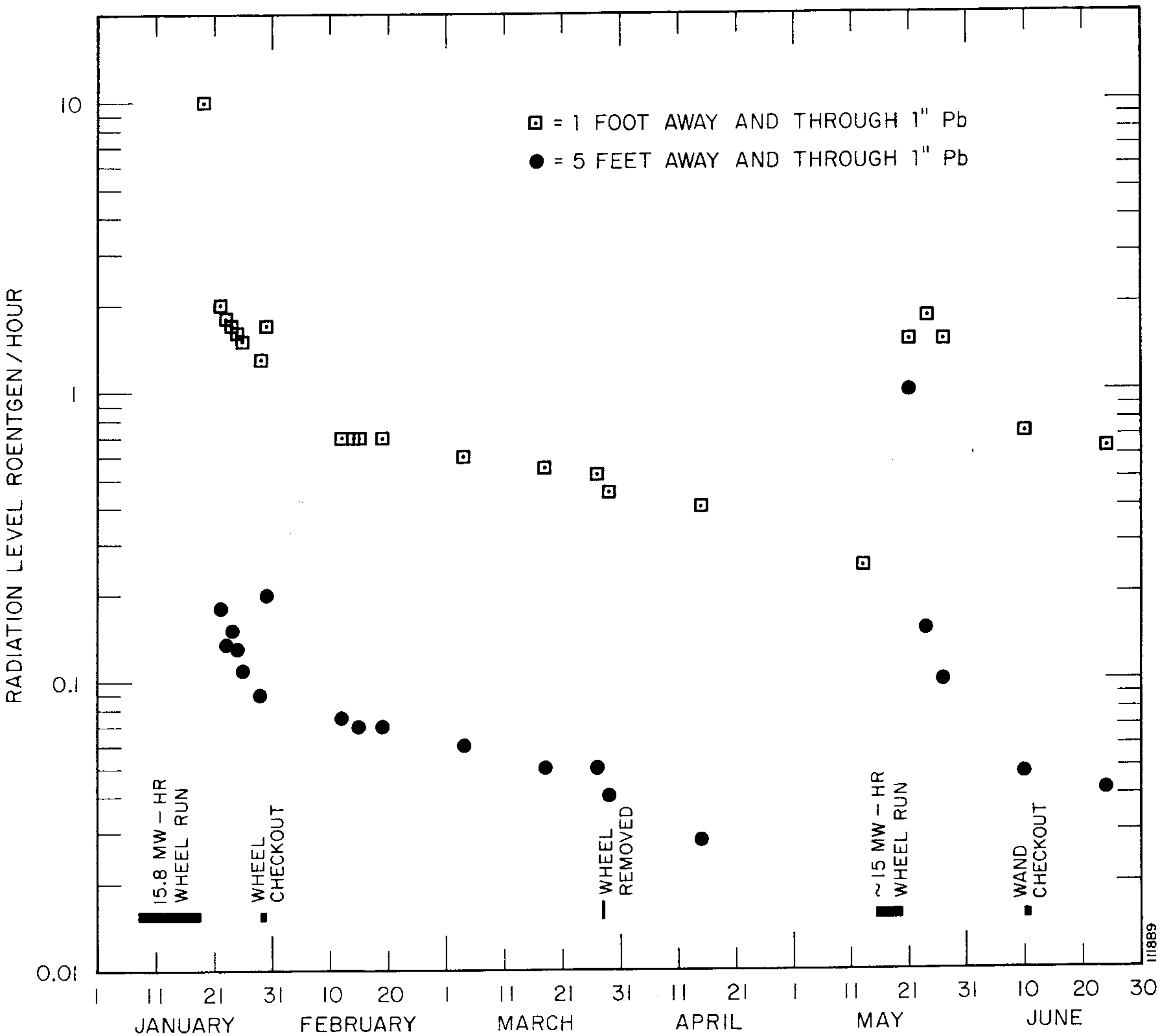

FIG. 14--Residual radiation level in the positron source area.

An electric motor drive for the wand was designed and installed. The new drive produced a harmonic motion which resulted in lower stresses on the wand structure. Deceleration at the ends of the wand strokes with the pneumatic drive system was very high and it was feared that the wand structure may fail from the high resultant stresses.

A meeting was held with potential positron users to determine the need for various types of positron sources in the future. The conclusion as a result of the meeting was that there will be only minimal need for positrons during the next year. The positron source improvement program was therefore de-emphasized.

VIII. COUNTING ELECTRONICS

A. END-STATION CHARGE MONITORS[1]

The previously reported End Station A toroidal monitor was expanded with the addition of a remote accumulator. This essentially allows two experimenters to make independently-timed runs using the same toroid and front-end electronics.

Construction of a complete additional monitor, identical to the system now installed, was 90 percent completed by the end of the Quarter. The unit will be installed in End Station A.

The End Station B type of toroidal monitor was improved with additional gain near the toroid in order to overcome cable pickup noise. The system now appears completely insensitive to such pickup. Also, a complete new system was built and installed in the K^o beam, bringing the total of such systems to three. Additional remote preamplifiers will enable each system to be time-shared by two separate toroids.

B. CENTROID TIME-OF-FLIGHT SYSTEM

Some re-design of the system was carried out in order to make measurements using cosmic rays. All previously reported tests of resolution used fast light pulsers as the source of excitation. Tests were made using a 3-inch × 3-inch × 1/2-inch Pilot B scintillator on an XP1021 phototube, together with 1-inch × 1-inch × 1/2-inch aperture counters on similar tubes, one of which supplied the timing reference. The full width at half maximum resolution was measured in two modes, (a) using the previously-described resonant circuit and mixing technique, and (b) using the phototube signals directly to start and stop the time-to-amplitude converter. The resolution obtained was a poor 1.5 nsec and 1.2 nsec respectively. The tests are presently being re-run using a 1-inch × 1-inch × 1/2-inch instead of a 3-inch × 3-inch × 1/2-inch scintillator on the main detector, in an effort to determine the contribution of scintillator and light-pipe reflections to the observed dispersion. In view of previous indications of dispersion from light-pulser measurements, the latest results are not understood.

C. VIDEO POSITION MONITORS FOR END STATIONS

Two more video position monitors were instrumented and installed, one each in the A and K^o beams. Each unit consists of an X and Y single-loop pickup with low-noise amplifier, plus a 6-inch aperture toroid with a similar amplifier. The unnormalized video signals are transmitted by coaxial cables to DAB.

D. K^{o} EXPERIMENT SUPPORT

Basic electronics for a multi-counter time-of-flight system were constructed during this Quarter. The system, to be used in conjunction with the K^{o} beam into the 40" hydrogen bubble chamber, has a resolution of ~ 0.3 nsec FWHM. The fast electronics consists of discriminators followed by time-to-amplitude converters (TAC's). The timing reference is derived from either the chopper rf signal, or directly from a beam pickoff device.

Circuits were also designed which peak-hold the TAC outputs from each counter channel, which in turn are presented to the multiplexer and ACD of an IBM1800 computer. Phototube pulse heights are separately digitized and read into the computer, in order to correct the data for variations in discriminator timing with input amplitude.

In addition, a high speed integrated circuit shift register was built for use in conjunction with strobed coincidence buffers to record the time-sequence of events in the time-of-flight scintillation detectors. The shift register, which is capable of 70 MHz operation, divides the 1.6 μsec beam pulse into 8 - 200 nsec "buckets", and strobes successively 8 coincidence buffers all fed in parallel. The information is later read into the IBM1800 by the standard data-bus technique.

A separate project was the development of a digital differential discriminator, which triggers the 40-inch HBC cameras when the beam pulse charge lies within preset limits. The digital input is obtained either from a toroidal charge monitor, or a scintillator detector with digitized output. When a trigger occurs, the digital number representing pulse charge is displayed on a data board which is photographed together with the bubble chamber event.

E. RHO EXPERIMENT SUPPORT

A set of spark counter units was developed for the LRL Magnetostrictive Readout System. The counters for the bins containing 4 scalers per channel count to 7 (binary 111) and latch, thereby indicating the actual number of sparks plus fiducials up to binary 110. A count of 7 or greater is represented by binary 111. Interface equipment is provided to read the information into the IBM1800 computer on the three most significant bits of the first scaler word.

For the 8-scaler readout bin, a special counter has been designed to read the number of sparks exceeding 7. That is, 9 sparks would be represented as binary 010. The 8-scaler spark counter can read up to 14 sparks, after which it latches. Approximately 60 percent of the channels have been instrumented.

In addition, a number of circuits have been designed and incorporated into the system to improve operational flexibility. These include a control unit with built in spark simulation test features, and a monitor panel containing switching for introducing test signals.

F. COLLIDING BEAM EXPERIMENT SUPPORT

In addition to supporting checkout of the fast logic, high voltage and scanning systems, Counting Electronics designed and constructed a 2-counter time-of-flight system to aid in discriminating against cosmic rays. The basic system consists of the two counters, followed by discriminators, fed to the start and stop inputs of a time-to-amplitude converter. The TAC output is digitized and displayed on a data board which is photographed with the spark chamber event. In addition, the pulse heights of the phototube outputs are digitized and similarly displayed. All fast logic including the ADC's is of commercial manufacture; the interface and display devices were specially designed.

G. MODULE DEVELOPMENT

A seven-bit analog-to-digital converter[2] for nanosecond pulses was developed for the Group G K_2^0 beam experiment. The unit is used for digitizing both pulse heights from shower counters, as well as time-of-flight information from standardized phototube pulses (discriminator outputs). The unit has a full scale range of 128 counts, with overflow capability to 160 counts. Nanosecond pulses are integrated and digitized with a sensitivity of 1.2 pCoul/count. In the time-measurement mode, using standard logic pulses of -750 mV into 50Ω, the sensitivity is ~80 psec/count.

The previously reported buffer storage unit,[3] which accepts 8 channels of nanosecond pulses and stores the information for later readout into a computer, was modified to include a coincidence front-end. In the new unit, overlap of 3 nsec pulses applied simultaneously to input and strobe lines will trigger the tunnel-diode flip-flop.

H. INTEGRATED CIRCUIT STUDIES

Some high speed integrated circuits, such as the Motorola MECLII MC1023 dual 4-input clock driver, are being investigated for potential application to large arrays of hodoscope counters. Both discriminator pulse shaping and coincidence logic are possible applications. The desired speed range is > 100 MHz, with coincidence resolving times of a few nanoseconds. With the aforementioned unit operated as a 2 input AND gate, rise and delay times are ~ 2 nsec.

I. EQUIPMENT POOL

Only minor procurements of new modules, principally discriminators, were made during this Quarter. Pool usage is running near 100 percent on the major items.

A system power supply to handle up to 10 NIM bins was developed during this period, and installed in the Streamer chamber facility. The general problem of power supplies for heavy current loads, i.e., which exceed the rating of existing NIM supplies, is being studied.

Additional Ortec cast bins and Power Designs NIM supplies were ordered during this Quarter.

LRS161 discriminator problems are still not resolved. A modified front end has been designed which appears to eliminate most of the previously reported stability problems. The latest problem concerns failures of output transistors. The company is seeking a substitute unit which will not degrade present performance.

Some EG & G TR204 discriminators with modified leading edge inhibit have been received and tested. The disadvantage of the present system is that the unit cannot be inhibited in one mode using the bin gate. The factory is considering this problem.

All pool equipment is being inventoried and entered onto punched cards for computer listing. In addition, logic modules for all groups are being listed. Equipment transfers, group listings, and SLAC totals will be more readily accessible with this system. Maintenance records for all types of modules will also be catalogued.

Demand for module and scaler repairs has been heavy, in line with the almost 100 percent usage of HEEP equipment.

J. LH_2 TARGET CONTROLS

During this Quarter, all target controls for the Drickey K^o-beam target were installed and became operational.

New control units for the for the A-beam target were designed, constructed and installed. The new controls simplify target selection procedures and permit selection of up to 6 different targets.

Investigation into the use of capacitance sensors for measuring the density of LH_2 within a target is continuing. Preliminary results show a measurable change in capacitance with density, but whether the effect is sufficiently large to make reliable measurement is as yet unknown.

A new airflow indicator chassis was completed and installed on the Drickey K^o-beam target.

K. REFERENCES AND NEW REPORTS

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2. "Seven-Bit Analog-to-Digital Converter for Nanosecond Pulses," D. Porat and K. Hense, SLAC PUB 442, July 1968 (Submitted to Nuclear Instruments and Methods).
3. "Instruction and Maintenance Manual for Buffer Storage Unit 114-102," M. Fishman, SLAC TN-67-28, September 1967.
4. "Fast Timing Circuit for Use with Cerenkov Counters," A. Barna and B. Richter, Nuclear Instruments and Methods, 59, 141-144 (1968).
5. "2 MHz Square-Wave Generator Using Two TTL Gates," A. Barna, Dale Horelick and A. Johnson, SLAC PUB 457, July 1968 (Submitted to Electronic Design).