TWO-MILE ACCELERATOR PROJECT

Quarterly Status Report

1 October 1967 to 1 January 1968

June 1968

Technical Report
Prepared Under
Contract AT(04-3)-400 and
Contract AT(04-3)-515
for the USAEC
San Francisco Operations Office

Printed in USA. Available from CFSTI, National Bureau of Standards,
U.S. Department of Commerce, Springfield, Virginia 22151
Price: Printed Copy $3.00; Microfiche $0.65.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

INTRODUCTION

This is the twenty-second Quarterly Status Report of work under AEC Contract AT(04-3)-400 and the sixteenth 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 October 1, 1967 to January 1, 1968. Contract AT(04-3)-400 provides for the construction of the Stanford Linear Accelerator Center (SLAC), a laboratory that had as its chief instrument a two-mile-long linear 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 milliamperes peak have been obtained. Also during this period, positrons continued to be accelerated through the machine and used in particle physics experiments. Both single and multiple positron beam experiments were performed.

The work of construction was divided into two chief parts: (1) the accelerator itself and its related technical environment; and (2) the more conventional work associated with site preparation, buildings, utilities, etc. To assist with these latter activities, Stanford retained the services, under subcontract, of the firm Aetron-Blume-Atkinson (ABA), a joint architect-engineer-management venture, whose work was completed during the first quarter of 1967.

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.

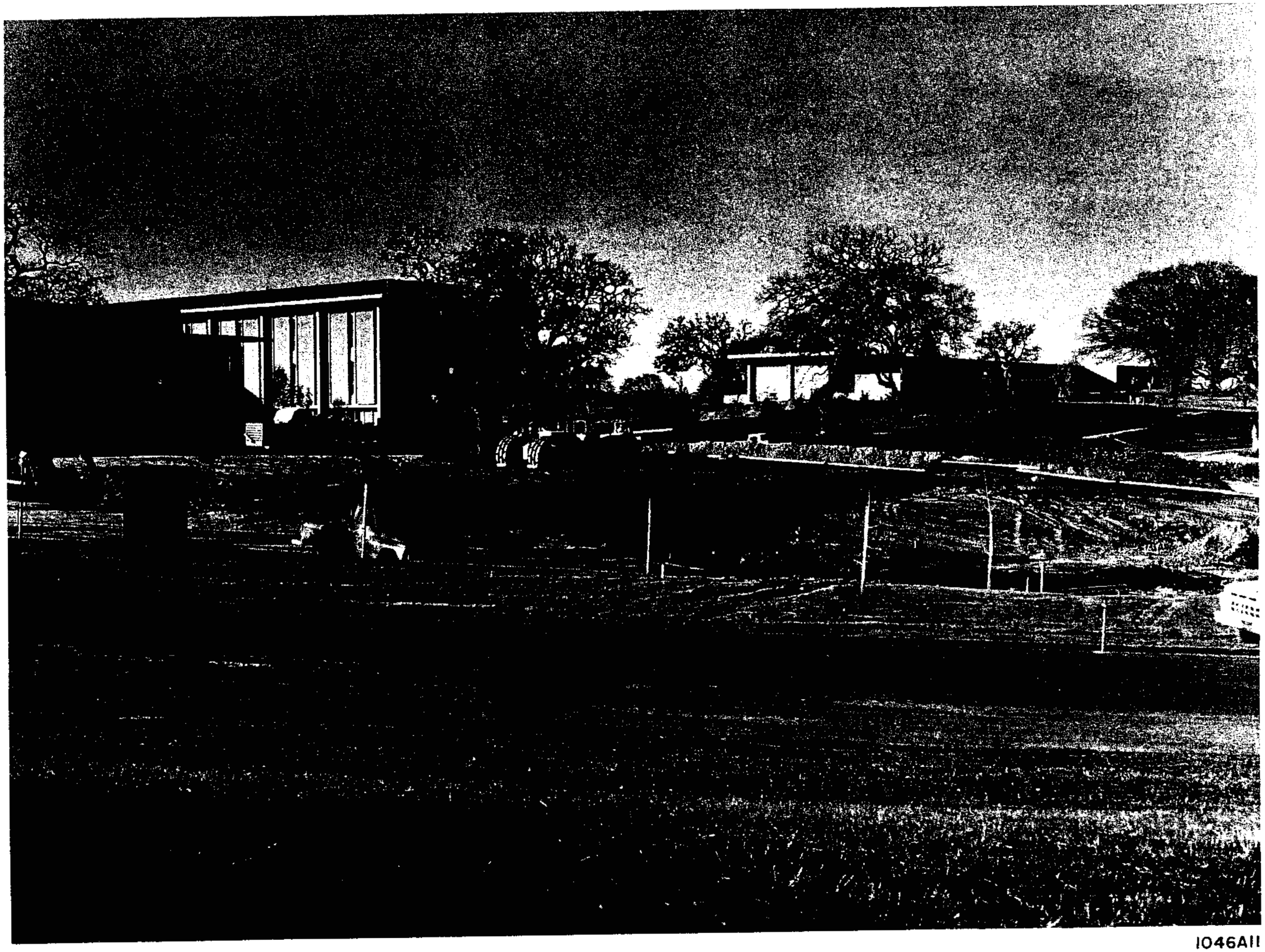
Contract AT(04-3)-515, which went into effect on January 1, 1964, provides support for the various activities at SLAC that were necessary in order to prepare for the research program which is being carried out with the two-mile accelerator. Among the principal activities covered in the scope of Contract 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.

During this quarter the following construction projects were completed: erection of a two-mile boundary security fence south of the Klystron Gallery; extensive modifications within the Electronics Building; modification of flow alarms in the Klystron Gallery cooling water systems to improve reliability; and the installation of a water-cooled, dc power cable network in the Research Yard.

Other projects are in various stages of progress. Engineering is underway on: Phase II of an expansion of the Temporary Computer Facility (the electrical substation is on order) and for additional space to house the program; the installation and housing of two motor generator sets on the south side of the Research Yard. Design work is complete and bids will be received in January 1968 on the following items: an extension of the End Station "A" Counting House; an extension of the Chilled Water Mains to the Central Laboratory Addition; the relocation of the Heavy Assembly Building (H.A.B.) alignment room operation. Construction continued on several projects, percentage of completion being as shown: H.A.B. Welding Shop Addition (84%); replacement of hot water service to the Cafeteria (98%); and SLAC Fire Station (91%).

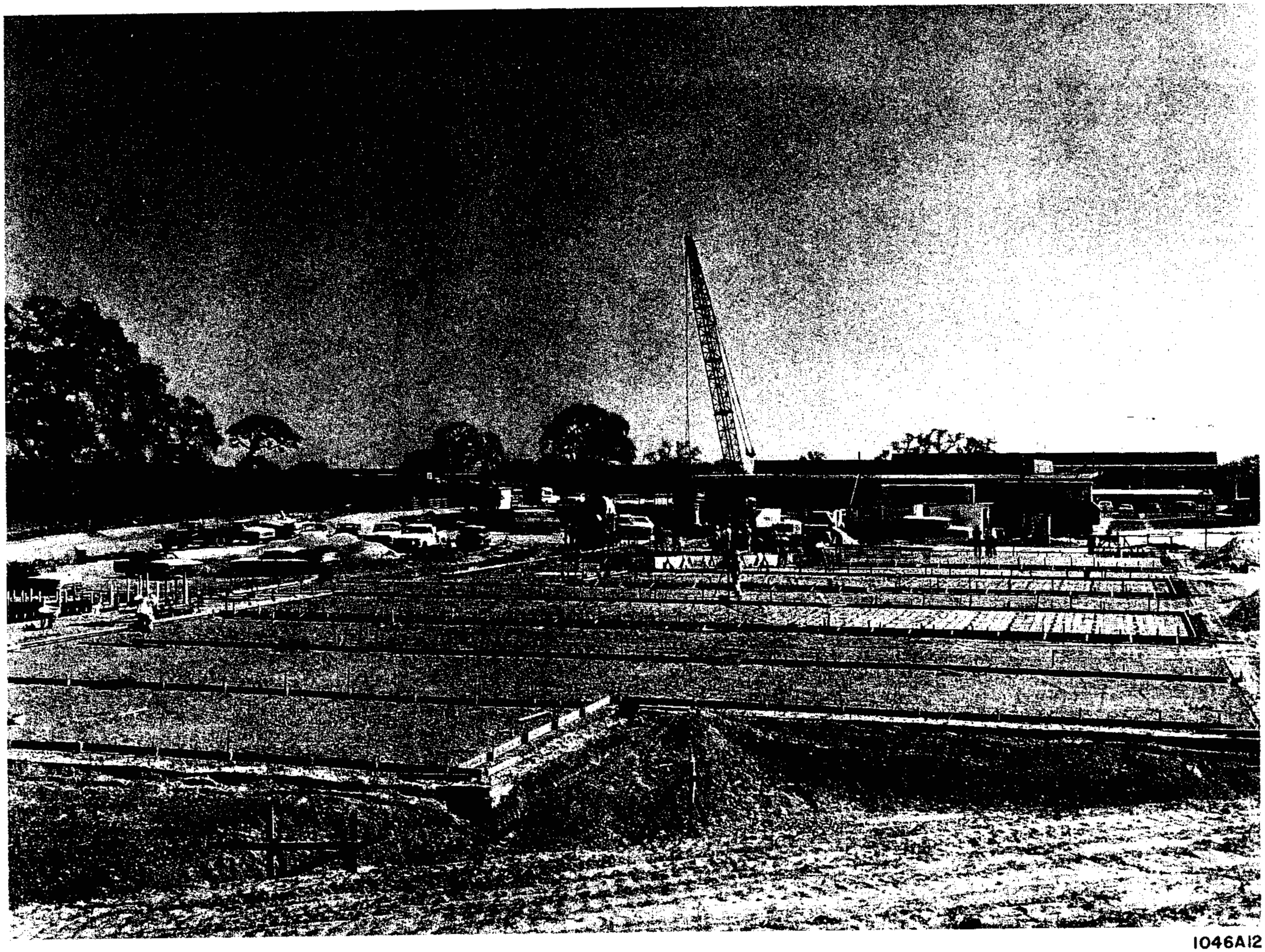
Late in the quarter construction started on two major projects scheduled for completion in the fall of 1968. These are the General Services Building and the Central Laboratory Addition. These and other facilities are shown in the photos that follow.

The highest electrical power demand experienced to date at SLAC was a peak of 37.82 megawatts in December.



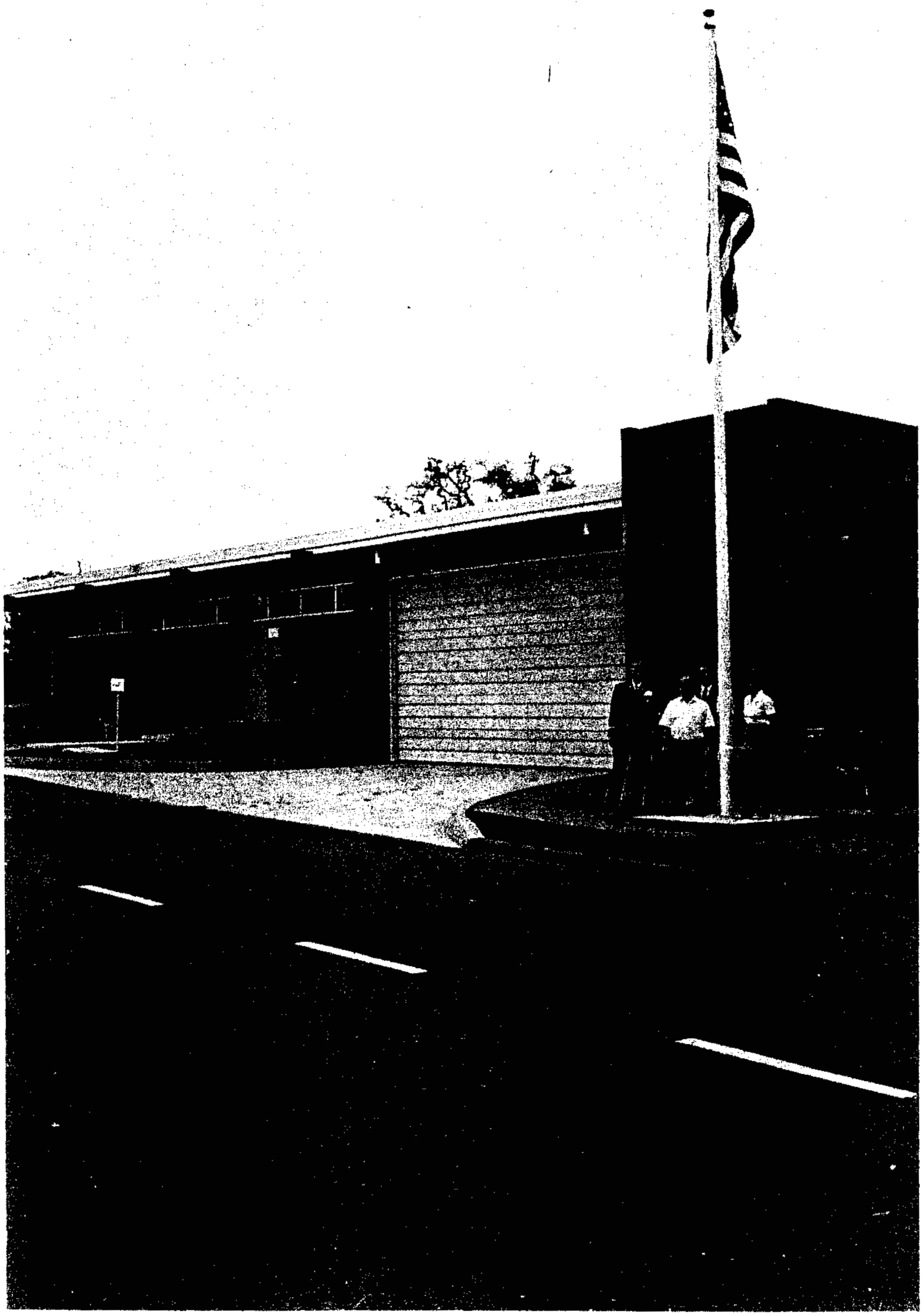
1046A11

FIG. 1--EXCAVATION FOR CENTRAL LABORATORY ADDITION



1046A12

FIG. 2--FOUNDATION FOR GENERAL SERVICES BUILDING



1046A13

FIG. 3--SLAC FIRE STATION

I. ACCELERATOR AND RESEARCH AREA OPERATIONS

A. OPERATIONS SUMMARY

1. General

Accelerator operation continued in the normal pattern of 16 shifts of manned operation per week. Scheduled maintenance of 12 hours duration on Monday was generally followed by two or three shifts of machine physics, with particle physics experiments then scheduled to run until the end of Shift No. 2 on Saturday. A two-week shutdown early in November, and an additional shutdown during the week of Christmas, cut the number of manned shifts for the quarter to 158, well below the average of 188 for the first three quarters of 1967.

Of the 158 shifts, 11-1/2 were scheduled for maintenance, 21-1/2 for machine physics runs, and 125 for particle physics. A breakdown of the scheduled operating shifts is illustrated in Fig. 4, with similar breakdowns for the preceding four quarters.

An examination of Fig. 5 shows that the percentage of delivered beam time has again risen, with an improvement in nearly all categories. There was little change (a slight increase) in accelerator failure. The decrease in scheduled maintenance time can be attributed to the shorter period required following the two-week off period plus the fact that there was a continuous 10-day run preceding the Thanksgiving holiday. It is to be hoped that the decrease in tune-up time and RAD/AP Request can be attributed to the increase in operator experience.

A breakdown of the weekly operating time is given in Fig. 6.

2. Accelerator Failure

As has been true in the past, accelerator failures cannot be attributed to only one area or type of equipment. (An exception to this statement is the positron source, which is treated elsewhere.) Examining the records for the three-month period it can be seen that most problems were minor and there were no long periods of downtime attributable to only one problem. A good portion of the downtime is made up of the sum of a relatively large number of short off periods, such as sub-booster recycling, modulator/klystron recycling, and sector gas bursts. Other problems during this period consisted of a malfunctioning of the injector trigger generator, a major scrambling of the accelerator phase when the drive-line was inadvertantly depressurized; and, for the first time in over a year, several occasions when the 40- and 50-kc tone loops used in the machine protection and personnel protection systems gave trouble. An analysis has been made of those failures causing all beams to stop during the period July to December 1967. It

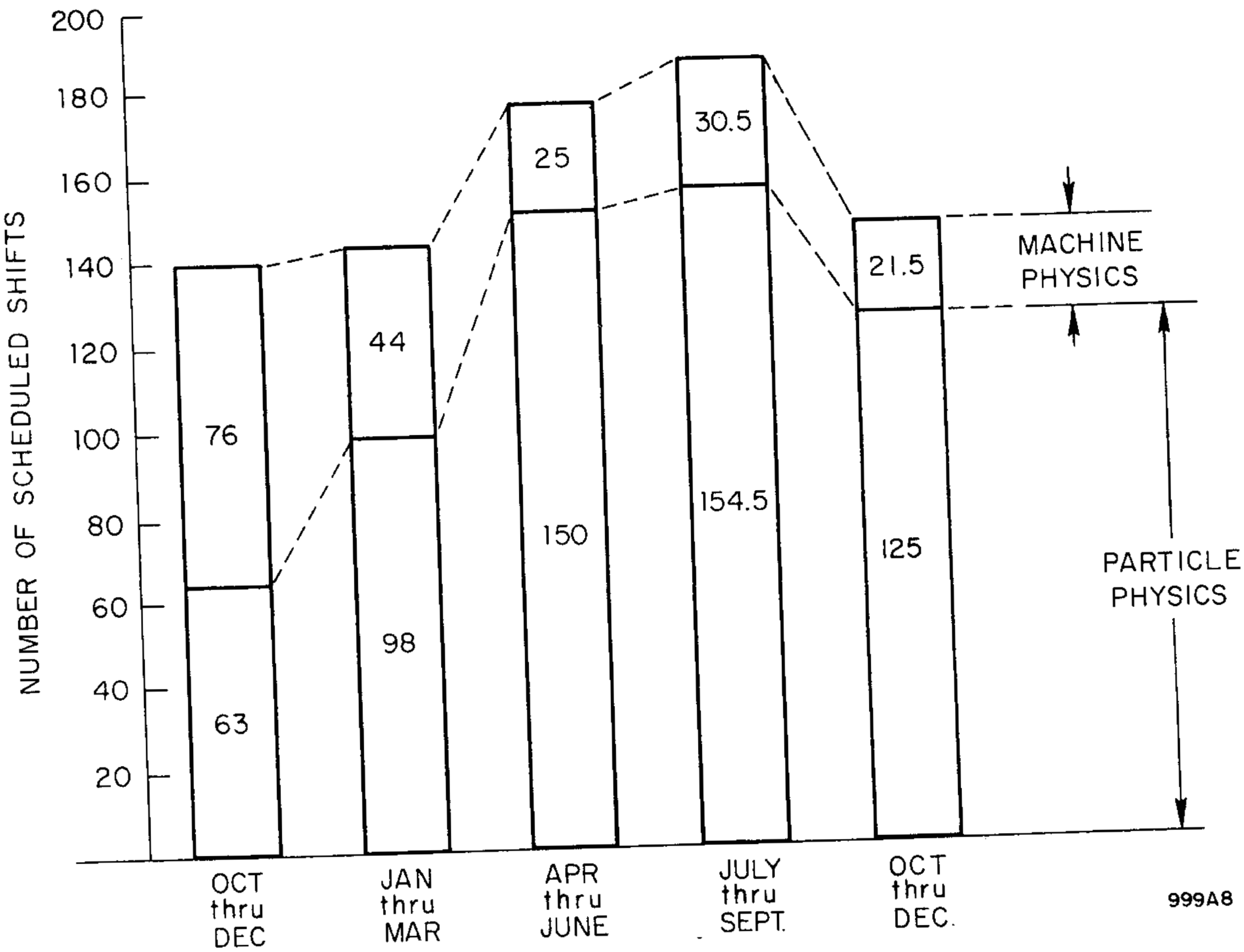


FIG. 4--PARTICLE VS MACHINE PHYSICS RUNS

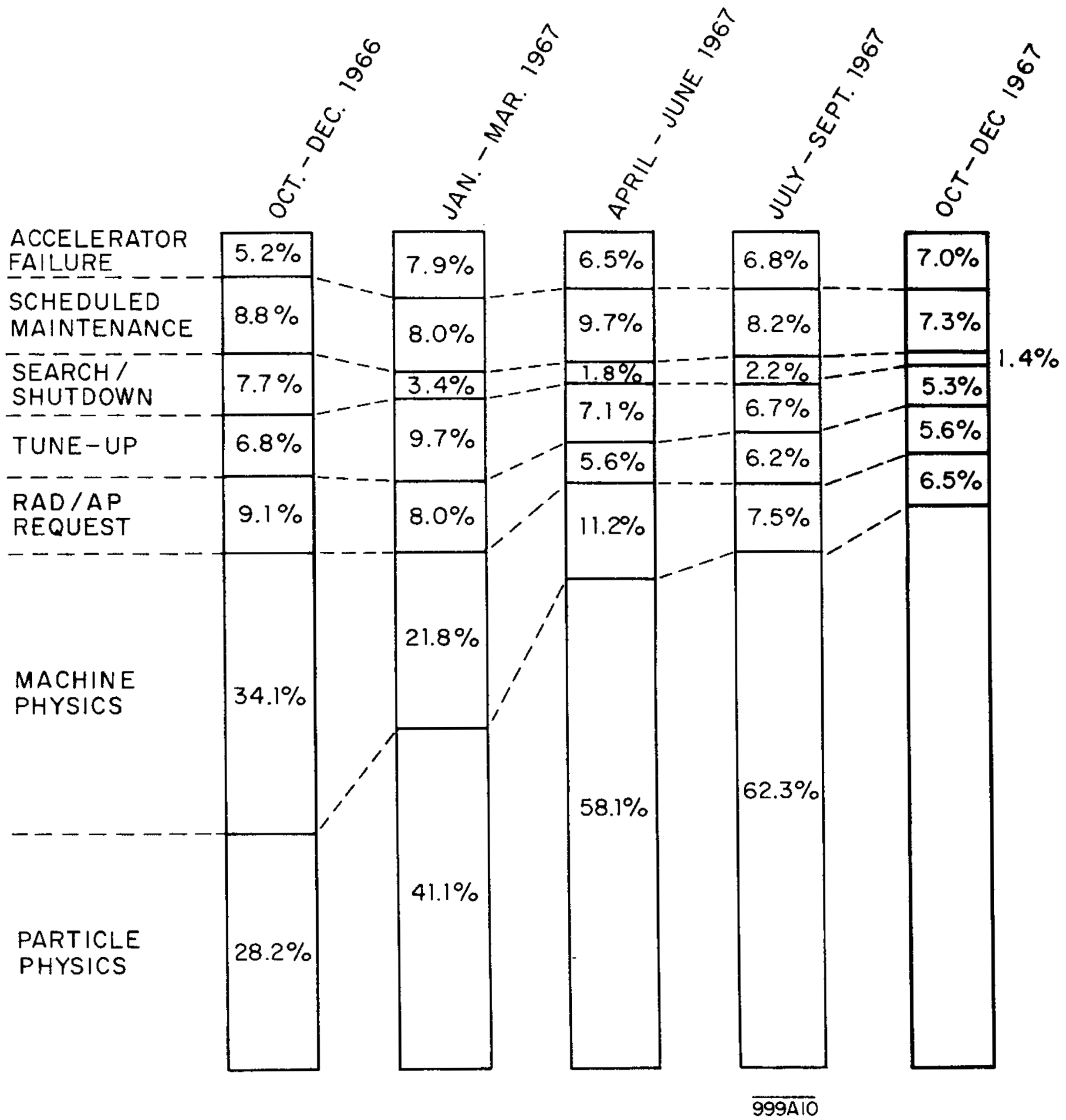


FIG. 5--QUARTERLY OPERATING STATISTICS, OCTOBER 1966 to DECEMBER 1967

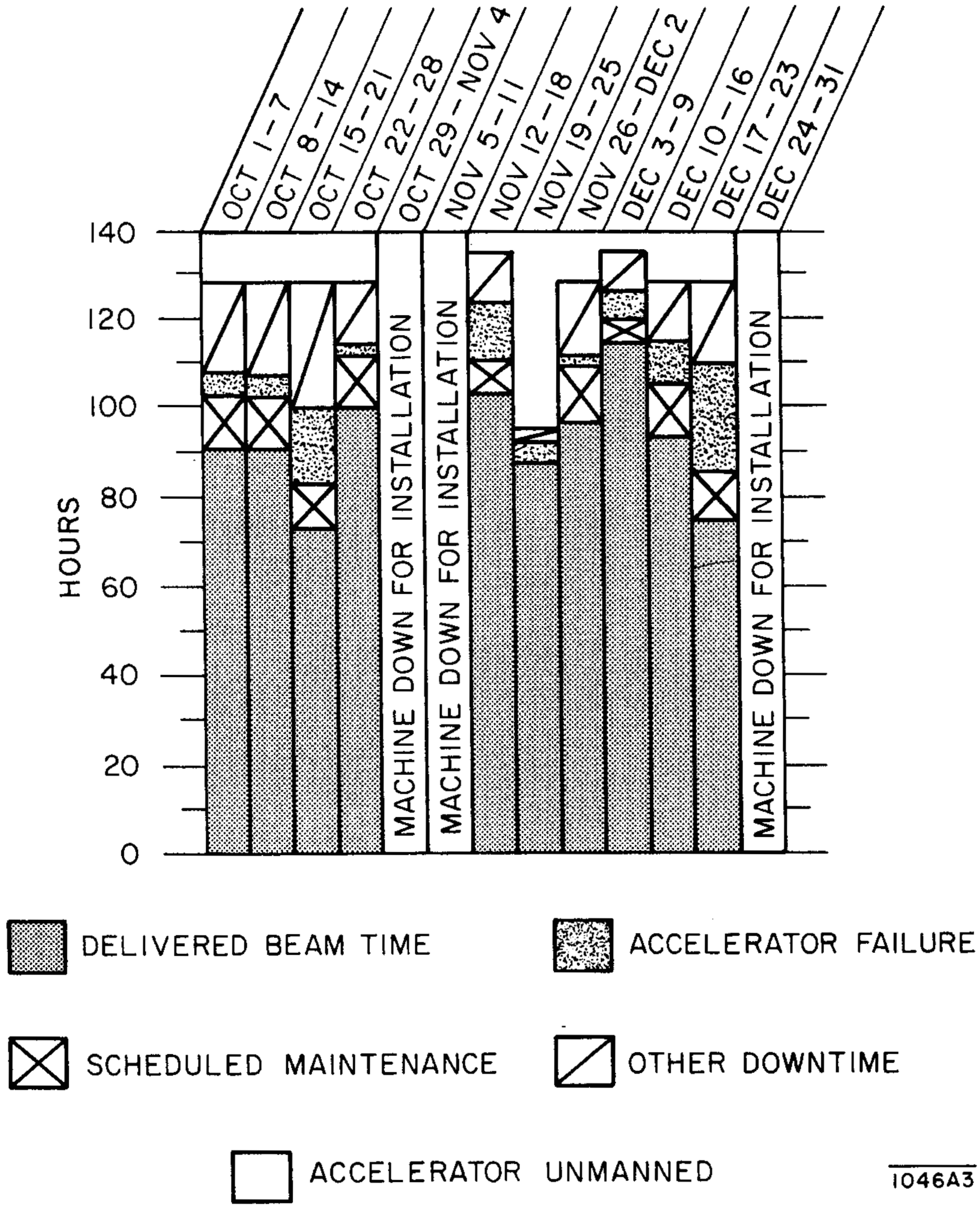


FIG. 6--WEEKLY OPERATING STATISTICS

was not always possible to identify the particular system causing a failure but the attempt was made as shown in Table I. Many troubles can happen during the time beam is on without immediate interference with beam operation. This becomes evident upon inspection of Table II in which a list of reported troubles by major system per 100 hours of beam delivered to the BSY is presented. In July, for example, there were 146 reports of trouble per 100 hours beam for the klystron/modulator system but these troubles only resulted in 0.30 hours per 100 hours of lost beam time.

The sector gas burst problem mentioned in the previous quarterly status report has not only continued but has spread to other sectors, although the total rate has not increased. It has been established that it is caused by gas released from an ion pump whose pressure is extremely low (in the 10^{-9} Torr range), with the pressure at some other part of the sector at least a decade higher. It appears that argon gas is released when the pressure increases. Work is continuing toward an understanding of this problem. However, as the problem does not jeopardize operation, no emphasis has been placed on its immediate solution.

3. Positron Source

Although there were many problems (see again Table I) and several discouraging periods associated with positron operation this quarter, it was also a period with some very encouraging results. Positron yield, previously limited to about 1-1/2 percent, has been increased to nearly four percent. A full week of very satisfactory wheel operation was achieved; likewise, a full week of operation with interlaced positron and electron beams using the wand was also achieved. As stated above, many troubles had to be overcome before such operation took place. This first installation of the wheel (in the previous quarter) was followed almost immediately by a rupture in the bellows. A new wheel was installed during the two-week shutdown in November. At the same time a new focussing solenoid (coil "0") was installed. Careful alignment of this new coil and realignment of the other solenoids by minimizing their steering effect on the beam led, at least in part, to the increased yield. A new wand was installed; before satisfactory wand operation was attained, a large vacuum leak developed. Some quick redesign and installation of a new gasket seems to have cured this problem.

There were other troubles associated with positron operation. The booster pump for the main positron water system developed a bad leak; repair was made difficult by high radioactivity. Several redesigns were necessary in the wand actuating and timing

TABLE I

HOURS FAILURE* IN ACCELERATOR SYSTEMS PER 100 HOURS DELIVERED BEAM

SYSTEM	1967 JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	AVERAGE
RF Drive	1.55	.1	1.04	.68	.31	.21	.65
RF Phasing	.61	.38	--	.55	.14	--	.28
Trigger	--	.44	.49	1.34	--	--	.38
Guidance/Monitoring	.88	.95	.26	.82	.35	.69	.66
Klystron/Modulator	.30	.40	.89	.38	.69	1.52	.70
Accelerator	--	3.84	--	--	--	--	.64
Vacuum System	.09	1.75	.32	1.86	.14	1.04	.87
Water/Air	.27	.40	.29	.66	--	.35	.33
CCR Equipment	--	.09	.06	.14	--	--	.05
Pers/Mach Protection	--	.75	.63	.14	1.04	.93	.58
A.C. Elec	1.27	.02	.06	.05	.66	.73	.47
Main Injector	1.55	3.46	.40	1.37	--	--	1.13
Positron Source	1.67	.18	.49	.38	3.22	7.72	2.28
D.C. Sys	.18	--	.26	.11	.42	--	.16
Personnel Error	.30	--	.37	.19	--	--	.14
TOTALS	8.67	12.76	5.56	8.67	6.97	13.19	9.32 hours

*Failure means all beams off.

TABLE II

NUMBER OF REPORTED TROUBLES BY MAJOR SYSTEM
PER 100 HOURS DELIVERED BEAM

SYSTEM	1967 JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	AVERAGE
RF Drive	7.6	2.7	6.3	14.5	10.1	5.2	7.7
RF Phasing	2.7	2.7	2.9	1.1	.7	--	1.7
Trigger	2.1	1.1	1.2	.3	1.4	1.0	1.2
Guidance/Monitoring	5.5	6.9	5.2	3.6	3.1	1.4	4.3
Klystron/Modulator	146.3	82.8	71.8	72.5	70.0	61.3	84.0
Accelerator	--	--	--	--	.7	--	.1
Alignment	.6	--	--	--	.4	--	.2
Data Transmission	1.5	3.1	1.2	.3	1.4	2.4	1.6
Communication	--	.4	.9	.3	--	.4	.3
Vacuum	6.4	5.8	6.3	9.9	3.1	1.4	5.5
Water/Air	2.1	5.6	7.2	22.2	6.9	10.4	9.1
CCR Equipment	3.3	4.0	2.3	2.2	3.5	3.5	3.1
Pers/Mach Protection	4.9	4.4	2.3	6.8	6.9	.7	4.3
A.C. Elec	.9	.9	.6	1.4	1.0	1.7	1.1
Main Injector	2.1	1.1	.9	.6	--	1.4	1.0
Positron Source	.3	.4	.9	2.2	.7	1.0	.9
Bldg/Grounds	1.2	.2	.3	.6	.4	1.4	.7
D.C. Sys	--	--	--	--	.4	--	.1
Personnel Error	--	--	--	--	--	--	--
TOTALS	187.5	122.1	110.3	138.5	110.7	93.2	126.9

systems; however, there is still room for improvement. Probably the major source of trouble is the three high current power supplies for the positron source solenoids. A great deal of time has been spent on maintenance and up-grading and the problems have not yet been cured. It was necessary, at least for portions of the positron source, to operate one or more of these supplies at reduced or zero output, cutting sharply into the positron yield.

B. SYSTEM AND COMPONENT PERFORMANCE

For this quarter, again, the contributions of the Accelerator Physics Department to the operation of the accelerator could be divided into three categories:

1. General assistance to the operations departments to set up the accelerator for a variety of experimental conditions.

2. Specific accelerator experiments conducted under the leadership of an Accelerator Physics engineer with the purpose of solving a particular accelerator problem.

3. Experiments which, although they required an operating beam, involved a specific system rather than beam operation as a whole.

1. Injector System Operation

During this period, the injector operated without any major difficulty. Routine maintenance is being performed, and documentation brought up to date.

2. Drive System Operation

a. Main and Subdrive Lines. During the past quarter, the drive lines continued to operate satisfactorily. The main drive line transfer switch and dummy load were changed because of an apparent high VSWR in the water load. Verification of the cause was not possible and an alternate load was obtained and installed. The spare main drive line switch was also changed on the supposition that high VSWRs might have caused some damage.

A waveguide type of switch was ordered for the subdrive line switch in the injector area because of continuous problems with the coaxial transfer switch. A manual waveguide transfer switch was installed and has been in use for most of the quarter. Installation of a motor driven model should take place by the end of the next quarter.

b. Main Booster Amplifiers. Operation has been satisfactory and no klystron failures occurred during the quarter. The arc detection system has been installed in one of the two amplifiers. As of the end of the quarter, no arcs had been detected. Installation of the arc detection system in the second amplifier is planned during the next quarter.

c. Varactor Frequency Multipliers. Preventive maintenance and continued observation considerably improved the operation of the varactor frequency multipliers. No new problems appeared.

d. Switchable Phase Shifters. The positron phase shifters performed satisfactorily during the last quarter. The other 20 phase shifters (called "π" phase shifters) have been used for beam deceleration when required.

e. Sub-Booster Modulators. The sub-booster modulators performed well this quarter in spite of the increase from 10 to 14 failures per month. Most of the failures reported were in the miscellaneous category such as fuses, vacuum tubes other than switch tubes and pulse width adjustments. Switch tube failures remained at about three per month and the power supply failures were less than one per month. Pulse width adjustments accounted for about half the reported failures.

f. Modulator and Klystron for the RF Separator. The modulator was installed and preliminary checks were completed. Actual operation was postponed until the waveguide and klystron could be installed. The latest schedule was to have tests of the complete system begin by January 24, 1968.

g. RF Drive for the RF Separator. The RF Drive System was installed and checked in place. Operation appeared to be adequate. The RF Drive System includes a new extension of the accelerator main drive line and an amplifier, a six-times frequency multiplier, a phase shifter and a power meter in the control room. The output stage consists of a Sperry SAS 60-SAS61 klystron amplifier system.

In addition to the above RF Drive System, the associated control panels, the modulator-klystron protection system and the vacuum system are to be installed in racks adjacent to the RF Drive System. These are presently scheduled for installation and checkout early in January, 1968.

3. Phasing System

Nine trouble reports were written during the quarter. The breakdown is as follows:

Type of Fault	Number Reported During the Quarter	Remarks
Programmer failed to step	3	Blown fuses.
Programmer failed to step	1	Low sector battery voltage.
Phase shifters failed to rotate	2	Relay contacts cleaned.
Undetermined	3	Systems functioned normally when trouble reports were investigated.

4. Beam Position Monitors

a. In-Line Beam Position Monitors. These monitors continued to operate satisfactorily during the quarter.

b. Beam Switchyard Beam Position Monitors. The system continued to perform satisfactorily.

5. Beam Analyzing Stations

The two stations continued to operate satisfactorily.

6. Klystrons

During the quarter, a total of 265,500 operating hours was accumulated on high power klystrons. The total number of failures in the gallery was 23, giving a cumulative total of 180 failures since the beginning of operation. There were approximately 120 spare klystrons including 20 ready for immediate installation as of the end of the quarter.

Driver amplifier klystrons accumulated 42,300 hours in the gallery and 2500 hours in the test laboratory. There were 9 failures this quarter.

There were no failures of main boosters during the quarter.

The gas burst problem continued to develop during the quarter effecting at least 25 percent of the sectors. We believe the reason for the gas bursts is now understood.

a. High Power Klystron Operation. The following table gives the summary of tube usage and failures in the gallery since the beginning of operation.

TABLE III

Klystron Usage and Failure

Dates	Operating Hours		Quarter		Cumulative	
	Quarter	Cumulative	Number	Avg. Life @ Failure	Number	Avg. Life @ 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 12/31/66	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 12/31/67	265,500	1,590,500	23	3833	180	1739

The general statistics of tube operation are now considered. Figure 7 gives the overall operating experience (average number of hours per tube and per socket, number of replacements and failures, and average life at failure) indicated per quarter since the beginning of operation of the accelerator. As can be seen, the average life at failure is still increasing rapidly. Both failures and replacements have decreased during this quarter, as have the number of operating hours. The ratio of replacements to failures is one of the smallest it has ever been (approximately 2.3:1). Whether the decrease in

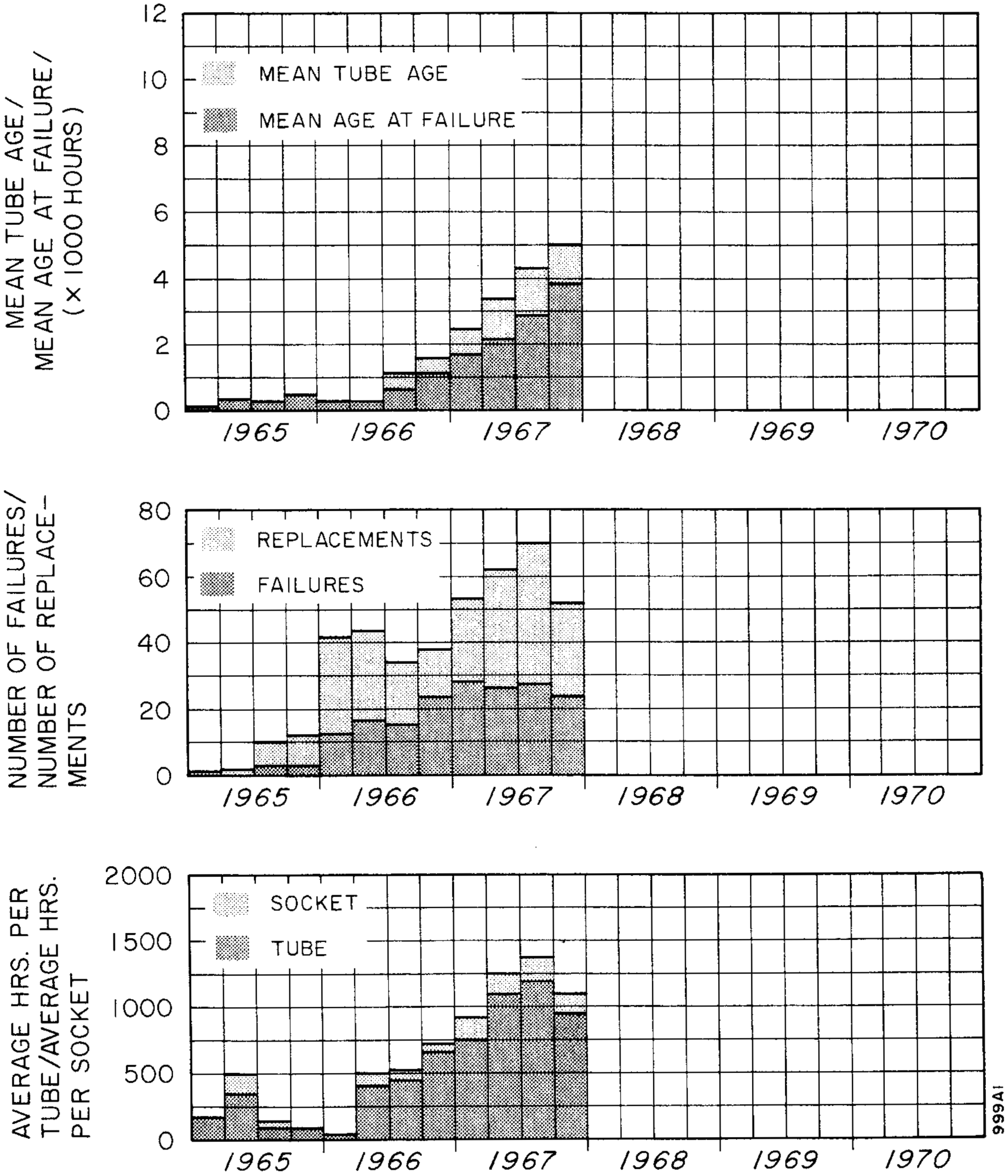


FIG. 7--KLYSTRON QUARTERLY OPERATING EXPERIENCE, ALL HPK VENDORS

this ratio is caused by improved techniques in determining the troubles in the gallery or by a real decrease in non-klystron problems (for instance, oil leaks, pulse cable connectors, pulse transformers, etc.) is not known at this time.

Figure 8 gives the mean time between failures (MTBF: number of operating hours per quarter divided by the number of failures per quarter), the mean operating tube age, and the mean age at failure for the past two years including all tubes. The MTBF, excluding all Sperry tubes from the statistics, is shown in Fig. 9. This also includes the cumulative MTBFs. Since there is only one Sperry tube left in operation to date, we feel that the exclusion of the Sperry data from the statistics makes the trend more realistic.

Figure 10 gives the klystron tube age distribution on January 1, 1968, and indicates a mean age of 5000 hours and a median age of 5750 hours.

Figure 11 is a plot on probability paper of failure distribution (excluding Sperry), as a function of age at failure. The previous experience indicates that this plot as given has always been pessimistic; hence, one would probably expect a mean time to failure (MTTF) for all tubes now installed on the machine to be between 7000 and 8000 hours. Note that this predicted MTTF is still much lower than the MTBF, but it appears as if these two values are beginning to converge.

b. Causes of Failures. The proportion of window failures continued to be predominant in the case of RCA tubes (5 window failures out of a total of 7 failures for the quarter). By contrast, Litton had two out of 10 window failures, one non-repairable water leak, one high voltage seal puncture, and the others probably connected with cathode "burning" problems. In the case of SLAC, two tubes failed because of temperature limited emission, one for overcurrent faults, and one for high voltage seal puncture.

c. Effect of Operating Levels. Accelerator operation is continuing at three distinct beam voltage levels of approximately 215, 235 and 245 kV respectively. The trend which showed last quarter a much higher number of failures and replacements in the sectors operating at 245 kV continued during this quarter. Similarly, the number of trouble reports is proportionately higher at the high operating voltage levels. Table IV gives some comparison of the first six months of calendar year 1967 compared to the last six months of calendar year 1967, indicating the trend towards increased maintenance and failure problems at the higher operating levels.

Similarly, it appears that the fault counts per sector per day were on the average 1-1/2 to 2 times as high for the sectors operating at 245 kV than for those operating at 235 kV, which in turn were somewhat higher than those operating at 215 kV.

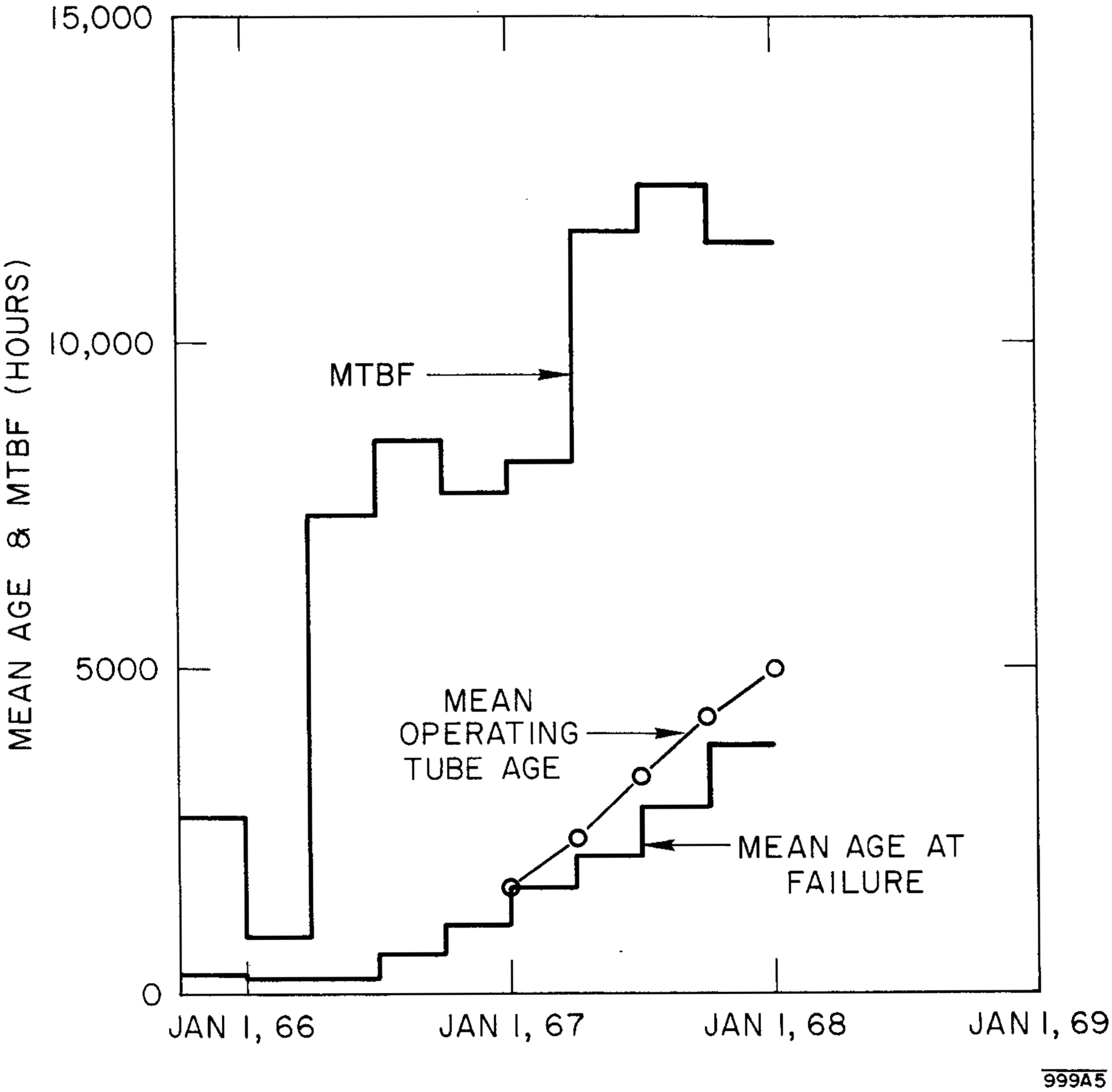


FIG. 8--OPERATING TUBE PERFORMANCE

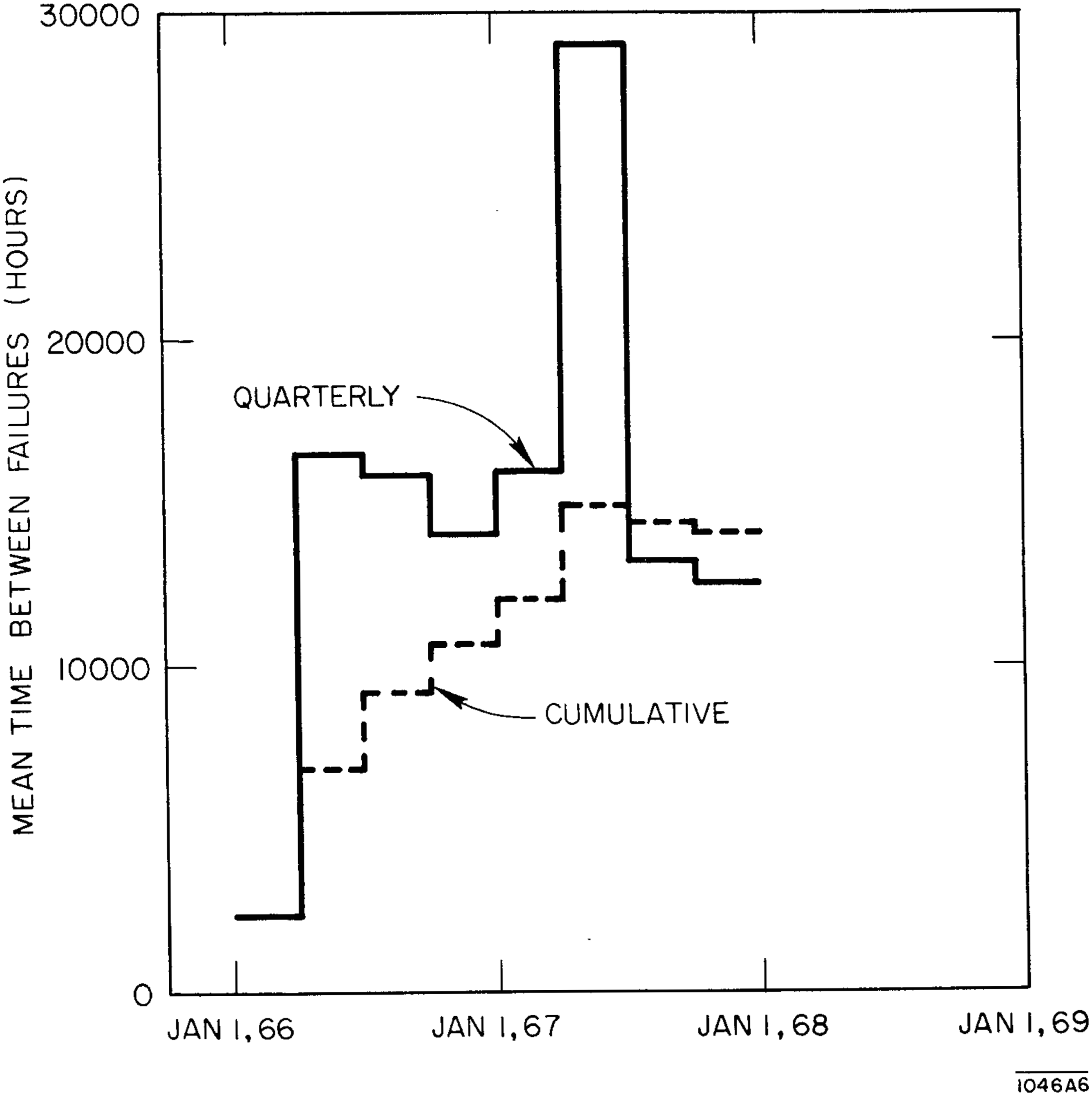


FIG. 9--MEAN TIME BETWEEN FAILURES, EXCLUDING SPERRY TUBES

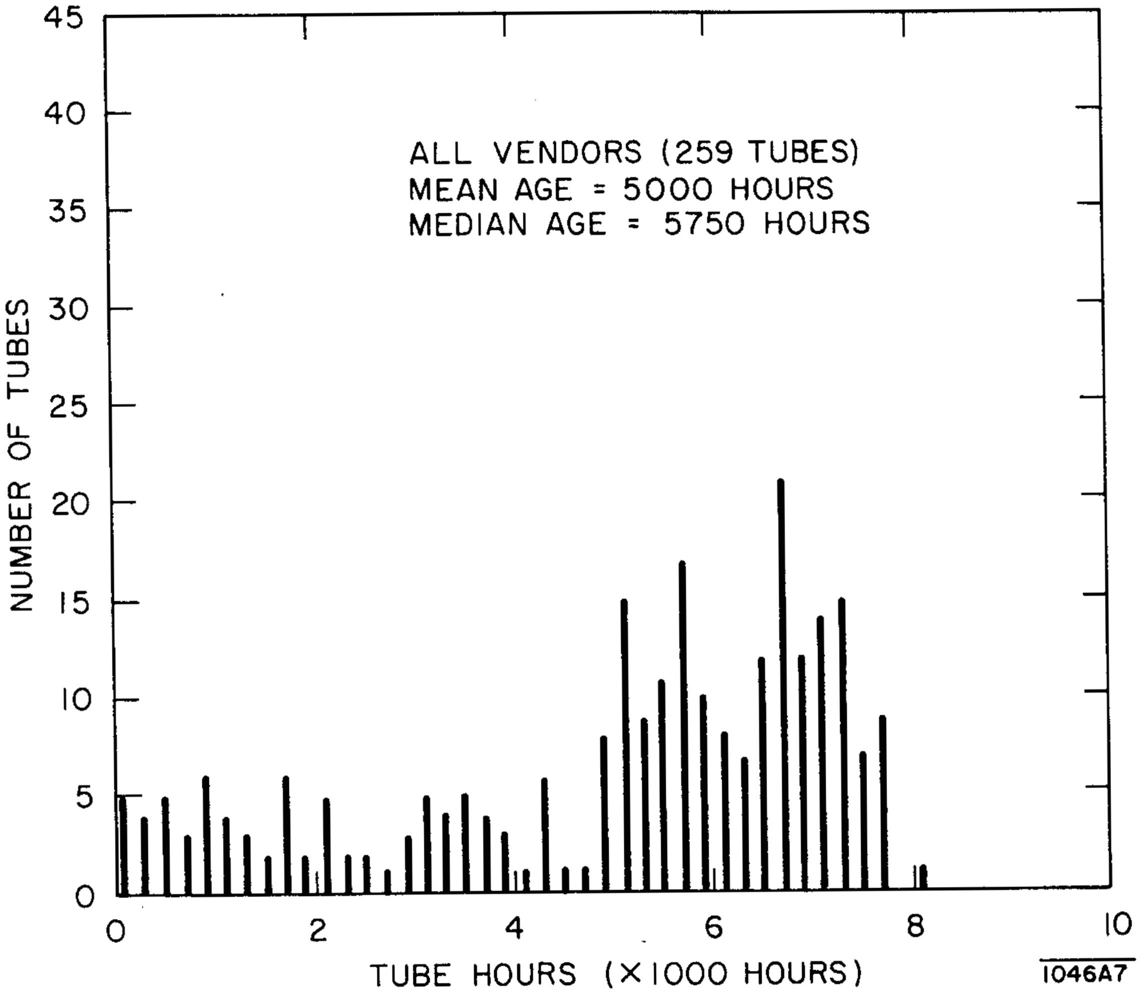


FIG. 10--KLYSTRON AGE DISTRIBUTION (ALL VENDORS) IN 200-HOUR INCREMENTS

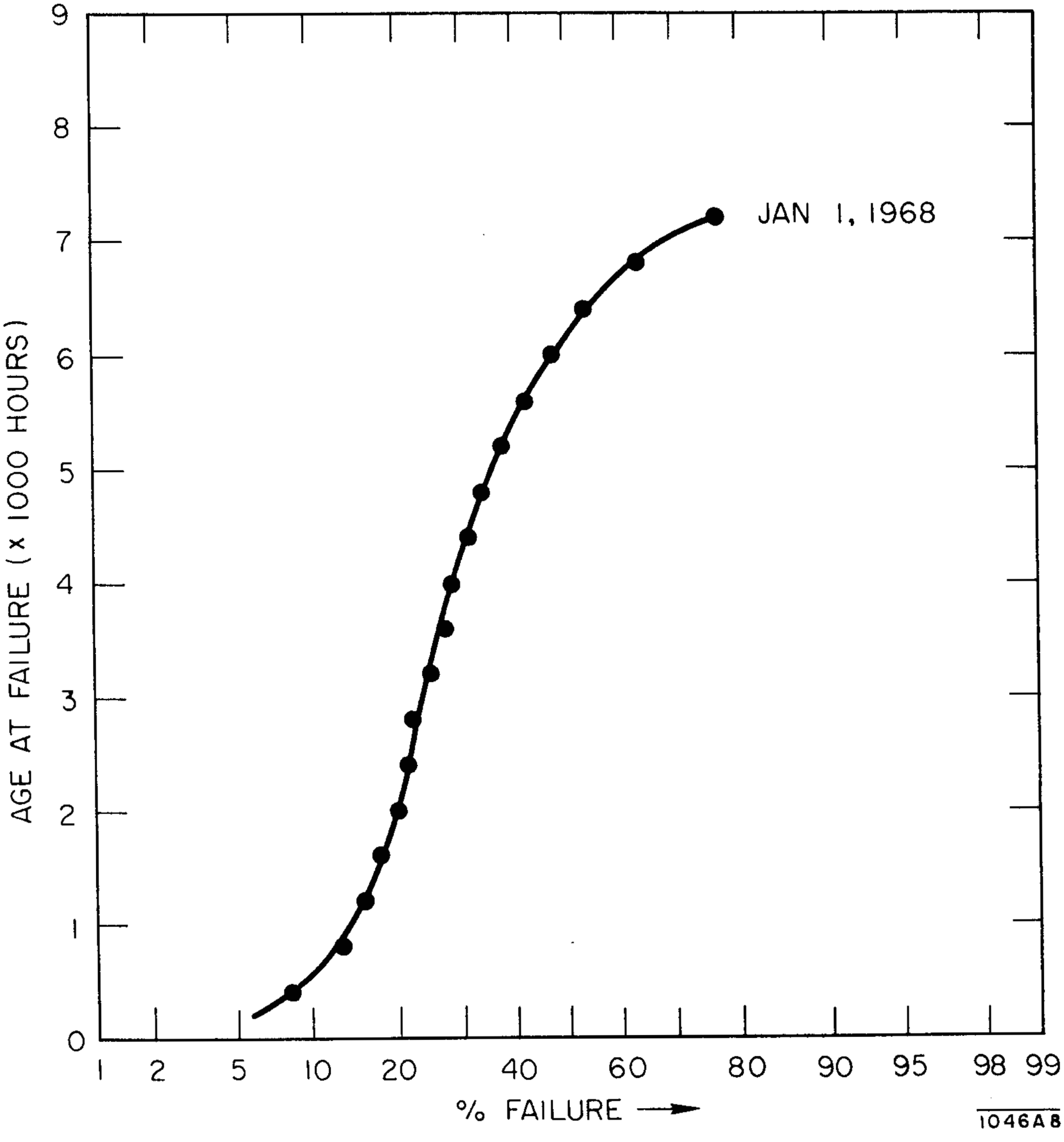


FIG. 11--KLYSTRON FAILURE DISTRIBUTION, ALL VENDORS

TABLE IV

FAILURE RATE AS A FUNCTION OF OPERATING LEVEL

Sector No.	0--2, 7--12		3--6, 13--16 20--30		17--20	
No. of Sockets	69		144		32	
Dates	1/1/67 to 6/30/67	7/1/67 to 12/31/67	1/1/67 to 6/30/67	7/1/67 to 12/31/67	1/1/67 to 6/30/67	7/1/67 to 12/31/67
Operating Levels	215 kV	215 kV	235 kV	235 kV	235 kV	245 kV
No. Klystron Hrs. (× 1000)	149.5	169.0	312.0	353.0	69.5	78.5
Total Failures	13	3	35	33	5	14
No. Replacements	30	13	71	76	15	33
No. Trouble Reports	319	224	587	608	136	250
MTBF	11,500	56,300	8,900	10,700	13,900	5,600
MTBR*	5,000	13,000	4,400	4,650	4,600	2,380
MTBTR**	470	755	530	580	510	315

*MTBR -- Mean Time Between Replacements

**MTBTR -- Mean Time Between Trouble Reports

The MTBF for all operating levels, excluding Sperry, are as follows:

1/1--6/30/67 -- 22,200

7/1--12/30/67 -- 12,900

d. High Power Klystron Maintenance. There were approximately 500 trouble reports concerning klystron operations during the quarter, corresponding to a mean time between trouble reports somewhat higher than last quarter--540 hours against 490. It is interesting to note that RCA on the average had approximately 40 percent of the sockets and accounted for approximately 32 percent of the trouble reports. Most of these concerned oil leaks and suspected window problems. Litton accounted for approximately 37 percent of the sockets, but for more than 49 percent of the trouble reports. Most of these concerned overcurrent and perveance problems corresponding to the higher failure rate of Litton tubes from those causes. SLAC tubes accounted for approximately 21 percent of the sockets and 19 percent of the trouble reports. A few tubes from other vendors remaining in the machine accounted for the rest of the sockets and trouble reports.

Preventive maintenance continued on a regular schedule with one station checked for every 590 hours of high power klystron operation, corresponding to an 8 percent improvement over the previous quarter. This routine remained a prime problem finder, locating--and to a great extent correcting--temperature limitation, klystron beam inverse conduction, and of late, malfunctioning windows.

e. Driver Amplifier Klystrons. Running time for the quarter was approximately 42,300 hours, a decrease from the previous quarter corresponding approximately to the decrease in klystron operating hours. There were a total of 9 failures (five Eimac at an average age of approximately 5750 hours, and four Litton which were mostly of the infantile mortality variety. Their average age was 750 hours). There were no failures in the Test Lab where the driver amplifier klystrons had approximately 2500 hours of operation.

Litton driver amplifier klystron failures were caused by gun problems including open filaments and temperature limited operation. It is suspected by Litton that the early temperature limited operation is caused by titanium introduced in the body of the tube to decrease secondary emission and increase stability.

The operation experience on Eimac driver amplifier klystrons since the initial turn on of the machine is given in Fig. 12, showing mean age at failure, number of failures, and the number of hours per tube per quarter since the beginning of operation of the machine. Figure 13 gives the tube age distribution of Eimac driver amplifier klystrons now in use. The median age is 7800 hours, and the mean age is 7250 hours.

Preventive maintenance on the driver amplifiers consists mostly of regular phase measurements which located the majority of faulty tubes. In addition, an attempt was made to improve the accuracy of power output measurements at the output coupler of the driver amplifier.

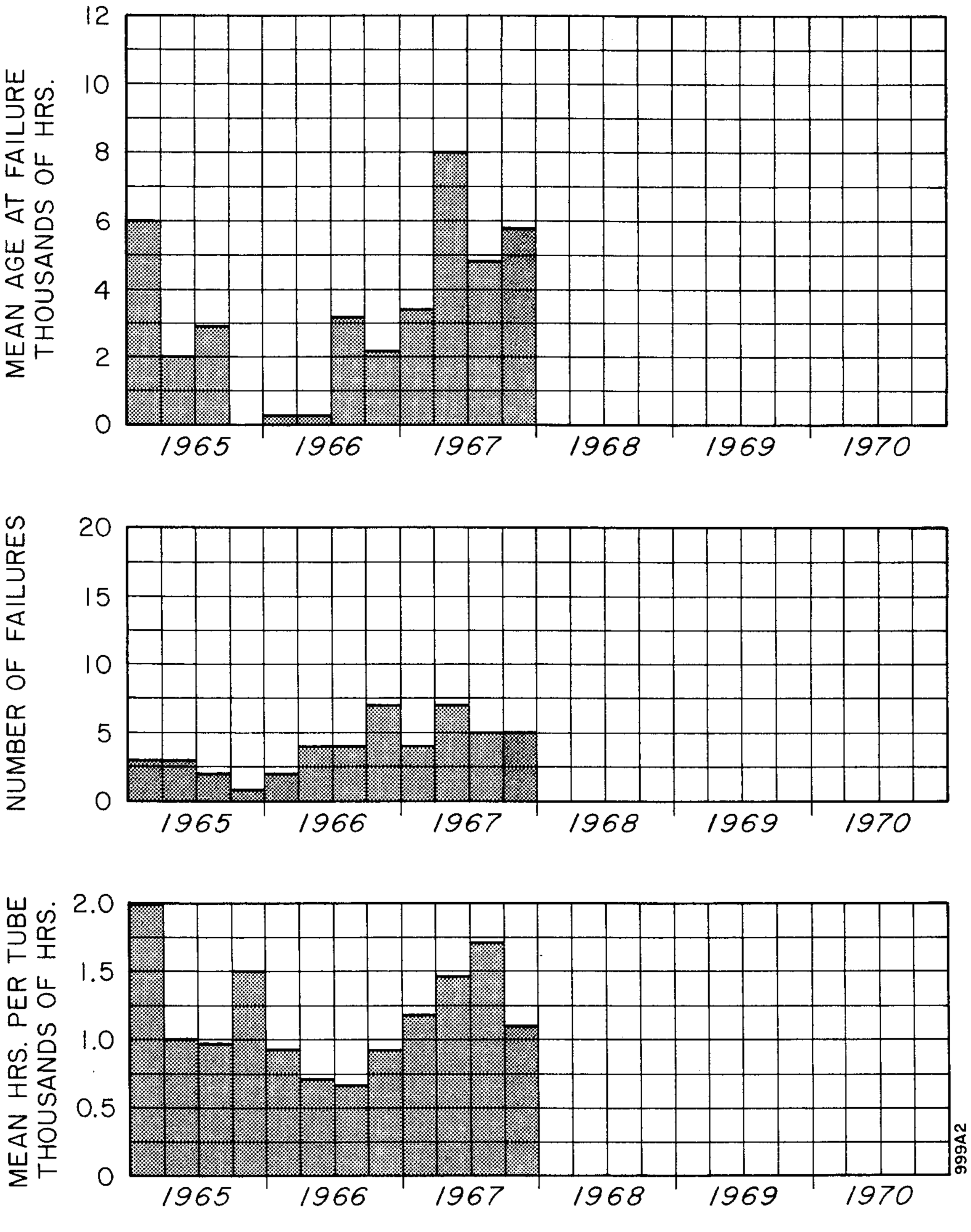


FIG. 12--EIMAC SUB-BOOSTER KLYSTRON OPERATING EXPERIENCE

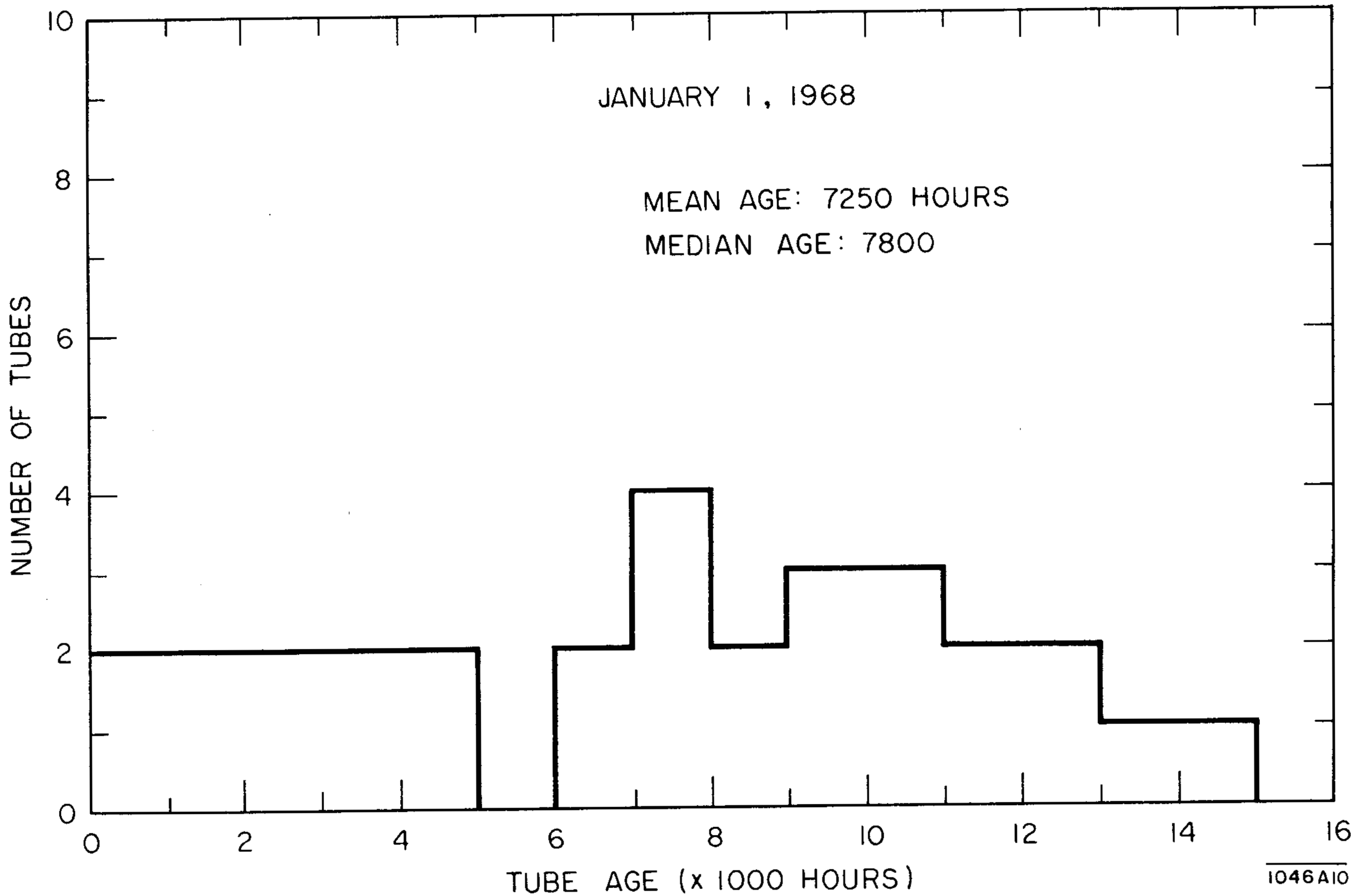


FIG. 13--DRIVER AMPLIFIER KLYSTRON AGE DISTRIBUTION

f. Main Booster Klystron. Operating hours for the main booster klystron were approximately 3100 hours this quarter, down from 3800 hours the previous quarter. There were no failures and no replacements.

The stability of operation was improved by the installation of regulated focus supplies which are operating satisfactorily. We also installed an arc detector in the output of one of the main boosters in the hopes of improving tube life by eliminating the output insulator failure which has been observed.

g. Vacuum System. In general, no major changes occurred in the accelerator vacuum system maintenance. Indicated pressure at the ion pumps continued to average about 1.5×10^{-8} Torr with klystrons operating.

A few vacuum problems appear to be related to klystron operation which may be connected with a gassy component such as an accelerator load located some distance from the station. At one station, analysis of excessive gassing finally lead to the discovery that the Viton O-ring in the three-inch valve had disintegrated over approximately a 1/4-inch length. It is suspected that this problem was caused by rf leaking and resonances in the valve. No other examples of such phenomena have been observed; hence, it seems to be an isolated problem.

The gas burst* problems continued to be present and appear to be increasing in frequency. Studies using a residual gas analyzer installed at bursting areas indicated that the gases released are argon and possibly neon. The bursts definitely are generated within the 500 ℓ/sec ion pumps. "Argon instability" in diode-type sputter-ion pumps is not uncommon if the pumps are subjected to pumping small air leaks for long periods of time. Argon composes about one percent by volume of ordinary air. Possible solutions to stop the bursts will be tried as soon as possible. Additional leak checks will be made to stop possible sources of argon.

Three cold cathode ion gauge tubes were removed and replaced. Two of them continually indicated a high pressure and were probably contaminated. The other gauge suffered a periodic extinguishing of the discharge.

7. Main Modulators

These units operated satisfactorily this quarter. Generally, 95 percent of them are operating during beam hours. Many of the ones that are off are off as a result of problems outside the modulators.

---

*"Two-Mile Accelerator Project, Quarterly Status Report, 1 October through 31 December 1967," SLAC Report No. 85, Stanford Linear Accelerator Center, Stanford, California.

The main problems with these units were about the same as last quarter, namely: pulse capacitor failures, main rectifier failures, main rectifier transformer and charging choke oil leaks, and de-Q'ing SCR failures.

a. Main Rectifiers. Four rectifiers burned out during this period, as compared with five last quarter, and four the quarter before that. In each case, damage was confined to only two or three cards out of a total of 60 because of prompt action of the fire alarm circuits installed in the modulators. In nearly every case the action of the fire alarm circuits extinguishes the fire before the fire truck arrives on the scene.

We have been able to save every damaged rectifier by replacing the burned out parts. This, along with the 29 back-up source rectifiers which are operating satisfactorily, has resulted in a very favorable spares situation.

b. Pulse Capacitors. These units continued to be our main problem this quarter. One hundred twelve failed this quarter and 102 the quarter before that.

Most of the capacitors we ordered from other sources, as mentioned in our previous report, were received this quarter. We obtained 25 from Cornell-Dubilier, 25 from Corson, and 25 from Axel. We ordered paper-mineral oil capacitors from Axel and found them to be satisfactory.

Another back-up measure we entered into as a result of the high failure rate of capacitors is to order 300 capacitors, 100 from each of three manufacturers. Deliveries are scheduled to begin in February or early March.

c. De-Q'ing SCR Assemblies. The failure rate of these units, which improved last quarter by modifications reported earlier, showed further improvement this quarter. Only eight failed this quarter (three of which failed because of faulty gate transformers). Last quarter there were 26 failures. This would indicate that these units are becoming reliable, long-lived assemblies.

d. Rectifier Transformers and Charging Chokes. These units continued to develop oil leaks around the bushing skirts. We repaired 30 transformers and five charging chokes during the quarter.

We experienced one complete failure of a rectifier transformer. The failure occurred after the primary tap jumpers were reset. Apparently the studs turned during this operation causing a short circuit between lugs on adjacent studs within the tank. The shorted winding overheated causing gas formation within the transformer tank and subsequent swelling and eventual rupture of the tank. In order to prevent this from happening in the future we designed a plug-in jumper arrangement which would not subject these studs to twisting. The system was thoroughly tested in the test laboratory and found to be satisfactory. We ordered the necessary parts and plan to install the system in all modulators during the beginning of the next quarter.

e. Hydrogen Thyratrons. During this quarter, we had a total of 31 failures, or an average of about 10 per month, of large single thyratrons, or pairs of smaller ones. This failure rate is one-half of last quarter's. A total of 192 have failed in all our operations to date, including test stands, and our early modulator work, giving us an overall average of 3374 hours per tube which is slightly higher than last quarter. The tubes provided by the three manufacturers had average ages at failure of 3296, 4584, and 3071 high voltage hours.

Both of our current manufacturers experienced quality control problems. Interelectrode spacings were varying too much from tube-to-tube and cathode problems occurred is some tubes. The rate of rejected tubes approached 80 percent at times. At the close of the quarter both companies were attempting to work out their problems.

One manufacturer, which has experienced rather short life among its tubes, redesigned its cathode so as to increase its size and, hopefully, its life. We received and tested several of these tubes but they did not look very good because of excessive number of kickouts, reservoir center point shifting with modulator average power, and cathode problems (quenching).

f. Pulse Cable Assembly. The failure rate on these cables appears to be increasing. We had two failures in October, two in November, and four in December. The machine was operated only three weeks in December which makes the failure rate in that month worse than it appears at first glance.

Most of the failures to date have been caused by problems in the connectors. However, recently we are starting to get failures in the cable itself. We have dissected failed cables and found that corona existed in them which deteriorated the polyethylene layers to the point of arc-through. The damage also appears all through the cable, apparently in air pockets which were formed when oil drained from the cables. The situation is probably aggravated by flexing of these cables during replacement of klystrons. Most of the failed cables generally have 5000 or 6000 high voltage hours on them. Our test laboratory samples, on the other hand, have 18,000 and 20,000 hours on them and are still working all right; however, they are not flexed because the test set-up remains fixed.

As a back-up measure, we ordered 50 spare assemblies and plan to order another 50 early next quarter. We also plan to enter into a study contract on an improved type of pulse cable using solid silicon rubber dielectric as the major insulation in place of the layers of polyethylene and silicon oil.

During the design phase of the modulators, we searched the industry and tested many types of cables and our present type appeared most promising. However, they are proving to be too short lived.

8. Research Area Experimental Activity and Support

Over two thousand hours of high energy physics was scheduled during this quarter. Beam time was about equally utilized in both End Stations.

a. Experiments in the End Station A Area. Most of the experiments conducted in End Station A during this quarter were continued from the last quarter. These experiments were, electron-photon elastic scattering (76 hours); electron-photon inelastic scattering (400 hours); comparison of positron-photon and electron-photon elastic scattering ratio (72 hours); multibody photoproduction study (40 hours); and, the study of cross sections of π, η, ρ, ω, and ϕ mesons.

A survey experiment on photo-meson production processes at backward center-of-mass angles was scheduled with 216 hours.

b. Experiments in the End Station B Area. The majority of scheduled beam time (748 hours) was for the continuation study of μ-p inelastic scattering. The study of photoproduction of boson pairs was scheduled for 208 hours and was continued from last quarter. A new experiment, the study of monoenergetic photoproduction, utilizing the 40-inch bubble chamber located in the central beam line in End Station B, had 96 hours of scheduled beam time.

c. C-Beam Experiment. Continuous beam optic and instrumentation checkout was conducted for the ex-LRL 82-inch hydrogen bubble chamber.

d. Accelerator and Beam Switchyard Study. Positron source study was the major task of the accelerator study. Beam monitoring instrument checkout and beam optic study also was conducted in this quarter.

II. ACCELERATOR AND RESEARCH AREA EQUIPMENT DEVELOPMENT

A. ACCELERATOR PHYSICS

1. Injection

a. Electron Gun. Parts fabrication on the three SLAC Model 4-2 guns was interrupted in October, and that effort channeled into the manufacture of three gun thin-valves. These valves are of the same type as those used on the accelerator at the present time. Because there have been minor gate sealing problems and some evidence of gun cathode poisoning, special care was taken in the selection of materials and some minor design changes were incorporated in the new valves.

Tests have continued through this quarter on the Stanford Mark III accelerator electron gun. Beam profiles of this gun were obtained after various changes in grid and cathode configuration. The tests ranged from 25 to 80 kV dc anode voltage and from 10 to 360 microamperes beam current. The information gained has applications to the Hansen Laboratory superconducting accelerator as well as to future SLAC requirements.

Mechanical work on two, 100 kV dc isolation transformers was completed. One unit was oil impregnated and given an electrical performance test. These special transformers are to be used in the new gun modulator which is being constructed.

An injector standby gun was installed in the gun modulator on a side opposite to the active accelerator gun. The standby gun uses a vacuum system built for the injector gun laboratory which includes a Faraday cup. This arrangement allows pulse testing at full voltage and maximum beam current, as well as insurance that the gun valve will be clean enough for insertion into the accelerator high vacuum when needed.

b. New Gun Modulator. Work continued at a high level on the new gun modulator. All electronic cards have been reduced to printed circuit format and assembled. New control and logic circuitry was designed and fabricated for the expanded beam control capability. The gun modulator cabinet with many of the chassis installed will be moved to the injector area in mid-February. A new fast pulser was constructed and is currently undergoing tests.

c. Beam Knock-Out Equipment. A new twenty-megacycle beam knock-out amplifier system was fabricated. The association second set of deflection plates has been designed and fabrication is in progress.

2. Drive System

a. Sub-Booster Klystrons. The remaining Eimac klystrons have performed well. All the klystrons that failed were well beyond the warranty period.

The contract with Litton Industries did not progress as well as was hoped as the problem of low output power had not been solved. A solution may be obtained when the new output window design is installed and tested early next quarter. One tube tested in a modified field magnet yielded 70 kW of peak output power. Further tests next quarter will determine whether either change will result in a full specification tube.

b. C-Beam. A drive-line extension in 7/8-inch coaxial cable was installed to provide 2856 MHz drive for the klystron which will feed rf to the C-Beam particle separator. A spare phase-shifter from the automatic phasing system was modified to provide direct manual control of the klystron input phase.

3. Phasing System

a. Fast Phase Shifters. The second Sub-Booster IØA in Sector 1 was modified so that the Fox phase-shifter is switched in and out of the rf circuit by the switching circulator. This enables the phase-shift adjustments to be "programmed"--i.e., to be applied to selected time slots. To extend the versatility of the Sector 1 phase-closure system, it is planned to make the injector phase-shifter "programmable" and to add two further identical units in series with it. Each unit will receive a separate pattern from the CCR. Such a system will permit completely orthogonal phase closure on three beams. The IØA units preceding the sub-boosters in Sector 1 will be changed back to conform with the sub-booster IØA's along the rest of the accelerator--i.e., the programmable switching circulators will switch a pre-set phase shift into and out of the rf circuit.

b. RF Detector Panels. Work is continuing on the design of a fast-latching ferrite circulator. Excellent characteristics are being achieved, with switching times less than 5 μsecs, insertion losses less than 0.5 dB and VSWRs less than 1.2:1. During the next quarter, two circulators will be combined in a stripline package with an attenuator and an adjustable phase-shifter in alternative paths, to make a fast-acting, phase-shiftless attenuator.

Drawings of the video amplifier to be used in transmitting phasing video waveforms to the CCR have been completed. PC cards, balance networks and cable assemblies are being prepared prior to modification of all rf Detector Panels along the machine.

c. Programmers and Electronics Units. No further progress on the beam detector circuit was made during the past quarter. It is planned to incorporate the driver for the fast-latching circulator on the same PC card as the beam detector. The design of the card will therefore continue when development work on the circulator has been completed.

Further changes are being made in the circuit logic associated with the "Phase/Don't Phase" and "Auto Advance/Hold" controls.

The programmer circuit for transmitting analog information to the CCR about the number of the klystron being phased is being designed.

4. Beam Position Monitors

Difficulties were experienced with the motor-driven potentiometers to be used for remote-balancing the position monitor diodes. Samples with a more suitable gear ratio were ordered, and a dynamic braking circuit to stop overrun was designed and tested.

Tests have shown that it is possible to widen the range of beam currents over which the in-line beam position monitors can be used.

The monitor in one sector will be modified and tested further before proceeding to modify the rest of the system.

5. General Microwave Investigations

Progress on the rf Separator structure proceeded quite well until tests were made on a short, brazed test section. These tests revealed that the early cavities shrank during the brazing operation, leaving no room for final tuning. As a consequence, the inside diameter of the cavities was enlarged by 0.003 inch. In addition, it was decided to lengthen the structure from ten to twelve feet as an insurance against possible high power breakdown which could limit the operation to below the 24-MW level originally planned. The waveguide and support systems also had to be modified to match the twelve-foot structure. Some delay resulted from these design changes but the whole system is expected to be in operation before the end of January.

6. Theoretical and Special Studies

a. Beam Break-Up Studies. Analytical as well as experimental work on the SLAC Beam Break-Up phenomenon continued throughout the quarter. A complete summary of progress to date can be found in SLAC PUB-350, "Progress Report on Beam Break-Up at SLAC."

b. Tuning Experiments on the Input End of a Constant-Gradient Ten Foot Accelerator Section. As outlined in the above paper, the objective of this experiment is to attempt to increase the beam break-up threshold by shifting the beam break-up frequency in the early part of the accelerator, probably as far as the end of Sector 2 and possible even farther. The method of obtaining this frequency shift would consist of detuning three to six of the early cavities in each accelerator section by applying a slight external mechanical deformation. The experiment so far has been successful in that it has confirmed that the frequency can be shifted by two to three megacycles without unduly disturbing the match at S-band. This work will continue throughout the next quarter until a fairly well streamlined procedure is found.

7. Magnetic Measurements

These consisted of the following during the past quarter.

1. The two-meter Streamer Chamber Magnet was mapped using the rapid magnet

mapper. The nominal field of the magnet was 8 kilogauss for this measurement. The grid of mapping was 2 inches × 2 inches × 4 inches. Approximately 200,000 data points were taken, i.e., 70,000 points for each of the three components of field.

2. Measurements were made on the optical bench magnets for the spectrometer calibration. There are three magnets in the set and measurements of $\int B d\ell$ and B vs. I_{ex} for various conditions of excitation were made. The data has been analyzed and given to Group A.

3. The 20-GeV Spectrometer magnet Q-204 was remeasured before and after its new coils were installed.

4. The rapid magnet mapper was extensively modified to allow three components of field to be measured and logged on magnetic tape simultaneously. Preparations were made for a new three-component map of magnet BR-1 to be made in January. Computer programs to read the magnetic tape and reduce the data were written and are being debugged. Changes were in progress for new mechanical positioning devices for the rapid magnet mapper. Position encoders were planned for installation on the mechanical positioning devices. These will allow the position of the mapper to be logged on magnetic tape, while mapping.

5. Preparations for mapping the 82-inch Bubble Chamber during the next quarter were instigated. The mechanical device designed and built by LRL for mapping the 72-inch Bubble Chamber will be used on the 82-inch magnet with the SLAC electronic data logging system.

6. In addition to the mapping of BR-1 and the 82-inch Bubble Chamber, other jobs scheduled for the next quarter are: mapping of a cosmotron magnet for Group D, remeasurement of the 40-inch HBC magnet, measurement of the laser beam dump magnets, and a remeasurement of the momentum defining magnets of the A-line and the DAB magnet (B-100). Preparations are being made for these measurements.

B. KLYSTRON STUDIES

The vendors continued development work to improve the performance of their tubes. The emphasis at RCA is on better understanding of window problems and a redesign of the window structure. Litton has been concentrating their efforts on mechanical redesign of the cathode mounting system to eliminate the arcing and perveance shifting problems. The emphasis at SLAC has been on development of high efficiency tubes capable of operating at higher beam voltages.

The driver amplifier development program at Litton still appears to be hampered by oscillation and feedback problems.

Some basic studies on behavior of ion pumps are also continuing which will hopefully lead to a better understanding of the gas burst problems.

1. Klystron Procurement

a. RCA Subcontract. As mentioned above, the major effort at RCA has been directed toward improvement of window life. Several approaches are being taken in parallel. First a braze seal is being tested replacing the RCA compression seal. It is felt that the compression seal increases the stresses on the window material sufficiently, in case of heating due to losses, to increase the probability of window failure. To date, the brazed seals tested at RCA have not been particularly successful, but the failures may have been caused by coating problems rather than by seal problems.

A completely demountable window structure was designed where the window is heliarced onto the waveguide so that it never sees any brazing operation as part of the final assembly after coating. Some samples have been shipped to Stanford for evaluation in ring tests.

Probably the most significant departure in technique is the development of an rf-sputtering device for coating the window. The equipment uses an rf source and a low-pressure argon plasma confined by a magnetic field to coat the window. It appears that repeatable coating techniques had not been obtained by the end of the quarter. However, it is expected that the coating rate can be decreased to obtain better control of the thickness. This work was initiated because of the possibility obtained from statistical evidence that the RCA coating is not as stable in operation as the coating put on SLAC or Litton tubes.

In addition to window work, moderate improvements to tube structure are continuing. To simplify tube fabrication, the tuners in the output waveguide were eliminated in a sample tube with satisfactory results. Elimination of these tuners should remove the possibility of sparking which has been noticed occasionally at the tuners.

RCA has also built and tested a klystron with a bigger collector than that presently in use. Since RCA's collector is quite small for the total power handled by the tube, it is expected that tube life may be improved by this new collector by reducing grain growth and the possibility of gassing.

b. Litton Subcontract. Litton's manufacturing performance over the last quarter has been marginal. Many tubes delivered by Litton showed low power output. A comparison of the initial deliveries against the contract indicates that the average efficiency of a batch of 20 tubes decreased from approximately 35.3 percent to approximately 33.2 percent for the last 20 tubes delivered. Litton is obviously aware of this problem, and have obtained information on the modifications introduced at SLAC to increase tube efficiency.

However, the main engineering problem at Litton remains one of low yield caused by cathode sparking and changes in perveance in operation. Studies carried out by Litton lead them to believe that the focusing electrode is running sufficiently hot to cause appreciable emission. This emission does not contribute to the beam, but is collected as losses on the anode. As a result, the direct beam perveance would be lower than was achieved when the tubes were initially built for SLAC, explaining the decrease in efficiency.

The solutions proposed by Litton to cure this problem are to: 1) revise the processing schedule to decrease the amount of barium deposited on the focus electrode, and 2) completely redesign the gun mechanically to maintain a focus electrode at a temperature not exceeding 200°C. This redesign involves a heat conducting focus electrode support which, in turn, is in contact with the oil surrounding the base of the tube.

c. SLAC Klystron Development. Processing problems are still present but have shifted from gassy to mostly arcing problems. Approximately 30 percent of the tubes built were unable to reach operating voltage because of arcing between cathode and anode. An investigation of the changes in the materials and processing techniques is underway to reverse the trend. In addition, three tubes failed through window failure in test. Two of these windows had a boron nitride coating and further work is now on the way to determine the reason for the failure of boron nitride coated windows on tubes when they behave so well in the test ring. There are indications that one of the windows failed because it had been tested in the ring while the ring itself was contaminated from a prior test on another window.

Tests on the improved efficiency design continued with a total of four tubes tested during the quarter which achieved 30 MW or better in electromagnets. One of the four tubes achieved 30 MW in a permanent magnet. Unfortunately, these tubes suffer from arcing problems and are not yet available for installation in the gallery.

Tests on 300 kV klystron tubes have been disappointing. Both tubes tested to date show severe gun oscillations at voltages in excess of 270 kV. In addition, there appears to be sufficient feedback caused by the larger diameter drift tubes to give severe amplitude modulation at voltages in excess of 240 kV. This modulation is very much affected by the focusing conditions, hence, the amplification of feedback problems.

The fact that oscillations were observed at 270 kV may lead us to an understanding of some of the arcing problems observed in our standard guns. Close examination of the focus electrode reveals a pattern of discolorations near the top of the focus electrode which might correspond to the presence of rf in the gun region. It appears that these patterns are more pronounced in the most efficient tubes built. The present hypothesis is related to the fact that the more efficient tubes contain more harmonics in the beam. Therefore, there is more chance for harmonic frequency to feed down the drift tube to the cathode region and produce these marks. If this hypothesis is confirmed by further studies, methods will be considered to eliminate the problem.

2. Other Development Work

a. High Power Window Work

(1) Boron Nitride Coating

Boron nitride coated windows have not performed well on SLAC tubes in spite of their satisfactory operation in the test ring. As a result of the high percentage of failures with boron nitride coatings on tubes, their use will be temporarily discontinued. Various potential causes of failures are being investigated, such as modification of coating properties during the cathode activation cycle, and the effect of impurities in coating.

(2) Resonant Ring Tests

Routine tests of SLAC windows have been continued at powers up to 85 MW peak to obtain additional evidence of the possibility of using our present windows at higher power without jeopardizing window life. In all, nearly 60 SLAC windows have been tested at this level without apparent failures. The ring has also been used to evaluate some of the RCA techniques on windows, which appear to suffer dielectric failure at much lower power than SLAC windows. A compression seal window failed at approximately 85 MW, and a brazed window failed at approximately 50 MW. The discrepancy between the power handling capability of SLAC and RCA windows is not understood, but could be caused by window geometry differences resulting in localized modes and/or the affect of brazing the window in final assembly.

(3) Window Coating Techniques

Further improvement was introduced in our titanium-sputtered coating technique by removing heat and immediate filaments. This improvement resulted in easier process control, and we feel that as a result, the routine presently used for testing of SLAC windows in the ring is no longer necessary.

The equipment for evaporating window coatings has been assembled and is being tested prior to final use. The station is adaptable to both high temperature evaporation and rf-sputtering processes. It should give us flexibility to study new types of coating which appear promising.

Work on the electron diffraction machine proceeded and the equipment is expected to be operable early next quarter for study of secondary emission of klystron windows.

b. Vacuum. One of the problems investigated was the determination of whether the waveguide valve or the three-inch valve leaks when the sector pressure rises during removal of a klystron. Several methods have been considered to determine which valve needs to be corrected. It appears possible to determine the offending valve by the introduction of a specially designed, manually-handled valve in the waveguide after the klystron has been removed. Should the problem of leaky valves reappear, we expect to be able to save considerable time in vacuum maintenance by the use of this technique.

Also in an effort to help eliminate leaks still existing in the accelerator vacuum system, an electric analogue has been designed and will be built next quarter.

Some work is also being initiated in the anomolous ion gauge behavior since a number of the Penning discharge gauges are beginning to show some instabilities.

3. Driver Amplifier Klystrons

a. Litton Subcontract. The low power output of the Litton driver amplifier has contributed to its low acceptance rate at SLAC. An investigation at Litton indicated that the heliarc joint in the output window could introduce a mismatch in the output line corresponding to a VSWR of 3:1. Such a mismatch not only could reduce the efficiency as observed on many Litton tubes, but also could contribute to the instabilities observed in some tubes by excessive voltages across the output gap, resulting in return electrons down the drift tube.

As a result, Litton has redesigned the output window which is now a flat, ceramic coax disc instead of the previous cylindrical ceramic seal. In addition, the output cavity has been lowered further into the magnetic field, and the field shape has been modified to improve the tube operation.

At the end of the quarter, one tube was produced with a power output almost 20 percent higher than the average of the tubes previously tested at Litton. If subsequent tubes duplicate the last performance observed, most of the driver amplifier klystron problems should be solved.

b. SLAC Back Up. In view of the difficulties experienced by Litton in their program, SLAC retested one beam tester which had been built earlier in the year, and built four more with parts on hand. In addition, we dismantled some of the old Sperry magnets and built five magnets for use with SLAC driver amplifier klystrons. It appears that at least four of the driver amplifiers built will be usable in the gallery in case of emergency.

C. MECHANICAL ENGINEERING AND FABRICATION

1. Positron Source

Fabrication of hollow conductor coils (for Coil '0') was completed. Magnetic measurement and full power tests of the coils were made. The coils were installed, replacing the partially shorted edge-cooled coils. The new coils performed satisfactorily at full design current of 4000 amps during beam runs. The solenoid coil power supplies, however, were plagued with minor troubles throughout the positron runs. Modifications to the cooling water system were made to supply high pressure water to the new coils

A vacuum leak developed whenever the wheel target was in use. The size of the leak seemed to be dependent on incident electron beam power. The leak was traced to the wand vacuum flange and was attributed to distortion of the vacuum seal from thermal effects. An additional sporadic vacuum leak appeared whenever the wand was oscillated. The latter leak was found to be in a water-to-vacuum weld on the tubing which supports the wand target. The wand was removed, the leak repaired, and the structure in the vicinity of the failed weld was strengthened. On reinstallation of the wand, the quick-disconnect toggle clamps on the wand vacuum flange were removed and replaced with bolted back-up flanges. No further vacuum problems were experienced.

The wand oscillating driver solenoid valve failed during a wand run and was replaced. The valve was moved from the Accelerator Housing to the Klystron Gallery to facilitate maintenance. The increased length of air line between the valve and the driver necessitated the interruption of a large number of beam pulses.

Fabrication of two, two-inch wheel targets was completed. One target was tested at approximately 300 kW of beam power in air in the central beam of the Beam Switchyard. The target was badly oxidized and cratered after the test. The damage did not, however, result in any water leaks.

A new convoluted bellows was received and installed on the pantograph type trolling mechanism. This bellows failed after 280,000 cycles at a 2-1/2-inch stroke and running at two cycles per second. A new two-inch wheel drive concept to moderate the motion of the bellows was implemented, designed, fabricated and installed in the Accelerator Housing. The second two-inch wheel target was mounted on this system. The new system ran successfully through a week long high power positron run in December. The maximum beam power incident on the wheel target was 140 kW (six GeV at 40 mA and 360 pps of electrons). The incident beam power limit was decided upon the basis of the central beam test results described above. A positron yield of 4 percent as measured at Sector 30 was attained. The total energy incident on the target during the run was eight megawatt hours.

In order to verify the adequacy of the bellows design for use with the moderated motion, a bellows testing mechanism to test the bellows at a 2-1/2-inch stroke was set up. At the time of writing this report the bellows under test had successfully undergone 10 million cycles and was still vacuum tight.

The design for a three-inch wheel target was initiated both as a backup for the two-inch target and also to allow a 200 kW, 60 mA incident beam to be utilized.

The design study for a new improved positron source was started.

2. Accelerator Maintenance

The accelerator sections on an additional 69 girders have been re-aligned since the last report. More than half of the accelerator has been re-aligned. This activity is continuing and should be completed at the end of next quarter.

Ten additional laser alignment target actuators were found to be inoperable. The actuator springs were replaced with new longer springs.

Strainer screens in several accelerator cooling water systems failed, releasing debris, including pieces of the screens, into the piping. Backflushing of accelerator section water jackets to remove any debris was initiated. At the end of the quarter, accelerator water jackets in three sectors had been flushed.

D. INSTRUMENTATION AND CONTROL

1. Positron Source I and C

A mechanically redesigned wheel positron source target was installed in November. New features added at the same time included an SCR-controlled, dc motor to drive the trolling motion, a remotely-controlled latch to hold the wheel in two fixed positions (replacing the former braking mechanism) and synchros to monitor the wheel's position.

The control system was redesigned to accommodate the new requirements; the necessary control panels were built and installed; minor changes were made to the proximity-switch and Wheel Speed Interlock panels. The system was checked out by the end of November and has since operated successfully.

Prior to the installation of the wheel, Coil 0 of the tapered field solenoid was redesigned to permit operation at higher magnet currents. A portion of the interlock protection had to be recorded to meet the new requirements.

The dc-steering supplies in Sector 10 were replaced by two sets of pulsed power supplies for the horizontal and vertical dipoles in Drift Section 10. With this arrangement independent steering was made possible to ease positron and electron operation.

2. Machine Protection

The program to improve the security and reliability of the Long Ion Chamber System (PLIC) was continued.

The present amplifier used to display the waveform on the PLIC scope has a switched gain of 1 and 10. A gain of 100 is desired to observe the waveform when low energy beams are accelerated. A new PC card was manufactured containing the X1, X10, and X100 amplifier and is being tested prior to installation.

The positron gate arrangement was modified. Because of the high amounts of radiation present in Sector 11 when positrons are being generated, the PLIC interlock needs to be desensitized during positron operation. Whereas, formerly the discriminator was disabled completely for the duration of the pulse from the positron source, the discriminator level is now merely increased from two volts to four volts during the time that signals from the positron source are being observed by PLIC. The Wand Driver chassis has been modified to transmit PLIC desensitizing pulses during actual wand operation to the PLIC Electronics chassis in the CCR. Since PLIC is desensitized continuously during wheel operation, this is done through a status relay in the CCR.

3. Central Control Room

Some control panels in the CCR were moved in an effort to improve operating convenience. Some new racks were installed to accommodate future display units and instrumentation and an oscilloscope was installed to monitor the pattern generators. A video signal patching arrangement was also installed in the CCR to increase operating convenience.

A meter, installed near the steering controls, can be used to monitor any of the steering currents along the accelerator. The steering switches double as a selector switch for this meter.

4. Data Handling and Communications

a. Remote Video Switching. The video system is being modified to allow the CCR operator to remotely select video signal sources along the accelerator for viewing in the CCR.

Work continued on the installation and check-out of this system. Modified video repeaters have been installed in all sectors. Completion of sector and CCR wiring is scheduled for January 30.

b. DAB-CCR Profile Monitor System. Installation and check-out were completed for a TV profile monitor transmission and display system. Profile monitors, selected by the DAB operator, automatically appear on TV screens in the CCR along with a nixie tube readout of the selected signal name.

c. Intercommunication System. Two engineering models of the proposed intercommunication sets were constructed and tested. Construction of the final models is expected to start in early 1968. Two versions are being proposed:

1) The model for the CCR and the DAB will have a 25-station capability, with additional features such as "all-call" and an evacuation siren input.
2) The version for other locations will have a 15-station capability.

5. Trigger System

Back-phase shifters have been added in all sectors from 11 to 30 (except 27 and 28, in which the klystrons are individually controllable from the CCR), and a switch panel to select the sectors to be back-phased has been added in the CCR adjacent to the pattern generator.

A pattern generator test panel was also installed in the CCR. Although originally intended to facilitate adjusting and trouble-shooting the pattern generator, it is also being used much of the time to enable operators to monitor the different beam request and beam pattern pulse trains. This is done by means of an oscilloscope that has been installed adjacent to the pattern generator.

All pattern generator, output line drivers have been improved to provide reliable operation when switching high-pulse-rate pulse trains on and off. It had been found that, under certain conditions, the envelope of the transient response was slightly oscillatory, resulting in a skipping or absence of some of the first few trigger pulses in the train when it was turned on.

E. ELECTRONICS ENGINEERING

1. PLIC Amplifier Modifications

The present amplifier used to display the waveform on the PLIC Scope has a switched gain of 1 and 10. A gain of 100 is desired to observe the waveform when low energy beams are accelerated. A new PC card was manufactured containing the X1, X10, and X100 amplifier and tested prior to installation.

2. Positron Interlock for PLIC

As a result of the high amounts of radiation present in Sector 11 when positrons are being generated, the PLIC interlock needed to be desensitized during positron operation. The wand driver chassis was modified to transmit PLIC desensitizing pulses, during actual wand operation, to the PLIC electronics chassis in the CCR.

3. New Pulsed Power Supplies

Three sets of pulsed power supplies were manufactured and tested. Two sets were installed in the gallery to power the horizontal and vertical sections of steering dipole magnet, DS-10.

4. Positron Wheel

A pair of synchros were installed in Sector 11 to monitor the positron wheel's position, and minor changes were made to the proximity switch chassis and wheel speed interlock chassis to accommodate the new wheel design.

5. Back-Phase Shifters in Sectors 11 to 30

Back-phase shifters have been added in all sectors from 11 to 30 (except sectors 27 and and 28), and a switch panel to select the sectors to be back phased has been added in the CCR.

6. Pattern Generator Test Panel

A test panel was installed in the CCR to facilitate adjusting and trouble-shooting the pattern generator, and to enable operators to monitor the various beam requests and beam pattern pulse trains.

7. Pattern Generator Line Drive Modifications

All pattern generator output line driver circuits were improved to provide more reliable operation when switching high repetition rate pulse trains on and off. It had been found that under certain conditions the envelope of the transient response was slightly oscillatory, resulting in a skipping or absence of some of the first few trigger pulses in the train when it was turned on.

8. <u>300 kV Modulator</u>

Design work continued this quarter, and specifications for large, custom-made parts were drawn up. Some construction work was done, and two 300 kV pulse transformers and voltage dividers were procured.

9. <u>Beam Knock-Out Modulator</u>

The beam knock-out modulator, which originally was designed to operate at 40 MHz, or at any frequency between 10 and 20 MHz, was expanded to operate at 40 MHz and 6.6 MHz, 9.9 MHz, or at any frequency between 10 and 20 MHz. This modification will allow simultaneous operation of two sets of beam knock-out deflection plates in the accelerator. This will yield short beam pulses consistent with the 40-MHz frequency and have a dead time between these pulses consistent with the lower frequency, (6.6 or 9.9 MHz) which is locked into the 40-MHz frequency.

10. <u>C-Beam Modulator</u>

One of our spare main modulators was provided for the rf-separator experiment in the C beam. The modulator was provided with a bank of variacs on its roof and installed in the end station.

F. COUNTING ELECTRONICS

1. End Station Charge Monitors

The digital averaging monitor in End Station A was modified: (1) to allow averaging either at a fixed 360 pps, or at the pattern trigger rate; (2) to allow calibration at simulated beams of 10^{-8}, 10^{-9} and 10^{-10} coulombs per pulse, and of either polarity (e^+ or e^- simulation); and (3) to allow connection of a future remote accumulator. Construction of a remote accumulator is planned for the next quarter.

Measurements with the different calibration signal levels and polarities have helped identify small errors in gain scales, and small asymmetries in the system. Some improvements have been made as a result.

In the End Station B unit, which is a non-averaging device, a new remote pre-amplifier unit has been designed which includes two additional switched-gain stages. This will provide a gain at the toroid of 100X greater than previously used for the lowest signal levels; this it is hoped will overcome present objectionable pickup noise between the toroids and the main chassis which is located in the experiment control area. Gains are switched from the existing control panel, with no change in operating procedure. Two units are under construction.

2. Time-of-Flight System

Measurements continued on the electronics portion of the previously-described centroid time-of-flight system. The correlation between full width at half maximum (FWHM) resolution and number of photoelectrons (N) emitted from the photo-cathode, measured by simulation of the ionizing particle with a light pulser, was confirmed to vary as $\frac{1}{\sqrt{N}}$. Also in order to roughly assess the degradation in resolution due to the presence of the scintillator, the solid state diode light pulser (Ferranti XP-20) was arranged to excite scintillators on both an XP1020 and an 8575 phototube.

Interpolation of the measurements shows: (1) that approximately 700 photoelectrons are required to achieve a FWHM resolution of 100 psec; (2) that the degradation due to random variations in pulse shape with a small scintillator present are $<$ 50 psec; and (3) that the best possible FWHM resolution with very large light signals is approximately 50 psec.

In a practical system, it will be necessary to restrict the aperture of the scintillator in order to minimize the normal transit-time spreads to be somewhat less then the desired resolution.

The system is due to be re-installed and tested using the rf-chopped beam during the next quarter.

Additional bench measurements are in process to determine the minimum resolution obtainable with a conventional leading-edge timing or zero-crossing system. This information is important in defining an optimum multi-channel system for use with the 40-inch Hydrogen Bubble Chamber. The required resolution for this system is 0.25-nsec FWHM.

3. Equipment Pool

All items purchased under the previously reported logic module contract are in-house and accepted. Much of the equipment is already in continuous service. Total equipment usage for the Pool is running near 90 percent, with items such as discriminators, scalers, gate generators, and majority logic receiving near 100 percent usage.

The LRS161 discriminators continued to exhibit stability problems; these are presently receiving attention from the factory.

Measurements of the LeCroy A/D Model 143 were performed for Group G. Time slewing measurements were made on the EG and G T140 discriminator using a phototube input. Time slewing measurements were also made on both the LeCroy 161 discriminator and the EG and G TR204 discriminator.

A new Scaler Display Unit was built for the High Energy Electronics Pool to be used in check-out of TSI and LeCroy scalers. Four new TSI scalers were received and checked out.

4. Magnet Measurement System Modification

The original magnet measurement system is being modified to permit simultaneous field measurement in three coordinates and to include absolute position measurement using digital shaft encoders. The job includes modification of the control system, design of a digital multiplexer, and design of a position display unit. Design and construction of the multiplexer was completed in this period. Design of the position display unit, and modification of the control system were also completed. Construction of these parts is scheduled for completion by 15 January 1968.

5. Rho Experiment Support--Groups B and C

Expansion of the LRL-designed spark chamber electronics was begun during this quarter. Some revisions were made to the control system. A new spark simulator test box using integrated circuits is being developed and is due for testing in January. A new magnetostrictive chamber preamplifier is also being designed.

Experimenter control panel, target controllers, voltmeter scanner, and secondary beam charge readout for the Hydrogen Bubble Chamber are additional projects completed during this quarter.

III. PHYSICS RESEARCH EQUIPMENT DEVELOPMENT

A. SPECTROMETER PROGRAM

Both the 8-GeV and 20-GeV spectrometers were recalibrated during this period. This has been done only a year before, but in the intervening period, the physicists had an opportunity to make a detailed analysis of the numbers, and with this better understanding of the problems involved, to plan and execute a more thorough set of measurements.

B. RESEARCH AREA INSTRUMENTATION AND CONTROL

1. Trigger System

Changes were incorporated in the basic trigger system to allow multiple beam pulsed steering without adding new power supplies. Steering of six beams is now possible on all pulsed steering power supplies, which should cover our needs for some time to come. Design work proceeded on major modifications to the research area pattern switching and trigger systems which will allow more flexible beam running conditions.

2. Interlock System

All basic chassis required to complete the system were constructed during the final quarter and were in test as a system at year's end.

3. Beam Monitor Electronics

Design work continued on revisions to the beam current monitoring signal distribution system, and tests were completed on the high gain toroid monitor. Results of the latter are now being evaluated. All chassis were completed and tested for the spectrum monitor system and this finishes the planned work on that system. Some problems remained on the "fast" analyzer but these will be solved on lower priority later.

4. Computer System

All basic problems with the analog input system for the control computer were solved. In addition, a new type of "flip-coil" mechanism was built to give about ten times previous reliability and life. The new mechanism also provides a reduction in data scatter by about a factor of five, to one part in 100,000. All changes and additions to the BSY Control System Program are being incorporated into one complete program. This will bring all the changes together in one listing, and will also provide a binary deck which is more manageable and more efficient. Implementing the incorporation will require some additional programming.

5. DAB Expansion

Equipment racks for the new DAB console were ordered and installed and preliminary layout of the control chassis started. Design of the cabling systems, ac- and dc-distribution systems and redesign of some of the instruments were completed.

C. ENERGY ABSORBERS

1. High-Power Beam Dumps

The new 500 kW Beam Dump East was installed at the beginning of the quarter. Average power up to 180 kW has been successfully dissipated.

2. Hydrogen Recombiners

The first full-size catalytic hydrogen recombiner was installed in the A-Beam Dump radioactive water system. Hydrogen and oxygen detection instrumentation and also temperature sensors were installed. The instrumentation was interlocked with the beam. The unit was successfully tested with hydrogen gas which was artificially introduced into the system. The hydrogen recombined was equivalent to 1 MW average power deposited in the dump. The recombiner was meanwhile exposed to beam conditions and performed as expected.

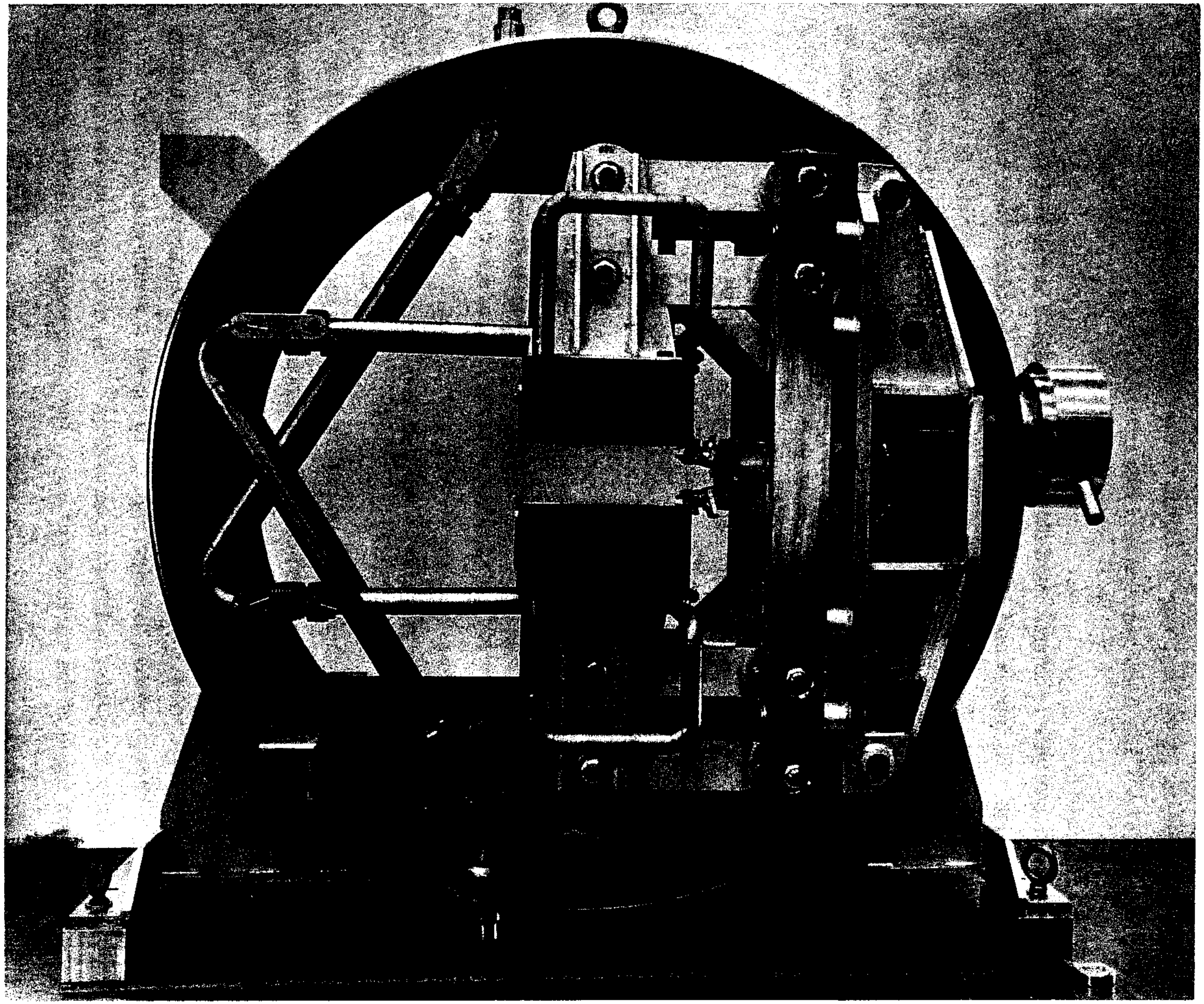
During the quarter three additional recombiners were built for installation in the radioactive water system loops of the high power collimator, the A-Beam Slit, and Beam Dump East. The unit for Beam Dump East has also been installed; its instrumentation, however, is not yet complete.

3. Photon Beam Collimator

During the first experiments in End Station A using the spectrometer, it became apparent that the jaws of the copper photon beam collimator (C-10) were not long enough (in terms of radiation lengths). While adequate for thermal protection, they are not sufficiently thick to eliminate entirely low-energy photon leakage through their faces. This was true particularly for the case where the beam wanders and thus can come close to the water-cooling channels in the jaws.

The existing jaw design of the high-Z slits and collimators was modified. Instead of approximately 30 r. ℓ. of copper the new jaws are of a composite of copper and tungsten. In this fashion the thickness of the jaws was increased to 60 r. ℓ. without increasing the actual geometrical length.

The new photon beam collimator was built and installed during the period. Preliminary results indicate that low-energy photon leakage from C-10 is not a problem anymore. Figure 14 shows a partially completed collimator assembly. The view is in up-beam direction and shows the down-beam faces of the vertical slit jaws, the pantograph assembly, and the water manifolds.



1046A14

FIG. 14--PARTIALLY COMPLETED COLLIMATOR ASSEMBLY

D. RESEARCH AREA POWER SUPPLIES

1. Magnet Power Supplies

Serious difficulties in the operation of the large power supplies marked this quarter. Failure of the rectifier transformers put the 3.4-MW power supply out of commission during the last one and one-half months. The 5.8-MW power supply was in operation some of the time, but never able to deliver its rated output. A 15,000-ampere tie-line which was completed during this time was used extensively with both power supplies. Plans for the procurement of oil-cooled replacement transformers for both power supplies were under way.

A contract was awarded for the purchase of a 3.3-MW power supply, to be delivered in July of 1968. Planning was also begun for the installation of a 3-MW motor-generator facility to be put into operation before July of 1968. Both the 3.3-MW power supply and the motor-generator sets are intended for the bubble chamber magnets. A contract was awarded for eight additional 400-kW power supplies, similar to equipment already in use.

Construction started on two new pulsed-switching power supplies and plans were under way to rebuild two existing pulsed-steering supplies for a higher rating. Modifications to upgrade ten existing pulsed-magnet supplies were also initiated.

Some work was begun for an in-house design of a 1.6-MW power supply. This effort has had to be temporarily abandoned.

2. Capacitor Charger Power Supplies

Two power supplies and control circuitry were built, tested, and delivered to Group D for use on their spark chamber.

3. B-Beam Switching and Steering Power Supplies

Design was completed, parts ordered, and some construction work started this quarter on the switching and steering power supplies.