SLAC-89
UC-28, Particle Accelerators
and High-Voltage Machines
(SR)

TWO-MILE ACCELERATOR PROJECT

Quarterly Status Report
1 January to 31 March 1968

July 1968

Technical Report
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Contract AT(04-3)-515
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TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

This is the twenty-third Quarterly Status Report of work under AEC Contract AT(04-3)-400 and the seventeenth 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 January 1, 1968 to March 31, 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 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.

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

	Jan.	Feb.	Mar.	Quarter
Manned Hours				
Physics Beam Hours*				
Machine Physics	19	12	43	74
Particle Physics	280	356	322	958
Total Physics Beam Hours	299	368	365	1,032
Non-Physics Hours				
Scheduled Accelerator Maintenance	27	6	37	70
Accelerator Failure	27	33	18	78
Search or Shut-Down	7	2	3	12
Accelerator Tune-Up	28	14	17	59
Beam Off-Accelerator Physics Request	16	--	2	18
Beam Off-Research Area Request	10	20	15	45
BSY or End Station Malfunction	10	10	9	29
Tune-Up and Adjust. of BSY and End Station	16	14	6	36
Search and Clearance of Radiation Areas	--	--	--	--
Other	--	--	--	--
Total Non-Physics Hours	141	99	107	347
TOTAL MANNED HOURS	440	467	472	1,379
Experimental Hours**				
Machine Physics	31	18	54	103
Particle Physics				
End Station A	214	303	268	785
End Station B	267	278	146	691
End Station C	12	231	252	495
Total Particle Physics	493	812	666	1,971
TOTAL EXPERIMENTAL HOURS	524	830	720	2,074

*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 down-time "normal to the experiment." Additionally, experiments run simultaneously are acknowledged.

	Jan.	Feb.	Mar.	Quarter
B. BEAM INTENSITY				
Peak	37.5mA	37.5mA	37.5mA	37.5mA
Average	12.0μA	14.0μA	14.0μA	13.3μA
C. KLYSTRON EXPERIENCE				
Total Klystron Hours	96,118	110,788	104,234	311,140
Number of Klystron Failures	9	4	7	20
D. BUBBLE CHAMBERS				
Number of Pictures Taken - 82" HBC	0	0	36,534	36,534
Number of Pictures Taken - 40" HBC	222,000	530,619	0	752,619
E. DATA ANALYSIS				
Spark Chamber Events Measured	7,856	6,555	6,184	20,595
Bubble Chamber Events Measured	10,772	14,696	10,534	36,002
F. COMPUTER OPERATIONS				
Manned Hours				
Computation Hours				
SLAC Facility Group	190	239	137	566
User Groups	339	261	425	1,025
Total Computation Hours	529	500	562	1,591
Non-Computation Hours				
Scheduled Maintenance	58	68	42	168
Scheduled Modifications	35	8	21	64
Unscheduled Down Time	23	14	10	47
Idle Time	--	38	24	62
Utility Failure	--	--	22	22
Total Non-Computation Hours	116	128	119	363
TOTAL MANNED HOURS	645	628	681	1,954

G. SPECIAL OPERATING FEATURES

1. Positrons

Using the Wand, interlaced positrons and electrons were delivered for approximately 61 hours in two beams and 199 hours in three beams during the quarter. Using the Wheel, positrons were delivered in all beams for approximately 206 hours.

2. RF Separator

During the quarter the R F Separator was installed and made operational.

3. 82-Inch Bubble Chamber

First experiments using the 82-inch bubble chamber were run during the quarter. Seventy-four hours of beam time were used and 36,534 pictures taken. The rf separator operated satisfactorily in conjunction with the bubble chamber.

4. Beam Knockout

The beam knockout was operated for approximately 3 hours during an experiment in January and for approximately 3 hours during a check-out run in March.

5. Power Supplies

The 3.4 MW power supply was restored to service in January and was operated for a total of 622 hours during the balance of the quarter. It was off for 23 hours due to malfunctions. From March 15 to the end of the quarter the supply was off for a scheduled relocation.

Installation of the motor-generator facility continued during the quarter.

6. Scheduled Shut-Downs

The accelerator was off for three weeks during the quarter for scheduled shut-downs.

II. ACCELERATOR DEVELOPMENTS

Klystron life performance to date continues to be much better than previous expectations. The mean age of all klystrons on the machine as of April 1, 1968 was 5,820 hours compared with 5,200 hours as of February 1, 1968, and the median age as of April 1, 1968 was 6,700 hours compared with 5,950 hours as of February 1, 1968. The mean time to failure will probably exceed 10,000 hours and may be close to 15,000 hours.

Because of production difficulties experienced by the vendor of the sub-booster klystron (60 kW peak) used in the drive system, SLAC has designed and placed in limited production a tube to be used in this operation. The first two tubes were completed during March and appeared to meet performance specifications.

The 12-foot traveling wave (2,856 MHz) rf separator was installed and became operational during the quarter. In tests, beams of π^+, K^+ and p were successfully separated in the central beam facility. A "clean" beam of K^+ particles was achieved with at least 1,000:1 rejection of the accompanying π^+ and p particles.

The initial injector gun failed during the quarter after 30 months of operation and the accumulation of approximately 14,000 hours. The replacement gun is substantially identical to the old, but has improved corona shielding to decrease the probability of high voltage arcs.

Both the "wheel" and "wand" targets at the positron source continued to perform well during the quarter. The "wheel" was removed during one of the shut-down weeks as too badly deteriorated from beam heating for further use and will be replaced by a new "wheel" before the next scheduled positron experiment. A larger "wheel" has been built and the velocity will be increased by 40 percent to reduce transient beam heating. Good yields ($\approx 4\%$) have been obtained at the end of the accelerator and about half of this can be transmitted through the beam analyzing system (with 1% slits) to the experimenter. The monochromatic gamma beam obtained from positron annihilation has been used to study γ-p interactions using the 40-inch bubble chamber.

Beam break-up (BBU) studies continued during the quarter. RF filters (Rizzi-type) were installed in the first sector of the accelerator with no significant improvement in the BBU level. Cold tests continued to determine the best method of detuning the accelerator sections in Sectors 1 and 2 to increase the frequency of the HEM_{11} resonance in the first few cavities of each section. It has been computed that raising the frequency by 3 MHz with respect to the rest of the accelerator would increase the

BBU current threshold by a factor of approximately 1.3. Recently it has been discovered that the individual HEM_{11} resonances and their orientation depend on the details of the dimpling technique that was used during manufacture of the accelerator. These differences are being taken into account in determining the final method of detuning that will be used.

A remote switching system which permits the Central Control Room operator to view any of 4 selected video signals from each sector was installed and is now operating. The signals available from each sector include rf amplitude and phase information from any klystron, beam pulse shape from the toroid beam current monitor, and TV signals of various types, e.g., the beam shape derived from the profile monitor located in various drift sections. Other signals can be presented by suitable "patching" at the sector alcove.

Design has started on an off-axis injector to enable electrons to be injected into the accelerator at points other than the main injector. Its main function will be to improve the operation of simultaneous beams with radically different intensities. It will also improve the reliability of the machine by permitting continuing operation during malfunction of the main injector or early accelerator sections. A gun of the main injector type will be used.

Detailed design of a disk loaded accelerator structure to start the acceleration of positrons within a few inches of the target instead of 30 inches as presently constructed has begun. The effect will be to decrease the phase slip and thus improve the positron spectrum. Fabrication and installation plans are not firm.

A method of remotely balancing beam position monitor diodes from CCR has been developed and successfully tested. The program consists of balancing these diodes by means of a motor driven balancing potentiometer. The system is to be installed gradually, sector by sector as the motors become available.

A prototype attenuator for the automatic phasing system has been built and successfully tested. The purpose is to reduce the diode unbalance in the detecting diodes and to accommodate wider ranges of rf powers, thereby increasing the dynamic range over which the system can operate and its stability. Parts have been ordered for a final prototype.

III. RESEARCH AREA DEVELOPMENTS

A. GENERAL BEAM SWITCHYARD AND RESEARCH AREA DEVELOPMENT ACTIVITIES

Primary activity within the Beam Switchyard centered on installation of the B-beam switching facility and the rearrangement of the B-target room. The B-switching facility will allow programmed pulse-to-pulse switching of the accelerator beam to three experiments in End Station B. The installation of the facility was completed during the shutdown week ending March 30. Preliminary tests of the facility indicate that it should operate satisfactorily. Beam checkout and calibration of the system is scheduled in April. It is also expected that the facility will be used to allow experimenters in the three secondary beams in End Station B to perform various counter checkouts in preparation for data runs scheduled during the summer.

Installation of a thick concrete shielding wall which isolates the B-target room from the remainder of the BSY is now complete. A radiation safety check was made, the B-target room is now 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. These have been checked out.

This change in access mode has already saved several hours of accelerator beam by allowing beam operation to A and C experimenters during repair of a B-target room equipment malfunction.

In the A-Beam various improvements in high power beam handling capability continued. 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 was tested and is operating satisfactorily as a beam monitor in the location. At the beam power levels involved a ZnS screen monitor fails in just a few minutes of operation.

During optics measurement of the End Station A spectrometers a small discrepancy was observed in the ratio of the beam energy given by the 8- and 20-GeV spectrometers compared to the BSY. A recalibration of the BSY momentum analysis system of A beam is in progress. Magnetic measurements were made on the A transport system bending magnets. The data have been analyzed and a new momentum calibration has been determined which gives the beam momentum in terms of a long coil magnetic measurement in the A-beam reference magnet located in the data assembly building. The change in calibration amounts to 0.24 percent at 2 GeV/c, 0.00 percent at 10 GeV/c, -0.09 percent at 15 GeV/c, and -0.12 percent at 20 GeV/c. The new calibration will be used starting April 1. The source of discrepancies of 0.1 percent to 0.2 percent between old and new magnetic measurements is unknown. Until this problem is better understood, the tolerance on the accuracy of the mean momentum determination is approximately that given in the SLAC Users Bulletin, i.e., $\pm$ 0.2 percent absolute with a reproducibility of $\pm$ 0.02 percent. Other work performed on the A-beam line includes installation of various beam monitors for improved beam steering into end station A. Design studies are also in progress for a rearrangement of beam components in the vicinity of the A-beam photon beam target which will allow space for installation of steering (Helmholtz) coils and for a possible new target installation for production of a mono-energetic photon beam by interaction of the electron beam with a single crystal.

DAB Control Room modifications and improvements continue. As a part of the program, chassis for a new interlock control system have been received and are being checked out. This system will allow individual interlock control for each experimenter's beam passing through the BSY. This system will improve the safety of the BSY operation with respect to protection of equipment against damage and will give versatility in the control of present and future beam lines.

As another part of this effort, the BSY control computer system is being improved to achieve more reliable and improved operations. Design of hardware and software is progressing to implement the future use of the computer for interlock readout, beam steering, BSY data processing and presentation, and other control functions. The digital voltmeter interface which is used by the computer to read BSY magnet currents has been unreliable in the past. This interface has been replaced with a redesigned unit and now seems to be operating reliably.

At present a new scheme for allowing ease in addition of new interface hardware is being developed. The principal software activity is the completion of a relocatable program which performs the present control functions assigned to the computer. The relocatable program will allow for ease in the addition of new subroutines which are required to perform the planned new control, monitor, and data processing functions.

A new sphere beam dump concept was developed as a result of efforts to reduce production costs, simplify assembly procedures, and achieve compactness while at the same time retaining power absorption capacity. The main power absorption medium (up to a depth of 14 r.l.) is a water-cooled bed of 1 cm diameter aluminum spheres. This replaces water-cooled plate assemblies of earlier versions. The diameter of the dump is 25 cm and in accordance with radial shower attenuation and radial excursion of the incident beam. The bed of spheres is followed by a solid cylinder of aluminum (4 r.l.) which is cooled peripherally. The aluminum cylinder in turn is followed by a copper cylinder (22 r.l.) to make the total length of the dump equivalent to 40 r.l. A vacuum cavity was machined into the aluminum cylinder for personnel and equipment protection. It can be interlocked with the beam and thus indicates a dump failure at an early stage. A first full-sized model of such a dump was manufactured for approximately $3,000, which represents a considerable savings over previous designs. If adequate water flow is available it should have a 400 kW average beam power absorption capacity. The unit will shortly be installed in the B-target room as the dump for the new neutral K_0^2 beam.

The long-range program for obtaining enough reliable power supplies for use in the research program is progressing; however, short-term operation is still plagued with power supply problems. Failure of a transformer in the 5.8 MW power supply interrupted a scheduled run with the 40" bubble chamber in January. New Askarel-filled transformers are being procured for the supply.

Revised design of the 5.8 MW power supply for use with Askarel-filled transformers is essentially complete and is being negotiated with the manufacturer.

Bids for new Askarel-filled transformers for this supply were received and a contract award was made. Progress on the new 5.0 MW power supply and the motor generator facility continues. The motor generator units were delivered during January and contracts for building and site preparation and other components of the system have been completed. Study of future requirements for research area dc power in the 400 kW and 1.6 MW range is under way.

The 3.4 MW power supply was moved to a new location in the research yard.

The dry-type transformers in this power supply are running too hot. New Askarel-filled transformers are on order.

B. SPECTROMETER, BUBBLE CHAMBER, AND STREAMER CHAMBER

In January and February the 1.6 GeV spectrometer was used for Experiment E-21/22, which is studying photoproduction of π^0, η, ρ^0, ω and ϕ mesons at small momentum transfer and various incident photon energies up to 18 GeV. A search for other mesons which are photoproduced is also being made during the experiment. Early in February a circuit failure resulted in serious over heating of the 1.6 GeV spectrometer magnet coil. Fortunately, the coil insulation seems to have survived the over heating and the spectrometer is still operable. The effect of the incident on the life of the coil is unknown. Several improvements have been made to the power supply and safety circuits which will help to prevent future damage to the spectrometer coils.

In January the accelerator was used to produce a positron beam for E11/24 for approximately 30 shifts.

The 20 GeV Spectrometer was used during February for Experiment 10. This experiment is studying the photoproduction and angular distribution of various mesons and meson-baryon resonances.

In March Experiment E23 was run on the 20 GeV spectrometer for 15 shifts. This is a photoproduction experiment in which backward π^0 production is studied by looking at the forward produced protons in the momentum range 4 to 12.5 BeV/c. A one meter long hydrogen target was used. Afterwards, Experiment E10 was resumed for 17.5 shifts on the 20 GeV spectrometer. This examines photoproduction of π^+ and K^+ in the range of 5 to 18 GeV/c. Both hydrogen and deuterium targets were used.

The 40-inch bubble chamber was used early in January to take pictures of photon produced events for experiment BC-2. This run was terminated by the 5.8 MW power supply failure. The 40-inch chamber was reactivated with the repaired 3.4 MW power supply.

134,000 pictures were taken for experiment BC-3 and 300,800 pictures were taken for experiment BC-2. When this run was completed a period of five days was spent investigating the possibility of running a chamber with Helium dissolved in a concentration of about 1/2%. If operating conditions were sufficiently changed over those for pure Hydrogen, one might be able to bias a chamber filled with the mixture and containing a bag of pure Hydrogen, so that the two regions would have different sensitivities. After the tests were completed, the chamber was warmed up and pulled apart so that a new heat exchanger could be installed and hopefully give much better refrigeration of the chamber liquid. A prototype Hodoscope to be used in experiment BC-10 will be installed through a hole cut in the chamber tank.

The final repair work was done on the 82-inch bubble chamber optical system, and the system reassembled in preparation for cool-down starting March 1.

On March 1, the 82-inch bubble chamber was cooled down in preparation for experiment BC-4 which started on March 11. The chamber and beam ran with reasonable success during the assigned period and 36,000 pictures were taken. The chamber pulsed 1/4 million times during the period and the apparently large discrepancy in pulse to picture ratio was caused by the rigorous boundary conditions imposed on the beam quality. It is expected that the pulse to picture ratio will get smaller as improvements are made in the beam system. The chamber ran with the old Berkeley camera, using 1,000-foot reels, but the short reels were no problem because of the low picture-taking rate. During the month a new 4,000-foot camera film supply has neared completion and should be in use in April.

C. SECONDARY BEAM AND ASSOCIATED EQUIPMENT

The principal experimental activities in the B End Station during January used the annihilation beam which produces monochromatic photons. A 40-inch bubble chamber run at photon energies of 5 GeV (using 10 GeV e^+) took 134,000 pictures (for BC-3). The majority of the running time during the month was used by Experiment 11/24 which also uses the annihilation beam. No major changes in the beam line were required. A new condensing type liquid hydrogen or deuterium target was installed for use in the Experiment E 11/24. The program of the experiment comprises measurement of photon produced rho events from Be, C, Al, Cu, Ag and Pb at various incident photon energies, measurement of the absolute rho cross section from hydrogen and deuterium at various incident photon energies, and a search for the f^0 meson and the Regge recurrence of the rho meson.

Development of plans and construction of the new neutral K_2^0 meson beam for Experiments 31 and 32 in the south beam of end station B continued. Construction of a shielded cave in end station B for Experiment 32 was completed. The 18D36 magnet for E32 and various instrumentation requested by the experimenter has been installed. This experiment is ready for preliminary counter checkout runs scheduled on a parasitic basis during April. A trailer for E31 has been moved into place and setup of equipment for this experiment is in progress.

A new design and construction of equipment for modification of the annihilation beam is under way. These modifications will allow production of a Bremsstrahlung beam from a target located near the B beam pulsed magnet. This beam will pass through

End Station B to Experiment 11b. This beam requires installation of new permanent magnets, new collimators, and a major revision of shielding in the present annihilation beam. Also, all equipment of E11b must be shifted slightly from its present location. Construction of the neutral K_2^o meson beam in the south beam of End Station B was initiated in January.

Experiment 1 which uses the muon beam ran most of January and in March. This experiment is studying elastic and inelastic muon scattering from protons at various incident muon energies.

Final tests of the rf separated K beam for use with the 82" Bubble Chamber were completed. As it turned out, the separated yield at 12 GeV/c secondary momentum was ten K^+ per pulse with 18 GeV primary electrons and 3×10^{11} electrons per pulse, adequate for the 82" HBC run commencing March 11. This run used 12 shifts and took 36,000 pictures.

The development and design of the polarized monochromatic high-energy photon beam progressed in the central beam area. A shielded cave which houses a stripping magnet and other experimental equipment associated with this beam was completed. The permanent magnet for deflecting the electron beam into a dump after interaction with the laser light beam was completed.

The electron transport system including precise collimation to define the phase distribution of the beam in the region of interaction with the laser light was completed. Satisfactory results were obtained in an initial test of the ability of the accelerator to produce a satisfactory electron beam. However, further tests will be required to determine the compatibility of these requirements with those placed on the accelerator optics by other experiments. Bids were requested for the laser.

A considerable amount of use has been made of the central separated π-K secondary beam facility for parasitic user activities during this period. These activities include the following tests:

i. E. Dally, Stanford University, lead fluoride Č type total absorption shower counter.

ii. B. Hughes and W. Lakin, Stanford University, sodium iodide scintillator, total absorption shower counter.

iii. P. Meyer, University of Chicago, balloon borne telescope-shower counter, instrument package, tungsten-plastic scintillator sandwich type shower counter.

iv. W. Smart, Stanford Linear Accelerator Center, high resolution counting system for time-of-flight measurements in forthcoming K_o experiment with 40-inch HBC.

v. C. Heusch, California Institute of Technology, shower counter, sandwich type both lead-lucite ($\check{C}$) and lead-plastic scintillator.

vi. W. Smart, SLAC counter tests, fast timing for 40-inch K^o runs.

vii. A. Carey, U. C. Riverside, emulsion exposure, 14 GeV electrons.

viii. J. Lord, University of Washington, emulsion exposure, 14 GeV electrons.

ix. E. Bloom, SLAC counter tests, shower counter for 20 GeV spectrometer.

x. R. Golden, UCLRL counter tests, shower counter development for balloon experiment.

IV. RESEARCH DIVISION DEVELOPMENT

A. PHYSICAL ELECTRONICS

Several secondary emission monitors are in various stages of assembly and testing. The larger units (8-inch clear diameter) are intended for use in electron scattering experiments at SLAC. The details of surface contamination are being studied through the use of a quartz crystal thickness monitor.

Streamer chamber windows consisting of a transparent conductive coating on Mylar were fabricated during this quarter. Tests indicate that the deposition of cadmium oxide on Mylar does not significantly affect Mylar's principal physical characteristics. These coatings were able to transmit more that 90% of incident 6,300 Å light.

The study of alkali-halide secondary-emission foils was continued. Measurements were made of the statistical number distribution of secondary electrons produced from incident 1 MeV electrons. More rigid foil supports have been developed to alleviate the earlier rupturing problems.

The results obtained to date in the surface physics studies were summarized in a paper presented to the Fourth International Vacuum Congress.

A new activity initiated during this quarter is a study of the properties of superconducting microwaves (S-band) cavities. The aparatus required to study the high-field properties of various plated surfaces is being assembled.

B. MAGNET DEVELOPMENT

Resistance measurements were carried out on welded joints in superconducting wire. These joints are suitable for use with moderate magnetic fields, but some degradation is apparent at fields in the 65 kilogauss region.

A special water resistor has been constructed for use as an energy dump to handle quenches of the large SLAC superconducting coil. The dumping system was successfully tested; very little helium was lost, and there was no damage to the magnet.

The studies of fluxjump in composite conductors were continued, as were the studies of hollow conductors.

C. CONVENTIONAL DATA ANALYSIS DEVELOPMENT

This group's principal effort during the present quarter has been devoted to the continuing fabrication of the spiral reader, and of two new measuring projectors. The design and construction of three small scanning tables for use in the experimental area has begun.

D. COMPUTATION GROUP ACTIVITIES

In graphics applications, two major high-energy physics programs have been converted to visual on-line forms. The first is the Visual Transport program called PROFILE, which is a visual version of the beam optics program TRANSPORT. By inspecting the profile of the beam as it is being calculated through a range of input parameters one can zero in on the desired set of parameters in a very short time. This program has been used to design a spectrometer in a few hours as opposed to an estimate of a few weeks for the conventional batch processing form of the program.

The on-line SUMX program OLSUMX is now ready for users to try. During March, most of the work has been expanded to put it into the on-line graphic partition of the 360/75. In order to run in this partition it must be overlaid so that the maximum memory requirements do not exceed 100 K bytes. This has been accomplished and the program is now ready for evaluation by physicists. Features of the on-line version include:

- Incorporation of the frequently used blocks of the CERN SUMX program, including blocks 6, 7 and CHARM's. Almost complete upward compatability with the SLAC batch version of CERN SUMX.
- A file management system permits the user to create pseudo-data files on-line without requiring JCL statements defining the sets beforehand. This is done by declaring one very large file (with JCL) and doing the rest of the data management within OLSUMX.
- A text editor, so that the CGRN-SUMX control cards and other alpha numeric data can be easily edited.
- A "self-teaching" file to which the user can refer for help when necessary. Also a table of contents, which keeps track of all the user files.

The system is advertised as a "phase I" development, as far as its real value to physicists is concerned. However, the program is designed to be easily expandable, and it is anticipated that user feedback will provide the direction of expansion.

A computer program employing interactive graphics for the purpose of data-fitting by the method of least squares has been developed. Improvements and modifications are underway to expand its capabilities. The current version allows data-fitting by orthogonal polynomials, spline functions of any degree, Fourier series, and user-specified (nonlinear) functions. The interaction has been planned to make the system self-explanatory and very easy to use. Among the options allowed are choice of function, mode of data entry (cards, or keyboard, etc.), degree of fitting functions, and method of displaying the results. An interactive Gauss-Seidel type of minimization routing has also been developed which can be used to minimize any nonlinear function of several parameters.

A model of parallel computing programs has been developed. This model permits one to display the implicit parallelism present in computer programs. The mathematical soundness of the model has been proven. It has also been proven that the model is a universal machine. Practical implications of this are now being investigated. The model, if successful, could become the basis for control of multi-computer systems and for the control of data accessing in large data files.

Two contributions have been made to the pattern recognition effort. First, the Hummingbird I film digitizer has been modified to permit gray-scale levels digitization; this optical density information is of considerable use to a recognition scheme in identifying certain kinds of features in a photograph. Second, a light-pen control system for directing the scanner operations has been completed. This type of control system which permits one to see the digitizing and redirect the scanning operation on-line is very useful in picture processing research.

In addition, an investigation has been recently initiated to determine the usefulness of gray-scale information in the digital encoding of bubble chamber photographs. This will also involve the application of certain local homogeneous picture transformations to the gray-scale matrix in order to simulate the "gestalt" properties of human visual perception.

V. ACCELERATOR ENGINEERING

A. OPERATIONAL EXPERIENCE

1. Main Modulators

These units continued to operate satisfactorily this quarter. About 95% of them were kept on the line during beam operations. The ones that were off had troubles mostly in low level circuits. Main rectifier transformer and charging choke oil leaks, and pulse capacitor failures continued to be problems.

a. Rectifier Transformers and Charging Chokes. Oil leaks continued to occur around the high and low voltage bushings. In some cases, insulators around the low voltage bushings were cracked, necessitating replacement. Altogether, 20 transformers were repaired during this quarter.

The plug-in jumper arrangement which was mentioned in the previous quarterly report was installed on all modulators up to sector 20.

b. Pulse Capacitors. The failure rate of original capacitors appears to be increasing with 190 failures this quarter as compared with 112 last quarter and 116 the quarter before that. However, the quantity of spares has been built up to nearly 500 by the end of the quarter.

The old capacitors have been redesigned using a new dielectric system and deliveries of improved capacitors began. At the end of the quarter we had received 268 of these capacitors and installed 157.

Other backup source capacitors began arriving in increasing numbers this quarter. The rundown is as follows: Corson Electric Manufacturing Company 114 received and 45 installed, Sprague Electric Company 25 received and 5 installed, Axel Electronics Company delivered 113 and 84 were installed. In addition, Cornell Dubilier delivered 25 polyethylene-silicon oil capacitors, all of which were installed and have been running well. They also sent 61 polypropylene-mineral oil capacitors, of which 44 were installed. We experienced four failures of those units during the quarter.

Installation of as many backup source capacitors as fast as possible was attempted in order to gain life experience.

c. Main Rectifiers. Only two rectifiers failed this quarter as compared with four last quarter and five the quarter before that. It appears the failure rate might be decreasing, but it is difficult to say for sure since the failure rate is subject to statistical variations. In each case, the failed rectifier was repaired and put back into service. The 29 backup source rectifiers continued to operate satisfactorily.

d. De-Q'ing SCR Assemblies. Nine sets of SCR's were lost this quarter as compared to eight last quarter and 26 the quarter before that. This numbers seem to indicate a rather low steady failure rate since they were improved during the third quarter last year.

e. Pulse Cable Assembly. The failure rate of pulse cable assemblies appears to be increasing, 13 this quarter as compared with 8 last quarter. Most of the failures occur in the connector and are repairable; however, a few failures are appearing in the cable itself. Apparently, air pockets develop between the polyethylene layers, probably due to leakage of silicon oil with flexing of the cables. Corona develops in these pockets which deteriorates the dielectric materials to the point of failure. SLAC has ordered 150 new cable assemblies with improved connectors. The first model off the production line looked good. Deliveries should begin late in April.

A new type of cable using solid silicon rubber dielectric was investigated. We obtained and tested a sample of rather small diameter cable which was not rated for our full output current, but it operated satisfactorily well over its current rating. Later, another cable of larger size was obtained. At the end of the quarter it was about to be tested.

f. Hydrogen Thyratrons. Forty-nine failures, or an average of about 16 per month, of large single thyratrons or pairs of GL-7890's occurred. This failure rate is slightly below the average for the past nine months. A total of 241 have failed in all operations to date, including test stands and early modulator work, giving an overall average of 3762 hours per tube, which is higher than last quarter's (3374 hours). The three different tube types had average lives of 3465, 5285, and 3280 high-voltage hours. All these numbers are increasing as life experience is gained. With the present mix of tubes on the machine, an overall average life of about 5600 hours is predicted.

The average life of the tubes operating on the accelerator is 4120 hours. There are many still operating in the 6000-8000 hour bracket and one tube is still operating with over 11,000 high voltage hours on it.

Both manufacturers experienced problems with their tubes. Interelectrode spacing was still a problem as was cathode emission. The rejection rate was improved this quarter.

2. Pattern Generator Power Supplies

The power supplies feeding the Pattern Generator were expanded to provide more reliable operation. Three separate power supplies were installed, any two of which can carry the entire load while a third is being repaired or replaced in case of a power supply failure.

3. Pattern Generator Output Line Interlock Unit

The Pattern Generator system was modified to provide interlocking among its output lines to prevent damage to pulsed power supplies. The interlocking prevents simultaneous triggering of two pulsed power supplies feeding the same magnet.

4. Counter/Frequency Divider

This unit was modified to increase its capacity from 100 to 1000 in order to provide a wider range of repetition rates in accelerator beams.

B. EQUIPMENT DEVELOPMENT

1. 300 kV Modulator

This job was dropped this quarter for budgetary reasons. In its place, we explored the possibility of operating our present modulators at 270 kV output pulse voltage to accomodate the new 30 MW klystrons that are being developed in the Klystron Group. A higher power Powerstat and a voltage step-up transformer were obtained and installed on one of the test modulators in the Test Laboratory. With 10 percent higher ac input voltage to the modulator, the required 270 kV was obtained, but, of course, with shorter pulse width because the load impedance is smaller for such klystrons. The modulator otherwise operated satisfactorily.

Next quarter it is planned to install two additional capacitors in the pulse forming network (in order to increase the pulse width) and make further tests.

2. B Beam Switching Power Supplies

These power supplies were constructed this quarter and operated into the new B beam magnets. A few troubles were experienced but otherwise they were usable up to 18 GeV.

The maximum output current was 480 amperes instead of 550 as specified, mainly because the magnet inductance came out 22 percent higher than specified. The repetition rate could not be run over 180 pps because a choke in the output circuit of the power supply overheated. Also, there were additional unexpected losses in the system that necessitated keeping the maximum repetition rate below specifications. Further work is required on these supplies.

3. B Beam Steering Magnet Power Supplies

Two Ling Pulsed Steering Magnet Power Supplies were modified to provide higher output current for larger steering magnets.

These units were finished, installed and operated satisfactorily into their new magnet loads.

VI. KLYSTRON STUDIES

A. KLYSTRON DEVELOPMENT

1. Summary

Development work is continuing at RCA and SLAC in an effort to improve tube performance particularly at high voltages, and to develop tubes capable of reliable operation with a peak power output of 30 MW minimum. Litton is continuing a program to solve the arcing problems which has drastically reduced the yield and deliveries during the last six months.

SLAC has begun work on a driver amplifier tube.

The gas burst problems on the ion pumps in the gallery has been resolved. It was basically an argon instability problem, and various long range solutions are still being considered.

2. Klystron Procurement

a. RCA Subcontract. Twelve RCA klystrons were delivered and accepted during the quarter. The rate of delivery is governed by the number of failures, which continues to be extremely low.

Work has continued on window improvements, both from a standpoint of coating and fabrication techniques. A heliarc window design has been completed and preliminary tests have indicated satisfactory operation for this window. Work is continuing on rf sputter coating equipment and although the results appear encouraging, they are still not consistent enough from coating to coating to be applied to final tubes. It is believed, however, that the causes for the variations are understood and that the process will be completely in hand next quarter.

From a long range standpoint, RCA has been considering the possibility of operating their tubes at voltage levels up to 270 kV, and peak power outputs in excess of 30 MW. A set of tentative specifications which could cover such tubes have been submitted for their consideration. There appears to be, in general, agreement that the specifications can be met and engineering work is progressing to build and test several tubes which could meet new higher power specifications. It is hoped that these tubes can be operated in existing permanent magnets. In addition, in an attempt to increase the total number of immediately available spares for the line, SLAC has modified some Arnold Engineering magnets originally procured with Sperry tubes so that they can be mated to RCA tubes. The results to date are promising with, in general, somewhat better performance at the higher voltage levels. RCA may wish to use this particular field to operate their tubes at 270 kV.

b. Litton Subcontract. The main problem continues to be one of low yield caused by cathode sparking which prevents the delivery of acceptable tubes. In addition, there appears to remain some interchangeability problems between Litton tubes and magnets.

None of the solutions tried up to now to prevent cathode arcing have been completely successful. Litton is still looking into the minute differences in manufacturing and processing techniques which must have occurred between the deliveries of the first 50 tubes under this subcontract and those of the last six months. The rate of acceptance during the past six months is between 1/4 and 1/5 of that achieved for the first 50 odd tubes under this subcontract.

Many factors are being looked into at Litton, but as of the end of this quarter there seems to be no obvious solution to the problems.

c. SLAC Klystron Development. The main emphasis during this quarter has been in solving the arcing problems which had begun to be present during the previous quarter. None of the tubes built during January were able to operate stably at 250 kV mostly because of arcing.

A careful analysis of the cathodes showed a definite pattern of bright spots around the edge of the focus electrode. Some of these spots looked as if there has been some incipient melting. The appearance of these spots suggested the possibility of rf voltages within the anode housing, although no evidence of oscillations were detectable either by a probe in the oil tank or by careful examination of the rf output. However, it was known that the 300 kV tubes built had shown gun oscillations at voltages in excess of 270 kV, and their focus electrodes had markings similar to those observed in the standard 250 kV guns.

An examination of the records indicated that in November 1966 the spacings between the cathode and focus electrode had been reduced from 15 mils to 7 mils. It appears possible that with a 7 mil spacing, triode gun oscillations of some kind could be induced which would not be present with a larger spacing, since basically the decrease in the spacing corresponds to an increase of μ. This spacing was then increased in a number of tubes and the arcing decreased drastically with the following results: With 0.015-inch spacing, operation became marginal at 260 kV; with a 0.020-inch spacing, marginal operation at 265 kV; with a 0.030-inch spacing, marginal operation at 275 kV. With increased spacing we were able to take tubes which were still slightly gassy up to 270 kV without the arcing problems which were encountered earlier.

A few experimental (XM-16) tubes were built where the drift distances have been slightly modified from cavity to cavity, and the gap length of the first three cavities has been drastically reduced. One of these tubes did not operate because of severe breakup in the input. The other two gave power outputs of between 30 and 31 MW at 250 kV with reasonably good stability. Data on the best tube is given below in both electromagnet and permanant magnet (electromagnet data corresponds to focus optimized at all operating levels).

Electromagnet		
e_{py}	P_{out}	Eff.
200	16.5	45.0
225	23.6	47.3
250	31.7	48.4
260**	34.2	48.0
270**	37.1	47.9

Permanent Magnet		
e_{py}	P_{out}	Eff.
200	12.7	34.0
225	21.9	44.0
250	31.1	48.4*
260**	32.5	46.1

*The tube had a slightly lower perveance when run in permanent magnet.

**Data taken at 180 pps.

In addition to the above experimental klystron, a 300 kV tube was built incorporating the large 300 kV gun and the small anode. We succeeded in eliminating the severe gun oscillations observed in the XL-3a model, but still observe the drift tube feedback problems observed in all the large diameter drift tube klystrons built; i.e., 1.375-inch diameter. A new design has been completed using the drift diameters used on the 2422 klystron.

We are also working on experimental modifications of Arnold Engineering Company magnets which were originally purchased with Sperry tubes. It appears that these magnets can be used to operate klystrons at efficiencies approaching the electromagnet efficiencies at voltages of 270 kV to 300 kV. It would be desirable to have the same magnetic field to insure magnet interchangeability whether the tubes are 30 MW (at 270 kV) or 24 MW (at 250 kV), but it is not certain that this objective can be achieved.

3. High Power Window Development

a. Boron Nitride. Two windows coated with boron nitride failed on SLAC tubes during initial tests of the tubes, in addition to the tube which has failed during the previous quarter. The failures were thermal and are not understood, but may be caused by localized loss of coating. These windows had been coated during the previous quarter and no window failures have been observed on the klystrons built during this quarter.

b. Resonant Ring Tests. Routine pretests of klystron windows have been discontinued, and will be resumed only if there are indications that the window failure rate has been affected. Time was devoted to investigating some specific aspects of the window problem including tests of the efficiency of coating removal by the wet-blast process. It appears that even after wet-blasting, partial coating remaining has still considerable multipactor suppressing effects. Hence, there may be a way to remove excessive coating to improve the thermal stability of the present titanium coating techniques. New RCA window mechanical designs and coating techniques have also been tested including two specimens of heliarced windows and several samples of rf sputtered coating. Initial results indicate that the rf sputtered coating has a lower surface resistance than the standard SLAC coating of the same indicated thickness, but appears to be more stable through temperature cycling. RCA windows with thinner rf sputtered coatings are presently being tested.

c. Window Coating Work. The vacuum evaporation system for applying window coatings is now functioning. Initial operation of the electron beam evaporator has been devoted to producing titanium coatings, so that the evaporation rate control and the crystal monitoring characteristics can be evaluated of specimens of an otherwise familiar coating material. Ring tests have indicated excessive thickness of the initial test coatings; hence, more sensitive control of the coating process is being sought. Further investigation of boron nitride coatings will follow, when more effective operation of the evaporating system has been achieved.

Measurements of window coating resistance as a function of temperature during vacuum bake were resumed late in the quarter. The current experiment is a repetition intended to verify a previous measurement showing improved thermal stability of the modified coating distribution now being used. This test is to be followed by comparative evaluations of samples of the RCA rf sputtered coating which have been provided to SLAC for investigation.

4. Vacuum

The general investigations in vacuum problems have been concerned mostly with the instabilities in ion pumps which lead to the gas burst problem. A temporary solution appears to be to revert to the higher operating voltage (approximately 7 kV instead of approximately 5 kV). Gas bursts have not occurred in 2 out of 4 sectors where the change was made. An extensive study of the instabilities in ion pumps is being planned, particularly with the evaluation of the differential sputter yield ion pump elements which have been procured in hopes of achieving a permanent solution of the gas burst problems.

In the continuing study of electron noise from the pumps, strong evidence has been obtained that gas instabilities may be the result of mode shifts which appear to be a very critical function of operating voltage, magnetic field, and pressure. These shifts are easily detectable as step functions in noise output while no apparent change in system pressure is observed.

5. Driver Amplifier Klystrons

a. Litton Subcontract. During January we accepted three more Litton driver amplifier klystrons. However, the technical difficulties with the tubes continued. Either the tubes had adequate gain or power output but were not shippable because of oscillations, or the tubes were stable but did not meet specifications in either gain or power output. As a result, the Litton deliveries continued extremely slowly, and the total number of spares available was rapidly decreasing.

b. SLAC Driver Amplifier Klystrons. With the difficulties experienced by Litton, a mechanical redesign of the SLAC beam tester built in 1967 was undertaken. The tube was electrically a scaled down version of the big SLAC tubes operating with a slightly higher perveance gun (approximately 2.3). The gun dimensions are scaled by a factor of slightly greater than three and the drift tube diameters slightly less than three. The tube focuses well in a permanent magnet with a peak field between 800 and 900 gauss. The input cavity was mechanically redesigned so that it was possible to locate the rf input seal outside the magnetic field by using an evacuated coax input line from the input seal to the cavity running the length of the tube. The tube rigidity has been greatly increased, and thermal stability is achieved by water cooling some heavy drift tubes separating the cavities. A photograph of the completed tube is given in Fig. 1. The output uses the same window which had been used in the beam tester, but the coupling loop and transmission line from the cavity to the window have been redesigned to improve both electrical stability and mechanical characteristics.

The drawings were given to the machine shop on approximately February 15, 1968, the first tube was out of bake before the end of March, and was accepted on April 2, 1968

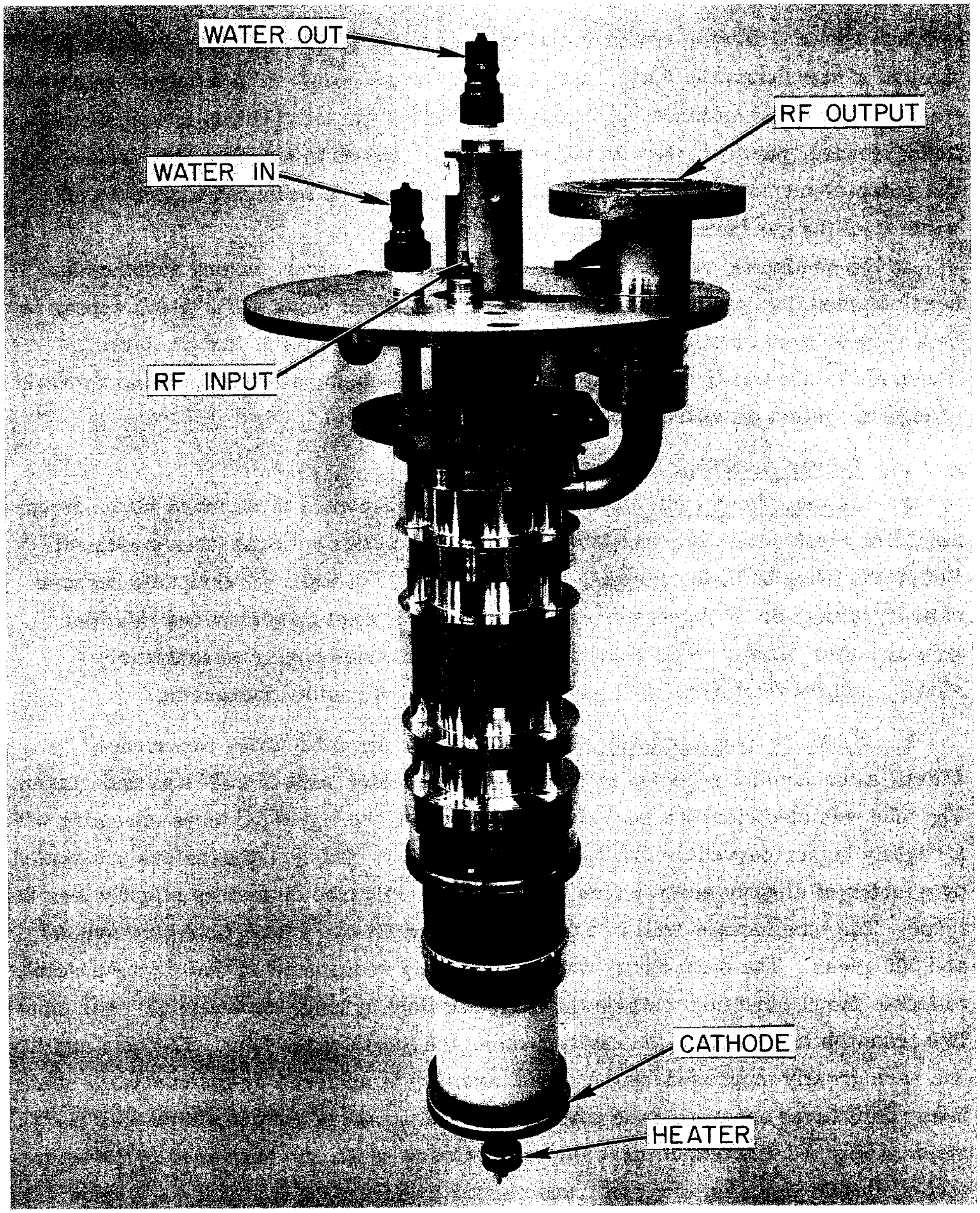

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FIG. 1--Driver amplifier klystron

with a power output of 81 kW in a permanent magnet. The tube appears to be very stable over wide ranges of drive power, and to the best of our knowledge, meets all specifications.

One of the main problems has been the procurement of permanent magnets for these tubes. It was not possible to wait for the procurement of commercial magnets which would meet the field specification, but it was possible to use enough of Alnico 8 material remaining from the experimental magnets procured for the big tubes to build in-house a few magnets with which the performance mentioned above was achieved.

B. OPERATION AND MAINTENANCE

1. Summary

Three-hundred eleven thousand klystron operating hours were accumulated by the high power klystrons on the line, with 20 failures during the quarter for a total of 200 failures since the beginning of operation. Approximately 120 klystrons were in storage, including 18 ready for installation in the gallery.

Driver amplifier klystrons operated a total of 43,000 hours in the gallery, and 2,700 hours in the Test Lab during the quarter. We experienced 8 driver amplifier klystron failures this quarter. Four driver amplifier klystrons were available as spares at the end of the quarter.

There were no failures of main booster klystrons during the quarter.

The gas burst problem has been considerably alleviated by temporary measures to cure the difficulties. However, a permanent solution has probably not been achieved yet.

2. High Power Klystron Operation

A summary of the tube usage and failures since the beginning of operation is given in Table 6-1.

More detailed information is given in the following tables and graphs. Figure 2 is the continuation of the operating experience by quarter giving the mean age of all tubes failed during the quarter, the number of failures and replacements during the quarter, and the mean number of hours per tube and socket during the quarter. It can be seen that the mean age at failure is still increasing and has reached 4487 hours during the quarter. The number of replacements decreased from 52 to 48 for the quarter, the number of failures from 23 to 20. Hence, the ratio of replacements to failures is still near the minimum achieved. Figure 3 gives the variation in mean

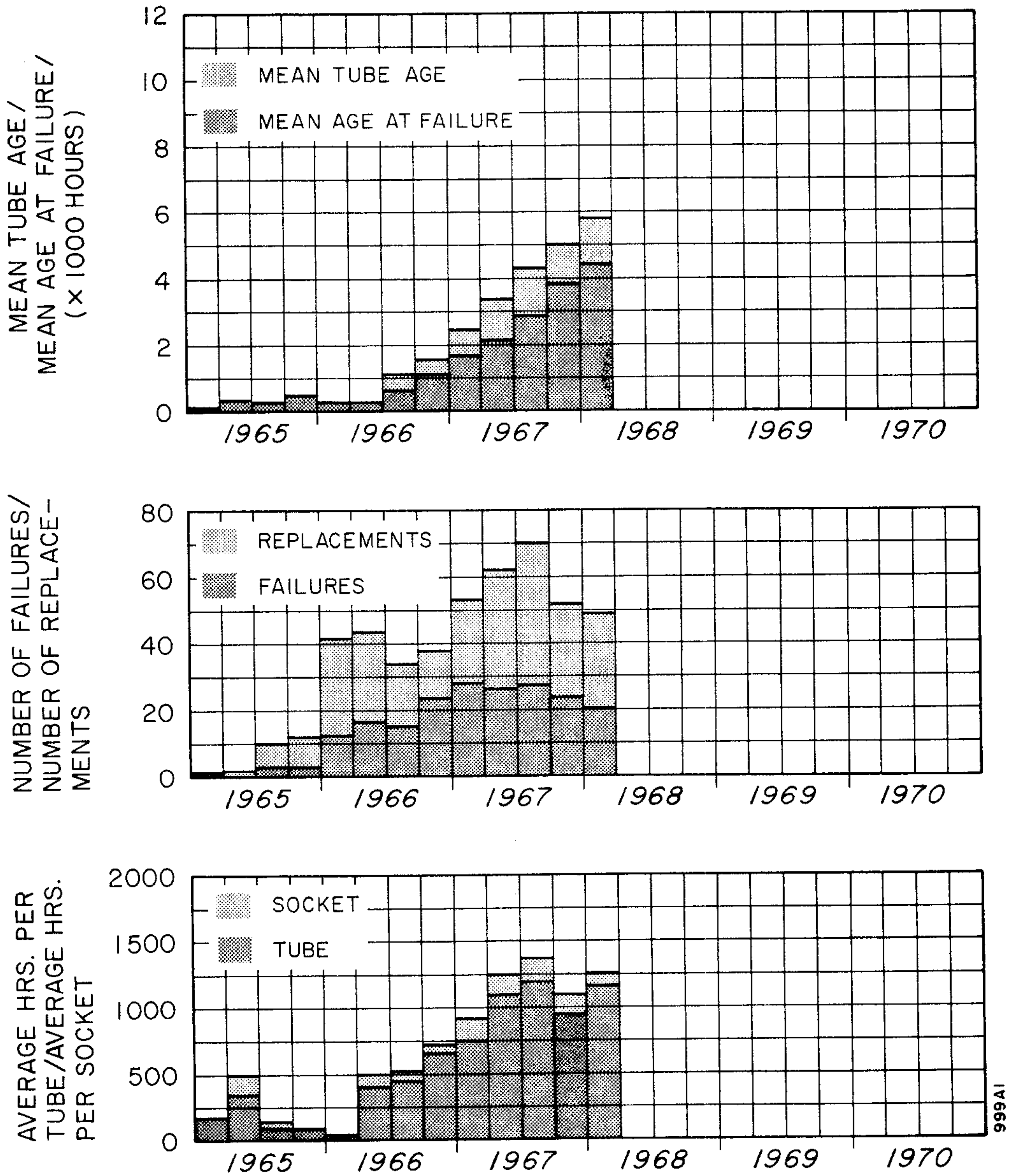

FIG. 2--Klystron quarterly operating experience, all HPK vendors

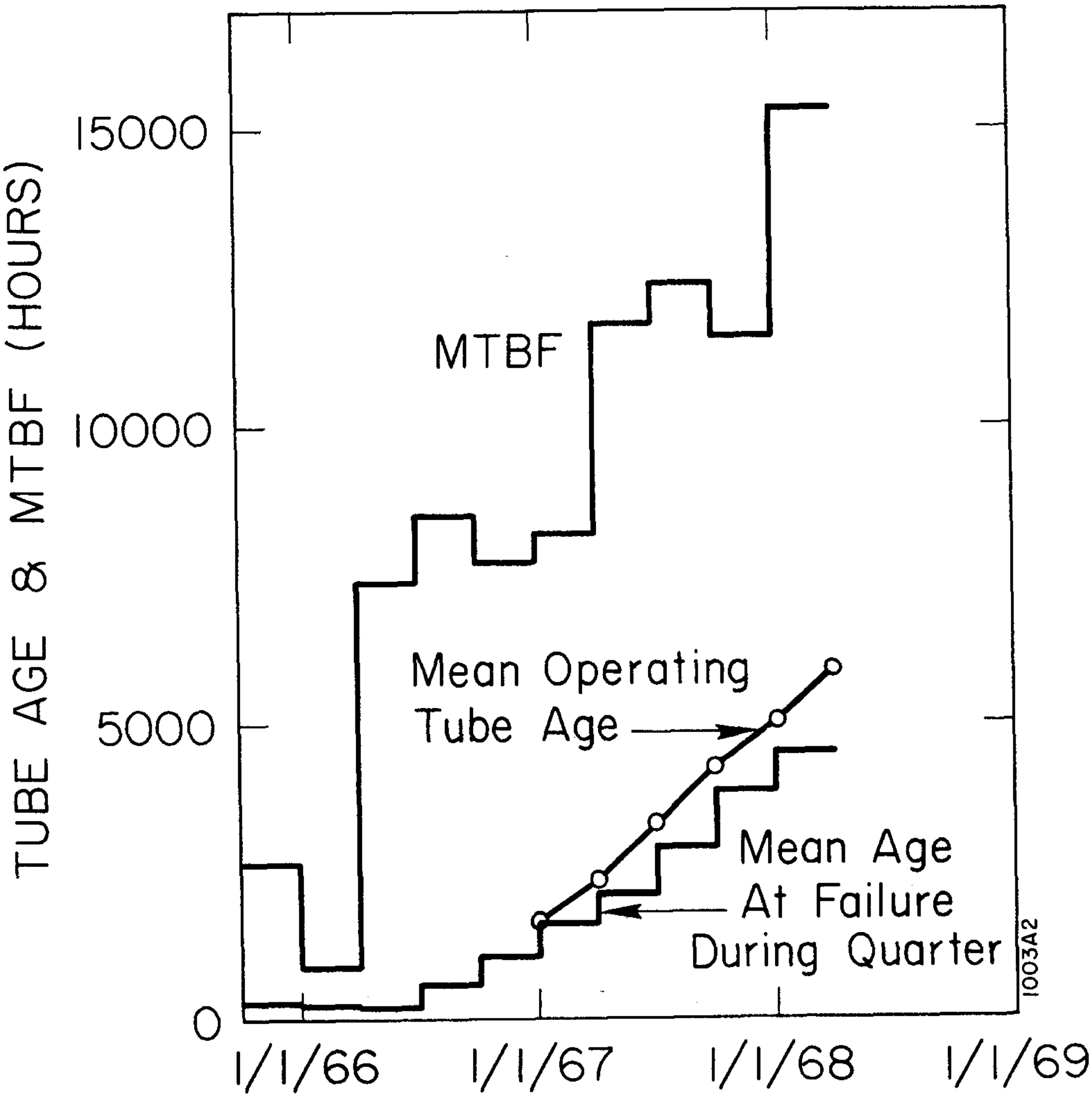

FIG. 3--Operating tube performance

time between failures (MTBF is defined as the number of operating hours in a given period divided by the number of failures in the same period), the mean operating tube age, and the mean age at failure during the quarter for all failures.

Table 6-1 - Klystron Usage and Failures

Dates	Operating Hours		Failures			
			Quarter		Cumulative	
	Quarter	Cumulative	Number	Mean Age at Failure	Number	Mean Age at 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 10/31/67	265,500	1,590,500	23	3833	180	1739
To 3/31/68	311,000	1,901,500	20	4487	200	2013

The statistics for the first two years of operation are probably distorted by the use of Sperry tubes (of which there is only one left in the machine at present), which had an overall MTBF of approximately 1500 hours.

Figure 4 gives the MTBF per quarter and cumulative for RCA, Litton and SLAC combined since January 1966. It can be seen that both the quarterly and cumulative MTBF for those vendors has been substantially constant at approximately 15,000 hours for the last three quarters.

Figure 5 gives the tube age distribution in 200 hour increments at the end of the quarter. Note that the mean and median age are both still increasing rapidly; they have increased between 800 and 1000 hours during the quarter.

The indications from Figs. 3, 4 and 5 are that the tubes have probably not yet reached their full maturity since the mean operating tube age is still increasing rapidly, and the MTBF has been substantially constant and almost three times the mean operating tube age.

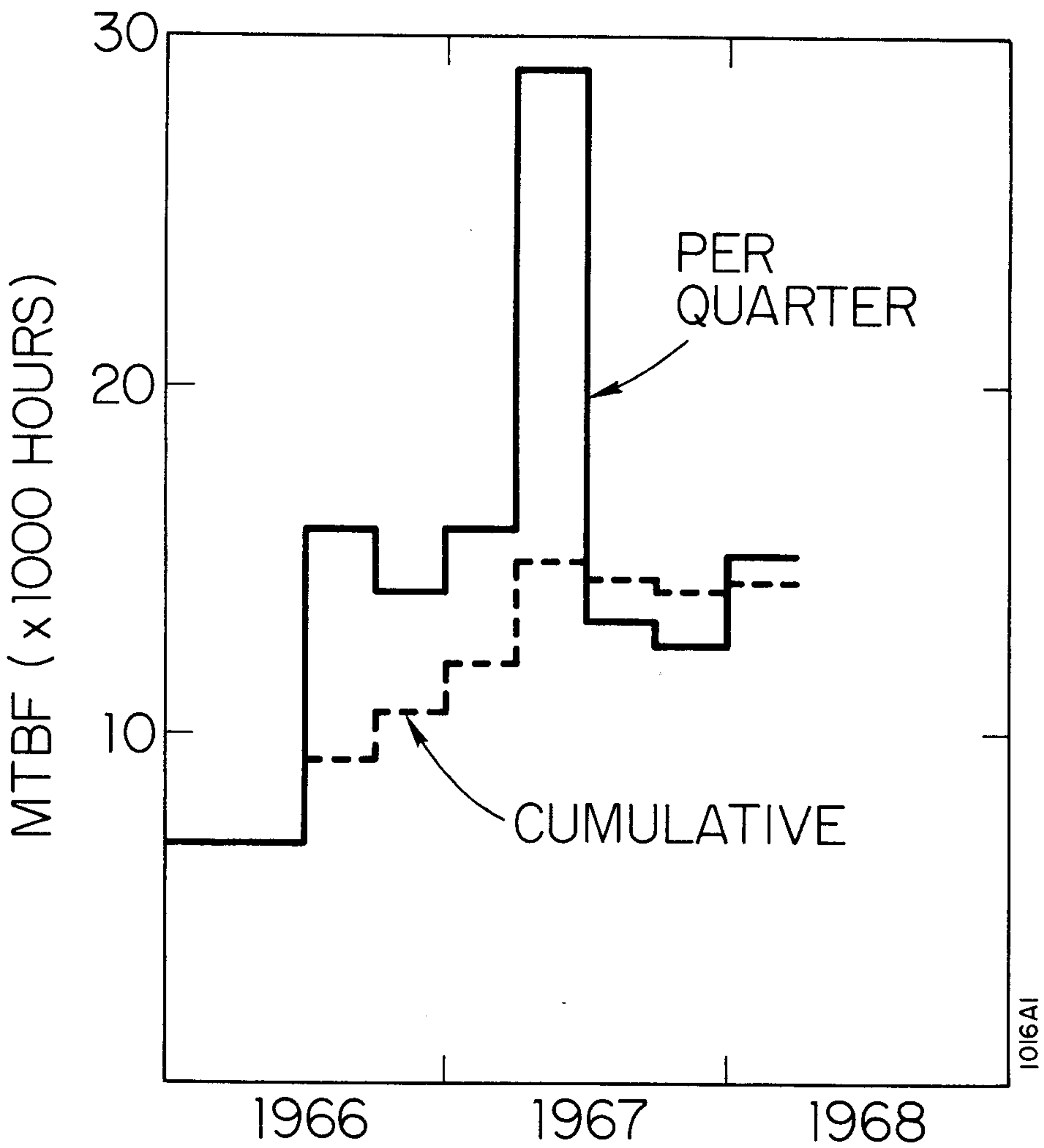

FIG. 4--Mean time between failures, excluding Sperry tubes

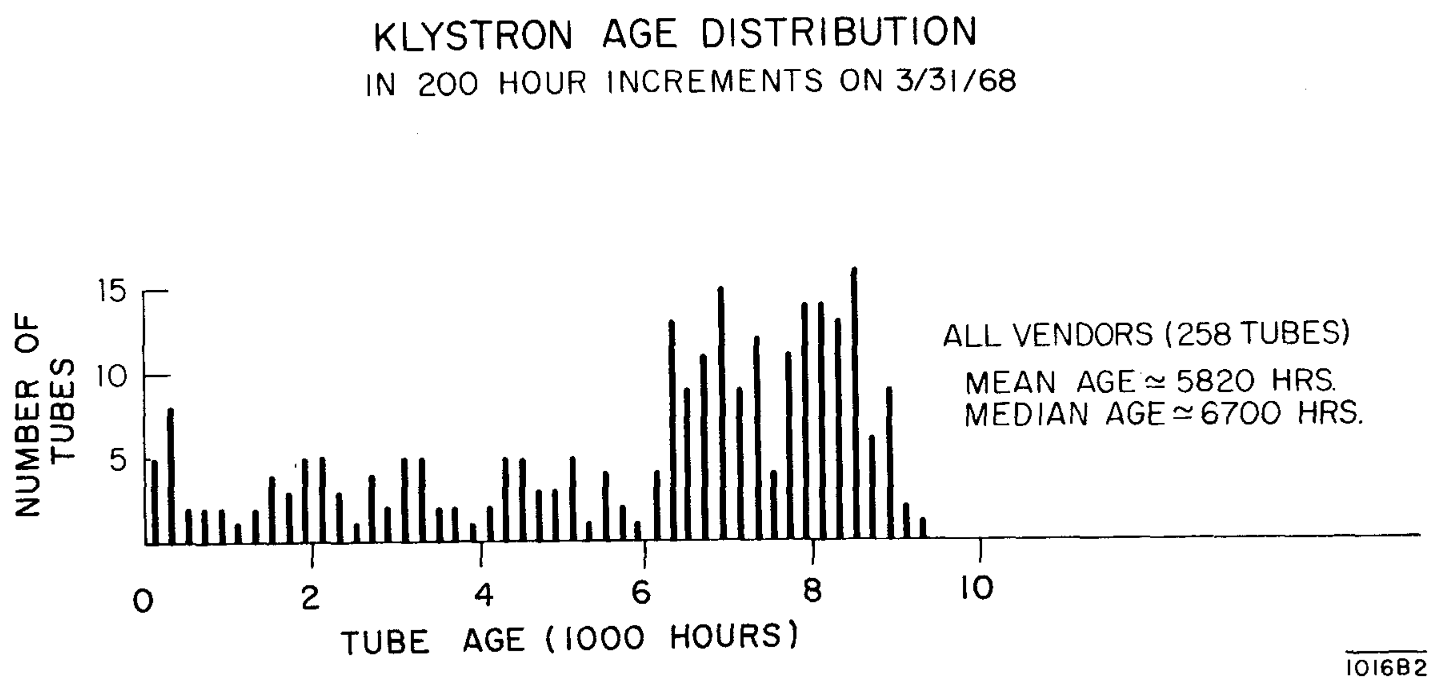

FIG. 5--Klystron age distribution in 200-hour increments on March 31, 1968

The problem of predicting probable tube life was investigated by Matt Sands (see TN-68-2), and the method he suggested has been used in determining the failure rates based on all evidence available at the end of the quarter. The results are shown in Fig. 6 and 7, giving the failure probability in percent per 1000 hours of operation and the survival ratio in percent as a function of tube age. It can be seen that the failure probability is nearly constant at approximately 5 percent per 1000 hours except for early failures which increase the failure probability during the first 1000 hours of operation. There is as yet no indication of a higher rate for older tubes. Based on the evidence to date, it appears possible that MTBF of all tubes now installed in the machine may be close to 15, 000 hours provided that no new failure mechanism of real wear out, such as cathode attrition, shows up before that time. Note that this number is close to the MTBF experienced over the last few quarters.

a. Causes of Failure. Table 6-2 gives the percentage of all failures by different causes for the three vendors. In all cases it is noticeable that the failures by cathode emission problems are only a very small percentage of failures observed. Hence, it is probable that we have as yet not experienced a real wear-out failure mechanism. This checks with the indication of 5 percent failure per 1000 hours of operation.

Table 6-2 - Percentages of Klystron Failures

	Percentages		
Causes of Failure	RCA	Litton	SLAC
Windows	65	18	22
HV Seal	5	5	5
Vacuum	23	18	22
Overcurrents	3	40	32
RF Output	0	12	0
Low Emission	3	7	14
Others	1	0	5
	100	100	100

The major cause of failure for RCA tubes is windows. The major cause of failures in Litton tubes is overcurrent (arcing, variations in perveance, "burning").

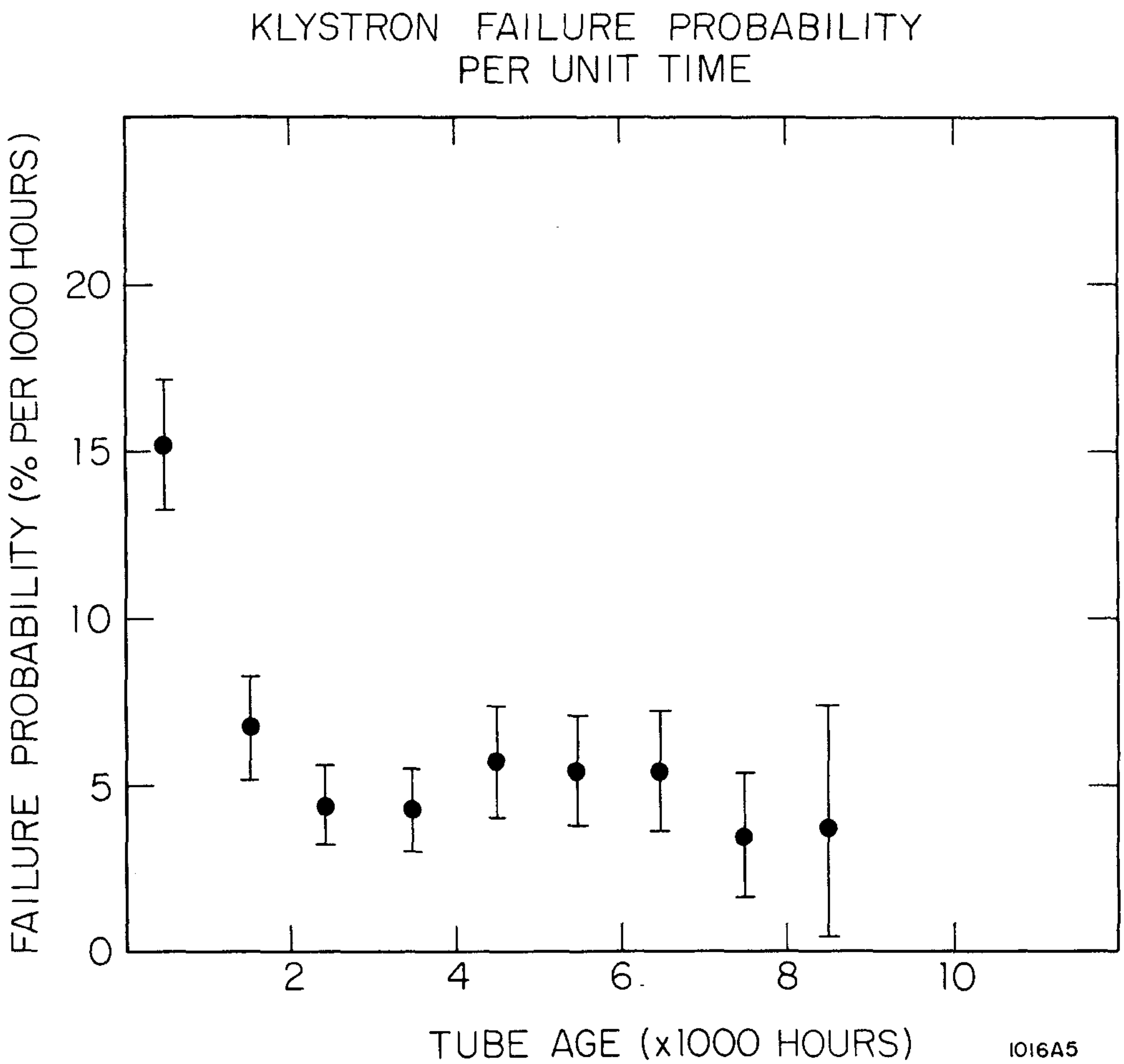

FIG. 6--Klystron failure probability per unit time

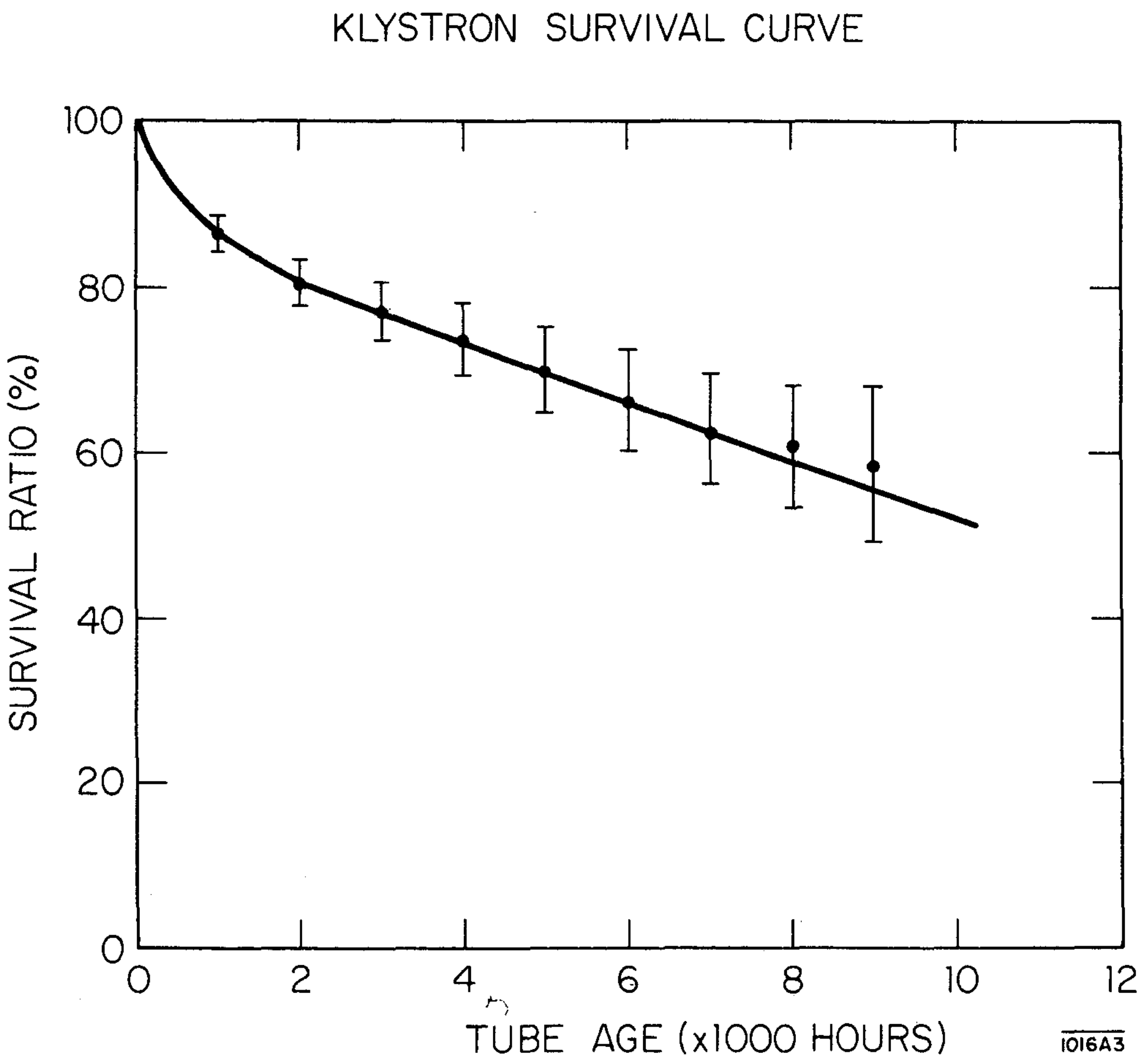

FIG. 7--Klystron survival curve

SLAC failures are more evenly divided between windows, overcurrents and miscellaneous. The ratio of causes of failures are substantially the same for the quarter as overall.

There were 5 RCA window failures during the quarter, 3 by dielectric failure and 2 by thermal failure. In the case of Litton, one tube was removed from the gallery because the window temperature was increasing during operation with a very high likelihood of eminent window failure.

Two SLAC windows processed in 1965 also failed in the gallery due to thermal cracking. In one case, the window produced gas bursts which were limiting operation.

There have also been 2 minute leaks in the ceramic discovered during rework of tubes which had failed for other reasons. In another case, a similar leak caused the shelf life failures of a SLAC tube.

b. Effect of Operating Levels. Accelerator operation has continued until early March with three beam voltage operating levels of 215 kV, 235 kV; 245 kV. In March, the majority of sectors which had been maintained at 215 kV were raised to 235 kV. During the quarter the MTBF's were substantially the same in sectors running at 235 to 245 kV (between 13,000 and 13,500 hours), and approximately half of the MTBF of sectors which ran at 215 kV (about 29,000 hours). However a decision was made to increase the operating level of all sectors to 235 kV in spite of the apparent difference in failure rate, since it is felt that the additional energy obtainable, or the additional number of spares available, by operating at least six sectors at higher power warrants the potential slight additional cost in klystron replacements.

3. High Power Klystron Performance

It appears desirable after nealy two years of operation, to analyze the performance of the klystron as measured in the gallery. Figure 8 gives the average value of beam voltage and peak power output per sector as measured during the quarter. On the average, there are between 4 and 6 measurements per sector per quarter, and the average values for each sector are obtained by computer.

The first obvious feature of the curve is the change in beam voltage and power output which occurred in sectors 7 through 12 during the quarter. This is the result of a decision to increase the reference voltage in those sectors from 100 to 110 V. In general, it appears that the beam voltage per sector is fairly constant. For instance, the largest deviation for sectors operating at the same nominal reference voltage is 9 kV, or less than 4 percent. Since there is uncertainty in settings of the reference

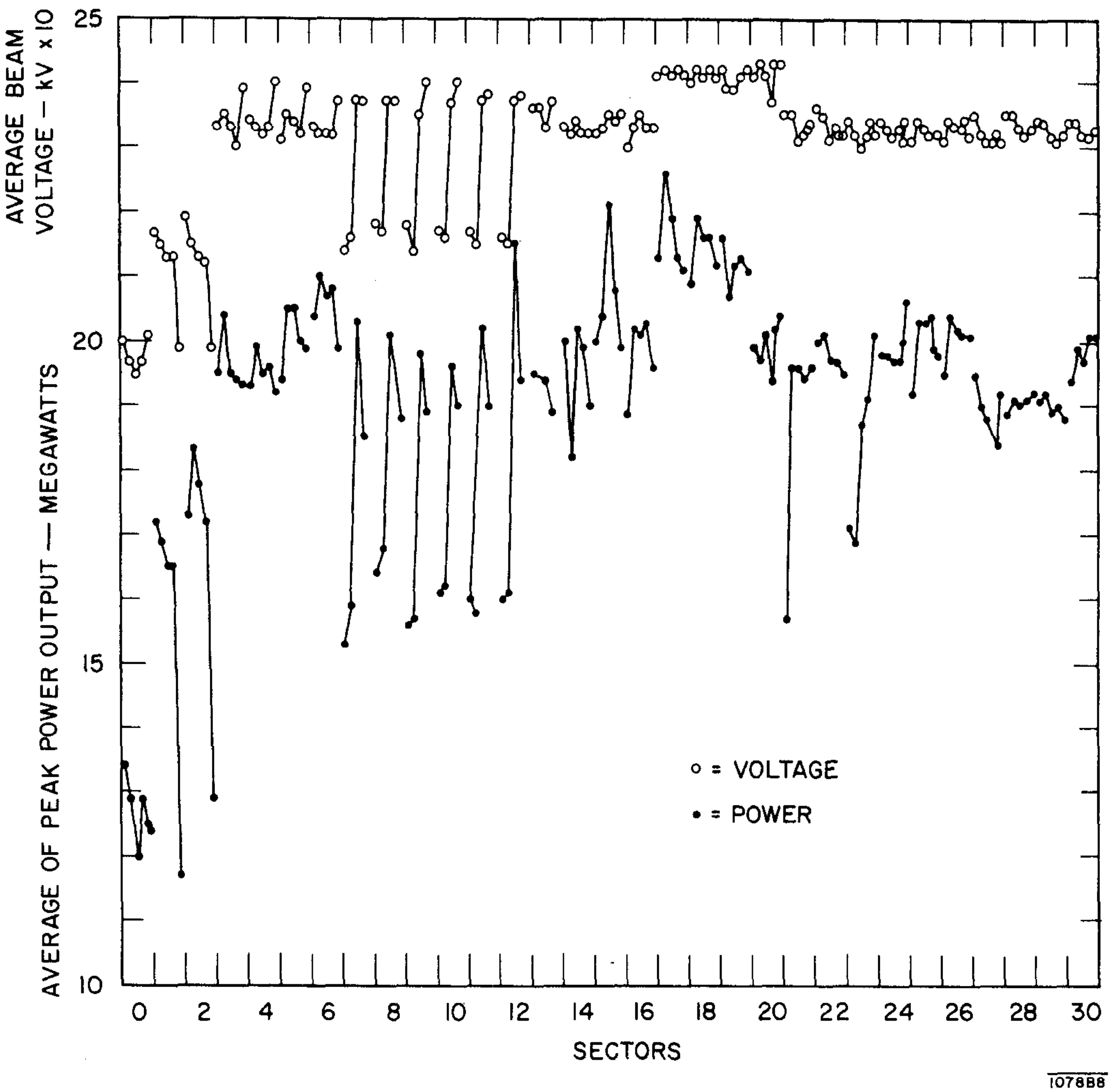

FIG. 8--Variation during quarter of beam voltage and peak power output per sector

voltage and the usual potential errors in beam voltage readings, one can see that the beam voltages have held very constant during the quarter.

However, the measured variations in power output for a given sector appear to be considerably higher than the measured variations in beam voltage. In fact, even discounting a few low points (sectors 20 and 22), we still find a variation of approximately 10 percent in many sectors. In addition, there seems to be quite a difference in the average power of different sectors operating at the same voltage level. For instance, the average power in sector 15 is in excess of 20 MW at a beam voltage of approximately 233 kV, whereas the average power of sector 28 and 29 is 19 MW at the same beam voltage.

Similarly, sector 20 has an indicated average power of approximately 20 MW at a beam voltage of approximately 242 kV.

There is, of course, a possibility that the measured power output from the tubes in those sectors is statistically different from the average. However, an analysis of such power output indicates that the difference at either 200 or 250 kV is approximately $\pm$ 2 percent from the mean of all tubes installed in the machine. Hence, there may be some statistical variation in the directional couplers used to measure the klystron power in the gallery.

The same data has also been plotted (figs. 9 through 12), to indicate the average of the measured power output versus the average beam voltage per sector during arbitrary intervals during the quarter. On the same figures, the dashed line joining the two circled points give the average of the calorimetric measurements taken in the Test Lab of all the tubes installed in the gallery on February 1 and March 1. Since the difference between these two averages of the Test Lab measurements is much less than 1 percent, it is safe to assume that there was, during the quarter, little variation in the real average power output per tube at a given beam voltage as a function of time.

The interesting thing to note from the curves in Figs. 9 through 12 is the apparent difference between gallery and Test Lab readings. It would seem that on the average the power output as indicated in the gallery by directional coupler is higher than that measured calorimetrically in the Test Lab. It also appears that this difference varies as a function of time, and readings taken in March in the gallery average very closely to the expected readings from the Test Lab measurements. Whether there is any significance in these possible variations is not known at this time, but will be investigated further.

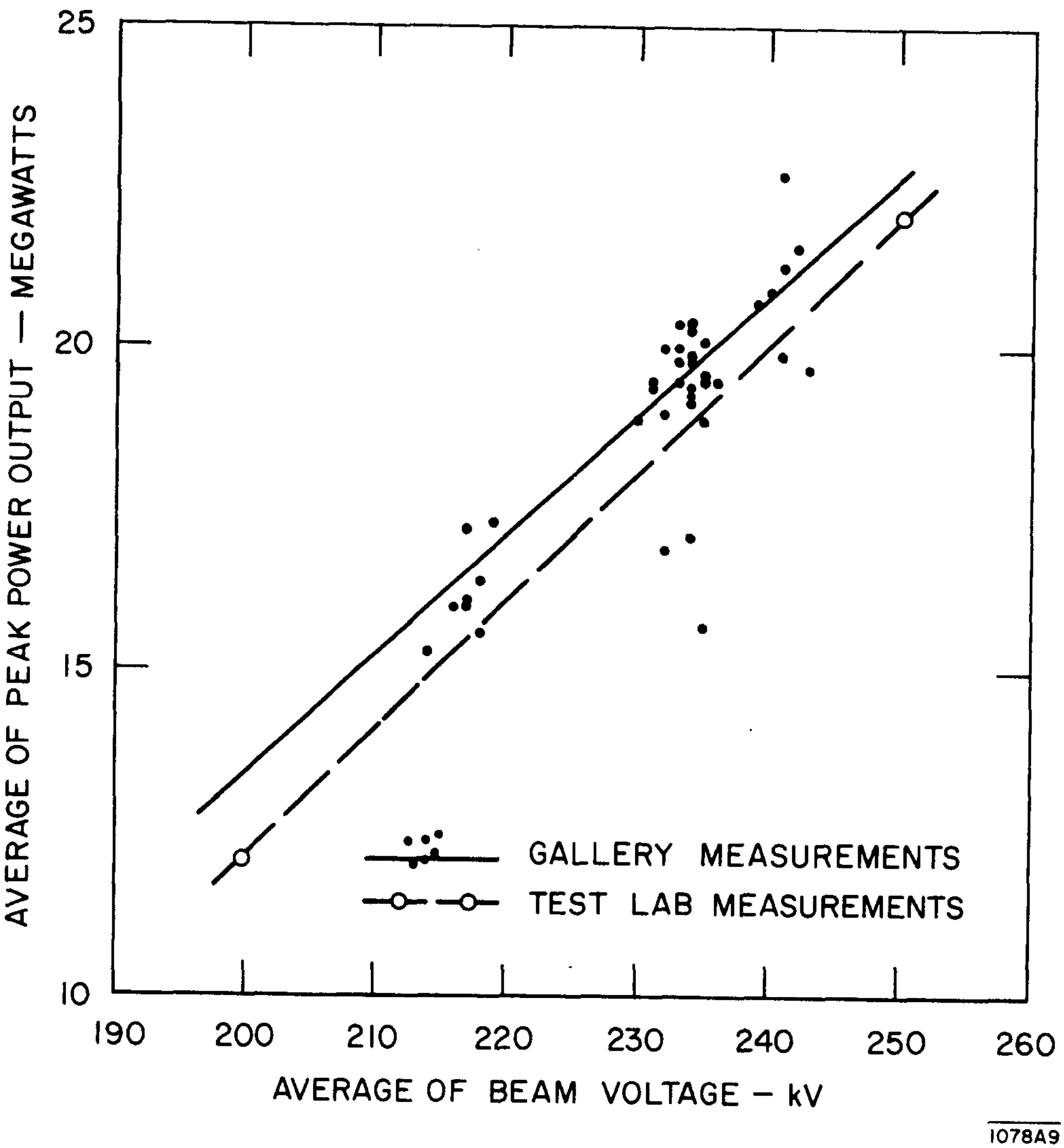

FIG. 9--Measured power output and beam voltage per sector, January 1-19, 1968

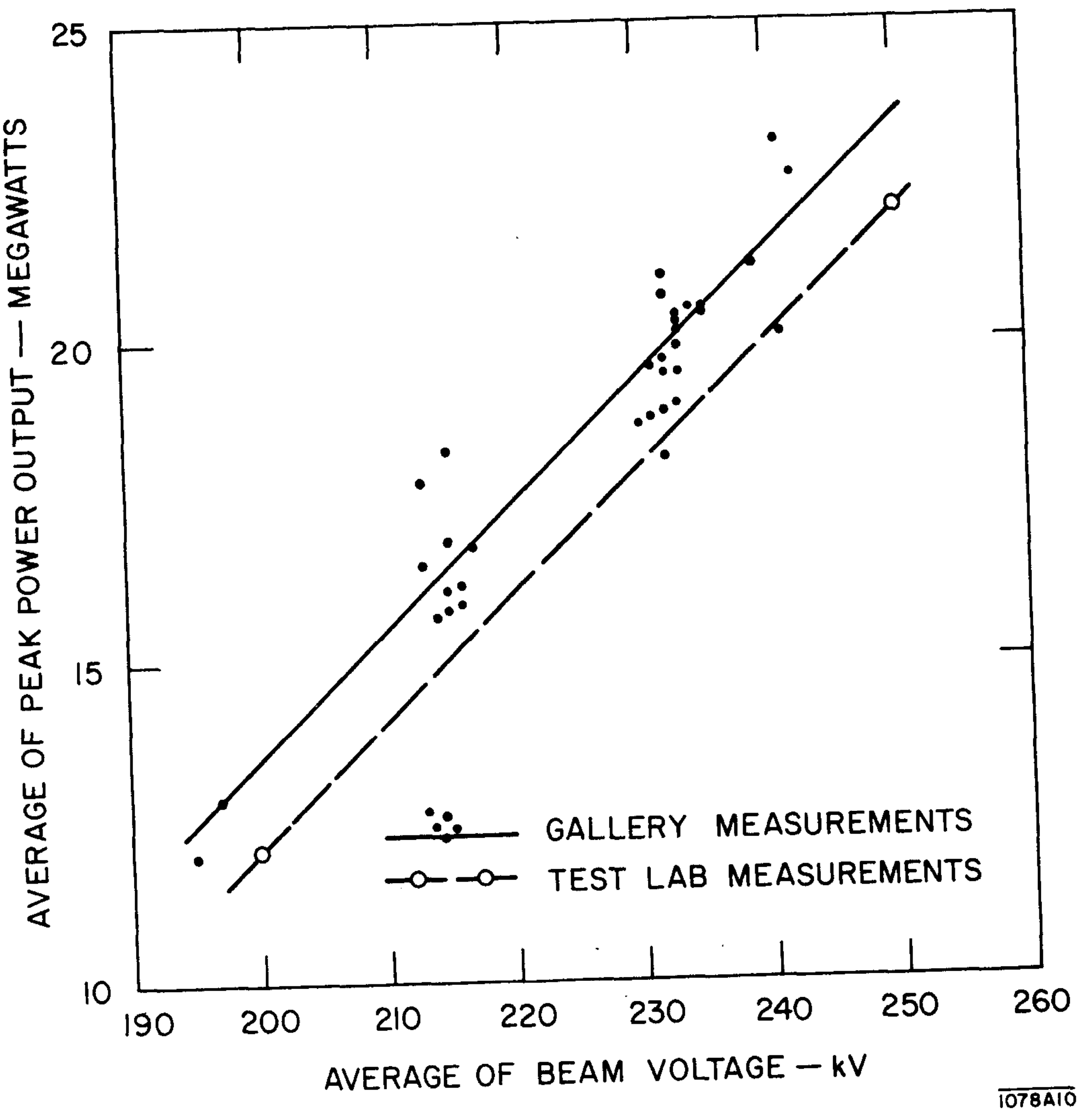

FIG. 10--Measured power output and beam voltage per sector, January 29 - February 9, 1968

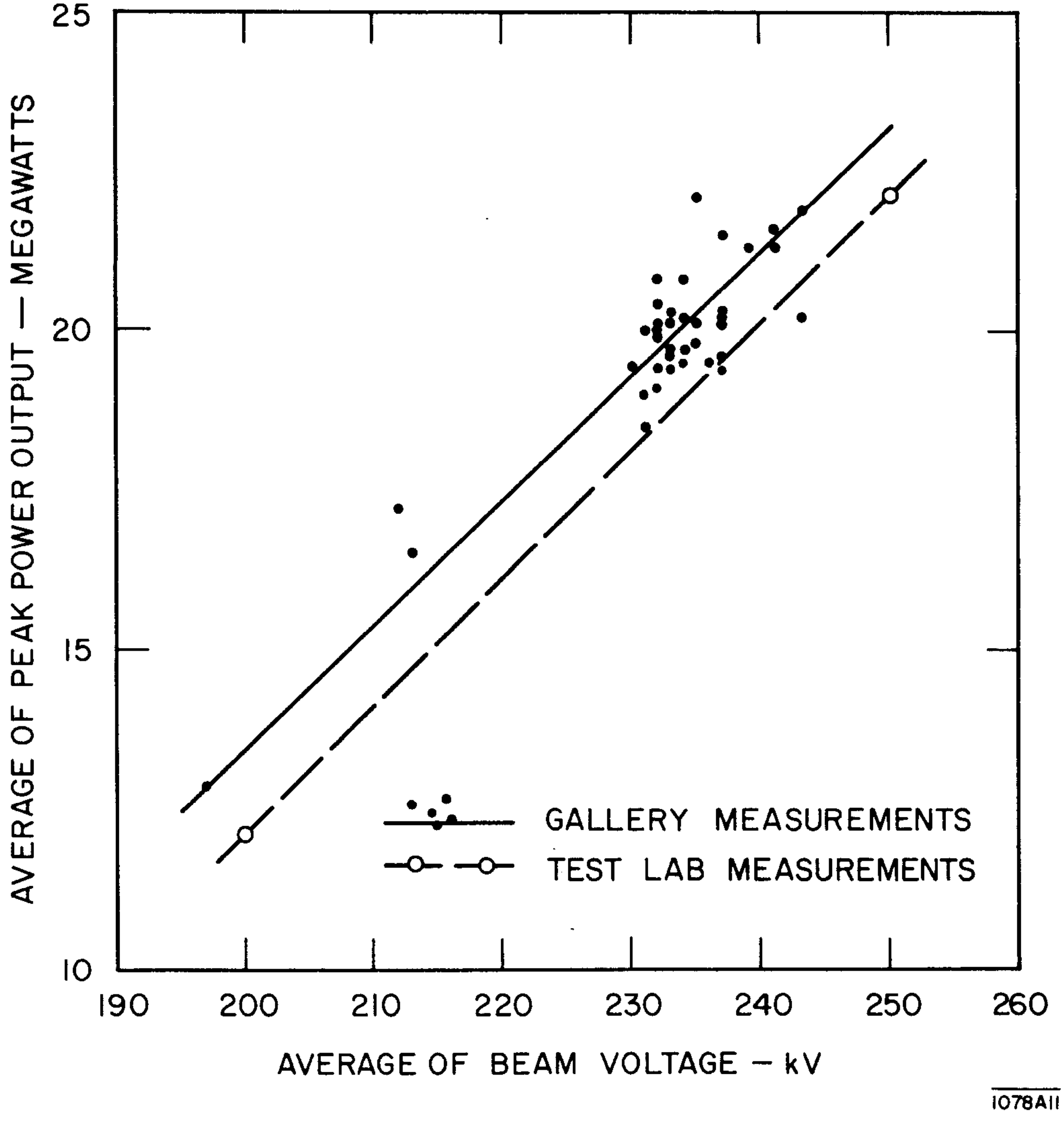

FIG. 11--Measured power output and beam voltage per sector, February 19 - March 8, 1968

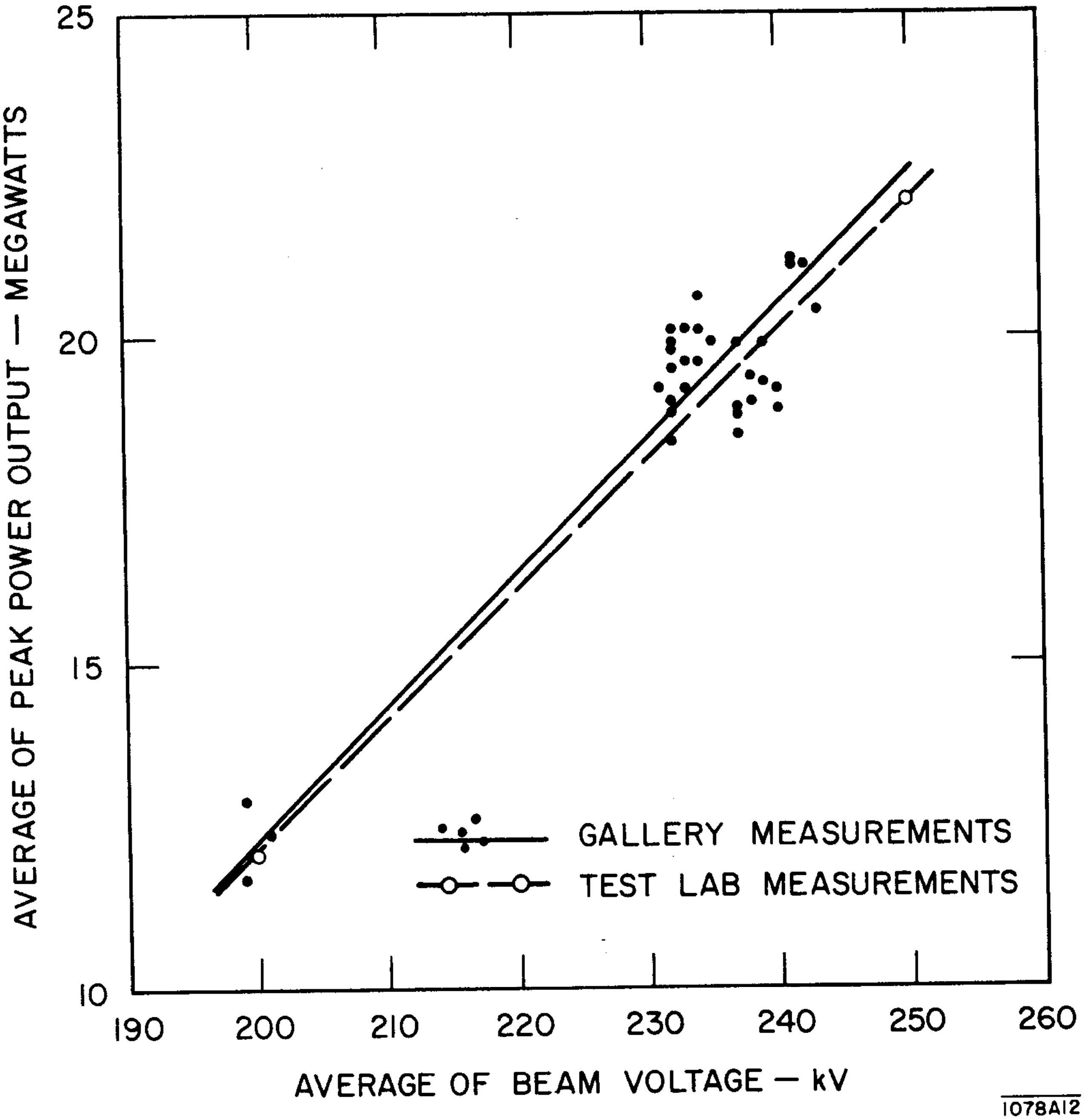

FIG. 12--Measured power output and beam voltage per sector, March 11-29, 1968

4. High Power Klystron Maintenance

There were approximately 400 trouble reports concerning klystron operation during the quarter, for a mean time between trouble reports of 800 hours. This number corresponds to a significant improvement in the previous quarters, which averaged approximately 500 hours between trouble reports.

It is interesting to note that the number of trouble reports per socket average 1.6, but vary from 1.25 for RCA, 1.55 for SLAC, and 2.2 for Litton. The high number of trouble reports for Litton is undoubtedly caused by the experience of back-swing breakup, perveance shifts and similar cathode troubles which have plagued Litton tubes in the last few months. It is also interesting to note that the number of trouble reports per socket are highest in the sectors operating at 245 kV (2.5), slightly less than 1 per socket in the sectors operating at 215 kV. The trend of trouble reports per vendor is very similar to that observed during the previous quarter where Litton also experienced the highest ratio of trouble reports per socket and RCA the lowest.

Preventive maintenance is continuing on a regular schedule and we are approaching the goal of one check for every 500 hours of operation. The routine maintenance, in conjunction with the (hopefully) weekly data provided by Accelerator Operations on each station, remains the prime source of locating problem tubes and problem areas in the machine. The correction of such problems, such as temperature limited cathodes, beam inverse conduction, variations in perveance, etc., appear to be helpful in maintaining satisfactory klystron operation in the gallery.

In addition, we have lately instituted a routine check of window temperatures during operation at the time of preventive maintenance. In this fashion, it has been possible to predict that a window is likely to give troubles and by removing the tube and recoating the window in the Test Lab to increase the total length of tube operation.

During the quarter we completed installation and began using a facility to strip the cadmium plating from permanent magnets. It appears that the plating is not as stable as had been anticipated by the magnet vendors. There has been evidence of plating falling off either in powder form or in small flakes, and causing damage to the pulse transformer tank components. The facility consists of four tanks which handle the stripping solution (Enstrip A) and trichloroethylene, water and alcohol rinses. So far, two magnets have been successfully stripped. One was demagnetized, the other was magnetized. In both cases, the bucking magnet assembly had to be removed since it contained some phosphor-bronze springs easily attacked by the stripping solution. In one case, the lower lead X-ray shielding was not removed during the process. Initial results seem to indicate that magnets can be handled easily without being demagnetized, and that it is not necessary to remove the lead shielding. Total time for the process before a magnet can be placed back in use will be about three working days. The actual time in the stripping bath appears to be about 12 hours, however this is quite dependent on the ambient temperature.

5. Driver Amplifier Klystrons

The total number of trouble reports and tube replacements increased during the quarter from previous experience. Although the official number of failures is eight for the quarter, it is probable that tubes still in retest will be found to be outside of specifications. The failures are divided as follows: 2 Eimac tubes (average age 5600 hours), 1 SLAC tube (170 hours), and 5 Litton tubes (average age 400 hours). The Eimac failures were of the usual type--pulse droop and phase stability presumably caused by tube gassiness. The Litton failures were caused by either temperature limited operation or open filaments. The SLAC tube failed because of excessive droop caused by gassiness.

Figure 13 gives the mean age at failure, number of failures, and mean hours of operation per tube per quarter since the beginning of driver amplifier klystron tests. The drop in the mean age at failure exhibited during the past few quarters has been caused more by the infantile mortality of the new type tubes (Litton and SLAC) than by a real change in the experience with the Eimac tubes. This is evidenced by Fig. 14 which shows the tube age distribution in 1000 hour increments for all driver amplifier klystrons installed in the gallery and the Test Lab at the end of the quarter. Obviously, all tubes with more than 3000 hours of operation are Eimac tubes since we did not begin installation of Litton tubes until June 1967 and SLAC tubes until January 1968. At any rate, the mean age of all driver amplifier klystrons in operation is in excess of 7500 hours and the median age is approximately 8750 hours.

6. Main Booster Klystrons

One main booster was replaced during the quarter because of low gain and signs of instability. The tube had been operated for some time with improper focusing resulting in erosion of the input cavity gap, The low gain was obviously caused by the detuning of the input cavity; the causes of instability are not fully understood.

A modified carriage assembly was completed during the quarter which features non-flattening wheels and arc detectors in the cavities of the tube. The new tube

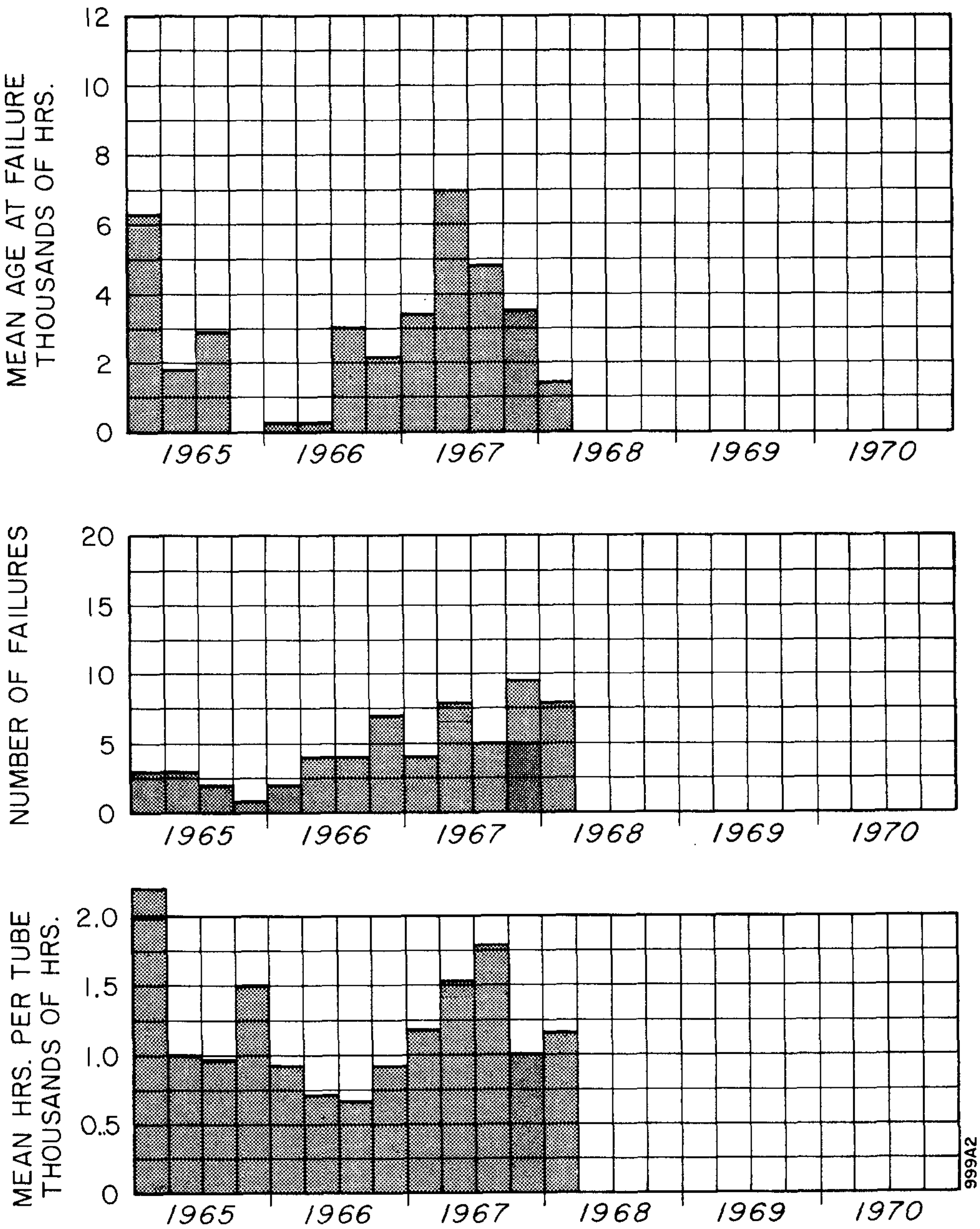

FIG. 13--Sub-booster klystron operating experience

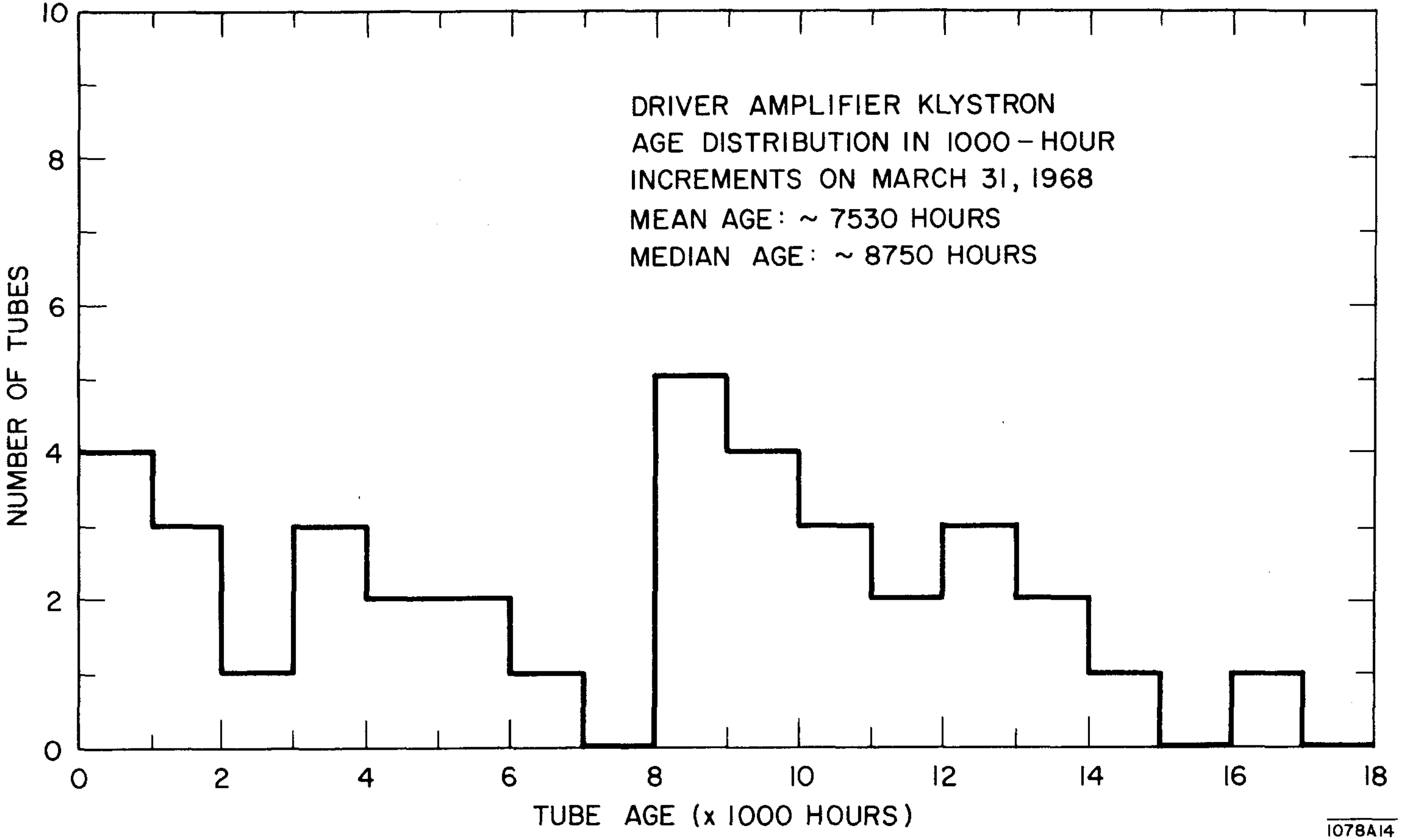

FIG. 14--Driver amplifier klystron age distribution

installed in that assembly appears to be operating satisfactorily. Unfortunately, the protection circuit making use of the arc detectors had not been put into operation.

7. Vacuum System

No major changes have occurred in the vacuum system with the pressure of the sectors continuing to improve. The ion pump readings average approximately 1×10^{-8} Torr with rf, and about 5×10^{-9} Torr without rf.

The gas burst problems continued to occur in the ion pumps located at stations 7-1, 8-1, 10-1, 12-1, 14-1 and 15-1. It has been observed that the gas bursts almost always take place in the first pump of a sector where the pressure increases going from the first to the eighth station along the sector. That is, the gas burst takes place at the pump with the best pressure in the system. One possible explanation for this phenomenon is the effective differential pumping which occurs between the pumps if a small air leak is located at the end of a sector. Typically, the conductance of a manifold between pumps is approximately 7 to 8 percent of the individual pump pumping speed for nitrogen. However, the pump pumping speed for argon is only a few percent of the pumping speed for nitrogen. Hence, at the leak the partial pressure of argon in the system is substantially the same as that found in air, or 1 percent. However, because of the effective differential pumping of the system, the partial pressure of argon at the pump farthest away from the leak is probably at least 10 percent of the partial pressure of nitrogen in that portion of the system.

It appears from evidence available in the literature that the total time needed to detect argon instability at a given pressure and pumping speed is a direct function of the partial pressure of argon in the total volume pumped. Hence, it appears plausible that the pump which shows in general the best total pressure is, in fact, the one which first shows argon instability because the partial pressure of argon is higher than that pumped in the pumps showing the highest pressure.

The obvious solution to the gas bursting problem would be to eliminate all leaks from the system, and much time has been spent in finding as many of the minute leaks as possible. Leaks have been found and corrected in sectors 1, 3, 12 and 14, but leaks in the other sectors, if any, have not yet been located.

As a temporary solution to the gas burst problems the operating pump voltage was raised from 5 to 7 kV. Pump voltage was reduced to 5 kV after three weeks in sector 7 and two bursts were observed almost immediately. However, no additional bursts were observed at that station. Conversely, the pump at 14-1 has had two bursts at 7 kV. Hence, this solution of raised voltages is at best a temporary solution. We believe the final solution will be replacement of either the whole pump or some of the pump elements by differential sputter-yield pumping elements which have been procured. Tests on this type of element will be made prior to installation.

In addition to the gas burst problems and the usual letups for modifications of hardware in the accelerator, there were only minor vacuum problems during the quarter. A 3-inch valve bellows developed a leak, the ion pump at 11-1 was changed due to excessive internal arcing, and the fast valve in sector 30 (FV-1) closed accidentally during a remelt cycle necessitating an addition of indium to the valve and clean up of the vacuum system in the immediate vicinity.

VII. PLANT ENGINEERING

During this quarter the following construction projects were completed: The permanent SLAC Fire Station (beneficial occupancy in January 1968); relocation of the magnet alignment facility in the Heavy Assembly Building; erection of annihilation beam equipment shelters in the target area.

Other projects are in various stages of progress. Engineering is underway on: Phase II of an expansion of the utilities for the Temporary Computer Facility (the electrical substation is on order); additional laboratory space in the Test Laboratory; additional chiller capacity for the ventilation system in the Central Control Building; a sandblasting Facility for the craft program. Construction continued on several projects, percentage of completion being as shown: extension of the End Station "A" Counting House (19 percent); installation of chilled water main to the Central Laboratory Addition (50 percent); and the extension of mezzanine office space in the Electronics Building (40 percent). A contract was awarded on March 1, 1968 for the addition of approximately 2,000 square feet of building space to the Temporary Computer Building.

Construction of SLAC's two major building projects continued throughout the quarter. The Central Laboratory Addition is 35 percent complete and the General Services Building is 22 percent complete.

A number of service projects for the Research Area Department are in progress and the field work is well along. Of principal interest are the following: installation and housing of two large motor-generator sets; relocation of the 3.4 megawatt power supplies; design and installation of two 2,000 KVA substations; and the provision of power for the B-beam switching magnets.