PROJECT WHIRLWIND
(Device 24-x-3)

SUMMARY REPORT NO. 12

SEPTEMBER
1948

Submitted to the

OFFICE OF NAVAL RESEARCH
Under Contract N5ori60
Project NR-720-003

SERVOMECHANISMS LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Cambridge 39, Massachusetts
Project DIC 6345

TABLE OF CONTENTS

FOREWORD

Project Whirlwind

Project Whirlwind at the Massachusetts Institute of Technology Servomechanisms Laboratory is sponsored by the Special Devices Center of the Office of Naval Research under contract N5ori60. The original objective of the Project was the development of a device that would simulate airplanes in flight. An integral part of such a simulator is a digital computer of large storage capacity and very high speed, to provide continuous solutions to the equations of motion of an airplane.

As Project Whirlwind has evolved, applications to other types of simulation and to control have become important. Because the digital computer is basic to all these as well as to important applications in mathematics, science, engineering, and military problems including logistics and guided missiles, nearly all project resources are at present devoted to design of a suitable computer.

The Whirlwind Computers

The Whirlwind computers will be of the high-speed electronic digital type, in which quantities are represented as discrete numbers, and complex problems are solved by the repeated use of fundamental arithmetic and logical (i.e., control or selection) operations. Computations are executed by fractional-microsecond pulses in electronic circuits, of which the principal ones are (1) the flip-flop, a circuit containing two vacuum tubes so connected that one tube or the other is conducting, but not both; (2) the gate or coincidence circuit; (3) the electrostatic storage tube, which uses an electron beam for storing digits as positive or negative charges on a storage surface.

Whirlwind I (WWI), now being developed, may be regarded as a prototype from which other computers will be evolved. It will be useful both for a study of circuit techniques and for the study of digital computer applications and problems.

Whirlwind I will use numbers of 16 binary digits (equivalent to about 5 decimal digits). This length was selected to limit the machine to a practical size, but it will permit the computation of many simulation problems. Calculations requiring greater number length will be handled by the use of multiple-length numbers. Five special orders expedite the subprogramming of multiple-length operations, so that coding is no more complicated than for single-length numbers, but computing time is substantially increased. Rapid-access electrostatic storage will have a capacity of 32,000 binary digits, sufficient for large classes of actual problems and for preliminary investigations in most fields of interest. The goal of 20,000 multiplications per second is higher than general scientific computation demands at the present state of the art, but is needed for control and simulation studies.

Reports

Summary Report No. 2, issued in November, 1947, was a collection of all information on the Whirlwind program up to that time. The present series of monthly reports is a continuation of the Summary Report series, designed to maintain a supply of up-to-date information on the status of the Project.

Detailed information on technical aspects of the Whirlwind program may be found in the R-, E-, and M-series reports and memorandums that are issued to cover the work as it progresses. Of these, the R-series are the most formal, the M-series the least. A list of publications issued during the period covered by this Summary appears at the end as an appendix. Authorized personnel may obtain copies of any of them by addressing a request to The Special Devices Center, Office of Naval Research, Port Washington, Long Island, New York; or where approval has previously been arranged, to Jay W. Forrester, Project Whirlwind, Servomechanisms Laboratory, Massachusetts Institute of Technology, Cambridge, Mass.

GENERAL STATUS

Installation of racks to support WWI electronic panels was well along by the end of September. One of the two synchronous alternator-generators and the 150-volt phase-controlled rectifier were installed in the power supply room.

The temporary staff members added to the mathematics group have terminated their summer work. Reports of their studies on the following subjects are being prepared: the two-register coding method (see Summary Report No. 10), the solution of integral equations by numerical methods, and a code for the solution of simultaneous equations by elimination.

The five-digit multiplier (see Summary Report No. 3) has served its purpose in establishing the performance of the present circuits in interconnected systems. It is now being converted to incorporate marginal checking circuits similar to those in WWI (see Summary Report No. 6). After this change, a reliability run of several months duration will begin. By periodic inspections with the new circuits the prediction of approaching failures will be attempted. A high-speed checking circuit will detect and record both transient and steady-state errors.

The fifth five-inch storage tube for study purposes was completed during September. Some difficulty has occurred with breakdown and failure of the aluminum oxide dielectric in these tubes. During the next months, experimental trials of mica and glass insulation will be made.

INDOCTRINATION PROGRAM FOR NEW STAFF MEMBERS

The high-speed electronic computer is such a specialized subject that new staff members, even those with several years of experience in related fields of electronics, have often lacked sufficient background information to carry on their research work with maximum effectiveness. Until recently, most new staff members have spent their first several days on the Project in the library reading reports on various phases of the activity.

With the accession of several new research assistants this fall, a planned indoctrination program has been inaugurated. The new men, as a group, are first given a general introductory lecture, then assigned a few hours reading in a carefully prepared list of reports and publications. A discussion period led by one of the senior members of the staff provides for digestion of this material. Then follow alternating sessions of reading and discussion on the various phases of the Project for a period of approximately two weeks, each discussion being led by a specialist in that field. A conducted tour of the laboratories occupies part of one day.

This program not only imparts general and specific information about computers, but also serves to acquaint the new men with the leaders of the various activities of the Project. Although still in the formative stage, this course has made a favorable impression on the first men to take it, and promises to make an important contribution to the effectiveness of the Project.

VISITORS

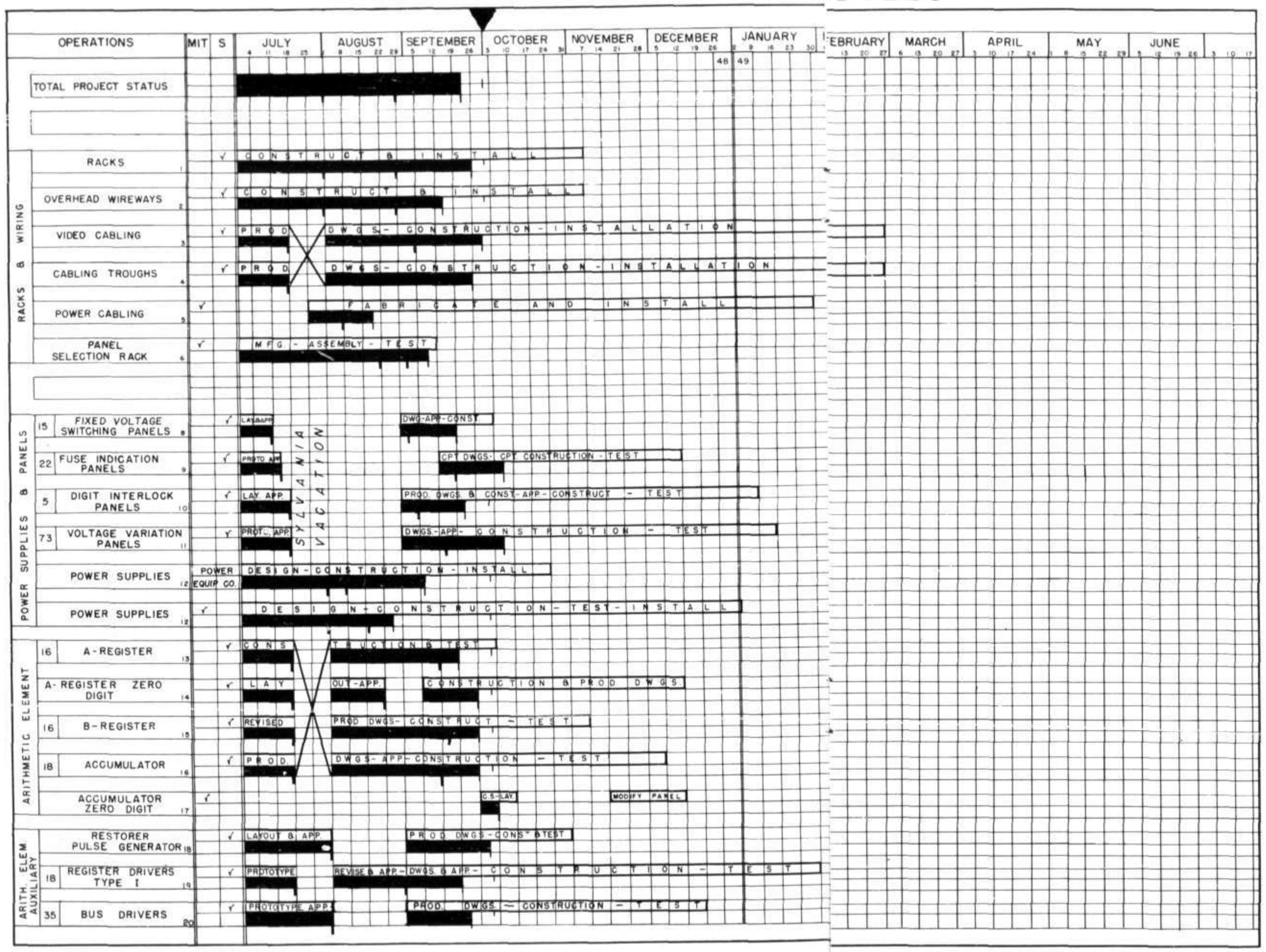
During September the Laboratory had among its visitors the following:

Lt. Comdr. David M. Rubel (USN), of the Panel on Computing Devices of the Research and Development Board, who spent a day and a half at the Laboratory inspecting our facilities and learning about our program.

Prof. Paul L. Morton, in charge of the ONR computer project at the University of California at Berkeley.

R. G. Canning of International Business Machines Corporation, who discussed vacuum tube failures which occur in digital computer circuits.

SUMMARY - WHIRLWIND I SCHEDULES



LEGEND

JULY

Period of one month, comprising the total number of days in the month.

PROTOTYPE

Operation to be performed, and estimated time allotted for its completion. Estimates made in July 1948.

Work done. The ratio of the length of the solid bar to the length of the open bar above it shows percentage of completion at the end of the month.

Date of latest posting.

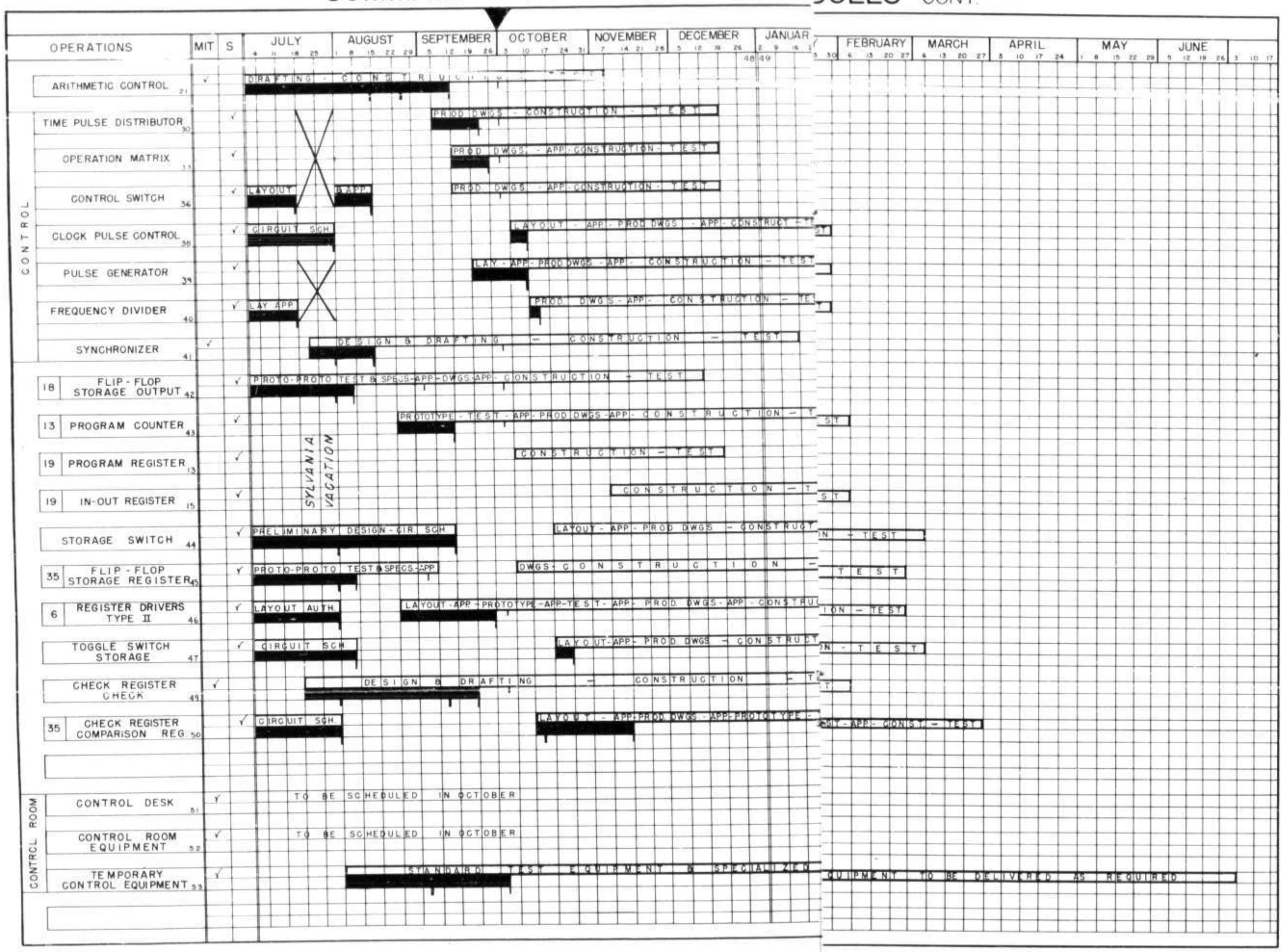
Summary line. Shows overall status of the project.

MIT	S
	✓

Column showing whether M.I.T. or Sylvania will do major portion of the job.

For a long-range plan from 1944 to 1952 showing the relation of this detailed schedule to past and future work, see Summary Report No. 11, August 1948.

SUMMARY – WHIRLWIND I SCHEDULES CONT.



LEGEND

JULY

Period of one month, comprising the total number of days in the month.

PROTOTYPE

Operation to be performed, and estimated time allotted for its completion. Estimates made in July 1948.

Work done. The ratio of the length of the solid bar to the length of the open bar above it shows percentage of completion at the end of the month.

Date of latest posting.

Summary line. Shows overall status of the project.

MIT | S

Column showing whether M.I.T. or Sylvania will do major portion of the job.

For a long-range plan from 1944 to 1952 showing the relation of this detailed schedule to past and future work, see Summary Report No. 11, August 1948.

SUMMARY - WHIRLWIND I SCHEDULES -CONT.

	OPERATIONS	MIT	S	JULY – JUNE (1948–49)
INPUT-OUTPUT	FILM READER - RECORDER 54	EASTMAN KODAK		COMPLETE BREADBOARD TEST - FINAL DESIGN — CONSTRUCTION — ASSEMBLY - TEST & DEL. 2 UNITS - ASSEMBLY — TEST - DELIVERY 4 UNITS
INPUT-OUTPUT	INPUT-OUTPUT CONTROL 55	✓		BLOCK DIAGRAM — DESIGN & CONSTRUCTION
INPUT-OUTPUT	KEYBOARD & PRINTING CONTROL 56	✓		BLOCK DIAGRAM — DESIGN & CONSTRUCTION
	TEST EQUIPMENT 57	✓		CONSTRUCTION OF TEST EQUIPMENT AS REQUIRED
	TROUBLE LOCATION METHODS 58	✓		FURTHER STUDY OF BASIC METHODS — APPLICATION OF METHODS TO ARITH. ELEM. / APPLICATION TO CENTRAL CONT.
	AIR CONDITIONING 59	CARRIER CORP.		ERECT HOUSE / INSTALL EQUIP
	PREPARATION OF COMPUTER ROOM 60	✓		PAINTING & RADIATOR REMOVAL
	OUTPUT CIRCUITS 62	✓		SPECIFICATIONS FOR WWI / DESIGN — PROTOTYPE — CONSTRUCTION
	DEFLECTION CIRCUITS 63	✓		COMPLETE TEST OF PROTOTYPE — FINAL DESIGN AND TEST — CONSTRUCTION / INSTALL
	CONTROL CIRCUITS 64	✓		PRELIM. BLOCK DIAGRAM / FINAL BLOCK DIAGRAM — DESIGN AND CONSTRUCTION
STORAGE TUBE	5 INCH TUBES 65	✓		2 TUBES EACH OF BE MOSAIC & CAL, TUNG. FOR 8X8 ARRAY + 2 TUBES OF BE MOSAIC FOR 16X16 ARRAY
STORAGE TUBE	EXPAND VACUUM LABORATORY FACILITIES 66 67	✓		RECORDING INSTRUMENTS - HIGH SPEED EXHAUST SYSTEM - AUTO. PROCESSING CONTROL
STORAGE TUBE	EXPAND TEST LABORATORY FACILITIES 68	✓		TV UNIT - AUTO. READ - WRITE - OUTPUT CIRCUITS - LIFE & RELIABILITY
STORAGE TUBE	STORAGE PHENOMENA RESEARCH 69	✓		BE MOSAIC STABILITY - CAL. TUNG. STABILITY
STORAGE TUBE	STABILITY RESEARCH TUBES & STUDIES 70	✓		BE STRIP TUBES - CONCENTRIC RING TUBES - HOLDING BEAM VELOCITY DISTRIBUTION
STORAGE TUBE	ELECTROSTATIC GUNS 71	✓		MISC. GUN STUDIES & DESIGN AS REQ.
STORAGE TUBE	LIFE & RELIABILITY TESTS 72	✓		PLAN TESTS - PROCURE EQUIPMENT - MAKE TESTS
STORAGE TUBE	EQUIP FOR PILOT QUANT. TUBE CONSTRUCTION 73	✓		DESIGN & CONSTRUCT
STORAGE TUBE	FINAL DESIGN FOR FIRST WWI TUBES 74	✓		DESIGN - PILOT CONSTRUCTION
STORAGE TUBE	CONSTRUCTION OF WWI TUBES 75	✓		CONSTRUCT

LEGEND

JULY 4 11 18 25

Period of one month, comprising [illegible] of days in the month.

PROTOTYPE

Operation to be performed, and estimated time allotted for its completion. Estimates made in July 1948.

Work done. The ratio of the length of the solid bar to the length of the open bar above it shows percentage of completion at the end of the month.

Date of latest posting.

Summary line. Shows overall status of the project.

MIT	S
	✓

Column showing whether M.I.T. or Sylvania will do major portion of the job.

For a long-range plan from 1944 to 1952 showing the relation of this detailed schedule to past and future work, see Summary Report No. 11, August 1948.

STORAGE TUBE BERYLLIUM MOSAICS FORMED BY EVAPORATION

The storage surface presently planned for use in the Whirlwind electrostatic storage tube consists of a thin layer of beryllium deposited by evaporation on a dielectric target. As described briefly in the August Summary Report, SR-11, a successful method for the formation of sharply defined beryllium mosaics has been developed.

Formation of the Mosaic

In order to obtain a mosaic, a nickel mesh with 40 0.002-inch wires to the inch is placed as closely as possible in front of the target. This screen produces an optical image on the surface, with sharp shadows of the wires separating the individual beryllium squares that form the mosaic. The attainment of a sharp optical reproduction of the mesh depends on two conditions:

(1) The molecular rays must propagate along straight lines.

(2) The molecular rays must originate from a point source.

With reference to condition (1): the rays, that is, the evaporating beryllium atoms, will move along straight lines as long as they do not hit an obstacle. Therefore, if the vacuum container is so well pumped that the mean free path of the evaporating beryllium atoms is of the order of ten times the length of the path between evaporating cup and target, the rays can be assumed to follow straight lines. In the experiments, the spacing between the evaporating cup and the aluminum target was 4 inches for 1-3/8-inch tubes and 7 inches for 5-inch tubes. It was concluded that straight-line evaporation would be obtained at pressures of about 10^{-6} mm of mercury or less. The temperature of the evaporating cup was raised to evaporating temperature (about 1000 C) only after such pressure had been obtained. By keeping the distance small between cup and target, it would be possible to reduce the vacuum requirements. On the other hand, a relatively large spacing is necessary to obtain a uniform coverage of the target surface, because the center of the disc-like target will receive a relatively higher density of coating than the edges if the spacing is small. The cup-to-target distances of 4 inches and 7 inches for the 1-3/8-inch and 5-inch targets respectively balance these factors adequately.

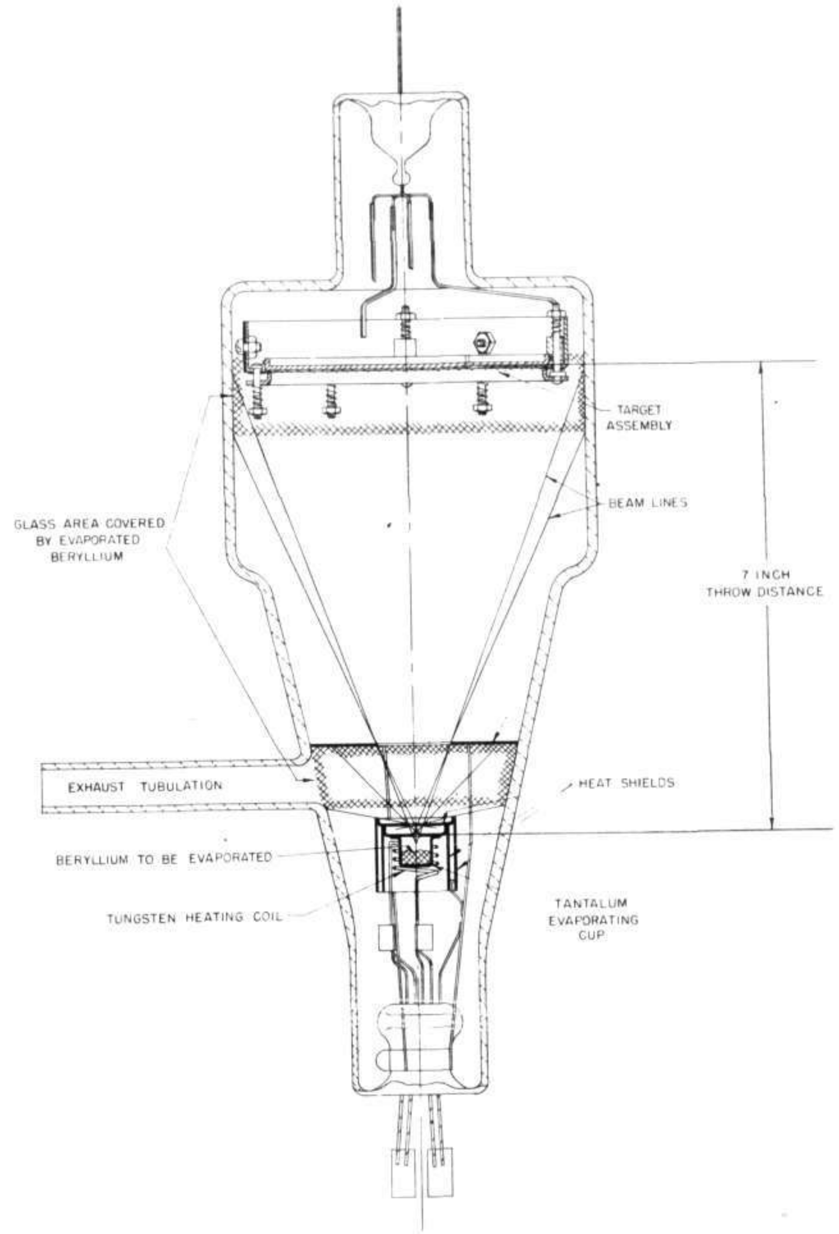
With reference to condition (2): originally, the evaporating cup was an open container. The resulting mosaic showed a very blurred picture of the screen mesh in spite of close spacing between mesh and aluminum surface. Some improvement in sharpness of the mosaic contours was obtained by confining the opening of the evaporating cup to a 1/8-inch hole. However, two secondary sources of trouble remained.

Use of Heat Shield

The target was still exposed to the heat radiating from the top cover surface of the evaporating cup, which assumed a temperature of about 1000 C during the process of evaporation. Heat radiated from this surface caused heating of the surface layer of the insulating coating, upon which the beryllium atoms impinged. The sublimation of metal vapors on a solid surface depends to a great extent upon the surface temperature. Therefore, improvement was expected from a reduction in the heat radiation from the evaporating cup to the aluminum target.

The other disturbing factor was the large aperture angle at which the evaporating beryllium atoms left the hole in the evaporation cup. Since during the evaporation procedure the side sections of the glass wall of the container were assuming a heavy coat of beryllium, it appeared possible that reflection of the molecular rays would take place at the glass walls and disturb the sharp shadow picture desired on the aluminum oxide target.

Both troubles, the heat radiation and the reflection of the evaporating atoms from the glass envelope, were eliminated by a combination of two heat shields, which simultaneously act as beam-forming apertures. To use the optical analogy, these shields were designed to act in such a manner that the full intensity of the beryllium beam just covers the desired target, while the "penumbra", which comes into existence because of the finite diameter of the evaporation hole, is kept from touching the glass wall at points below the aluminum target, from



EVAPORATION TUBE FOR FORMATION OF BERYLLIUM MOSAICS where rays could be reflected upon the target.

Experimental Results

Experimental results confirmed the principles applied. Evaporation was performed at pressures well below $10^{-[illegible]}$ mm Hg; the evaporation was continued for 24 hours at a uniform cup temperature of about 1100 C. The upper part of the container stayed relatively cold, and its temperature was further reduced by a slight air stream against the glass. The target was covered by a heavy, uniform, and sharply bounded mosaic. The wall of the glass container below the target stayed clear throughout the experiment. These results were confirmed in subsequent experiments.

INSTALLATION OF WHIRLWIND I RACKS

During September the installation of the racks for housing the panels and wiring of WWI was nearly completed. Ninety-six racks, 27-1/4" wide × 19" deep × 118" high, have been installed and painted. The racks, constructed of 3-inch wide aluminum channel, were fabricated and drilled at the plant of an outside supplier, were brought into the Barta Building in pieces, and were assembled in place in the computer room. The accompanying photograph shows an early stage of the installation of the racks, and illustrates the method of construction from prefabricated parts.

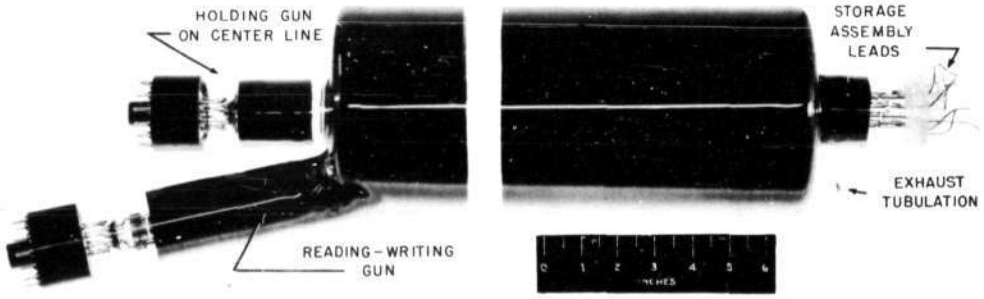
The power supply room in the basement of the Barta Building was prepared for the installation of the Power Equipment Company electronic power supplies, and the +150-volt, 50-ampere unit has been received and installed.

TEST SPECIFICATIONS FOR WWI REPETITIVE ELEMENTS

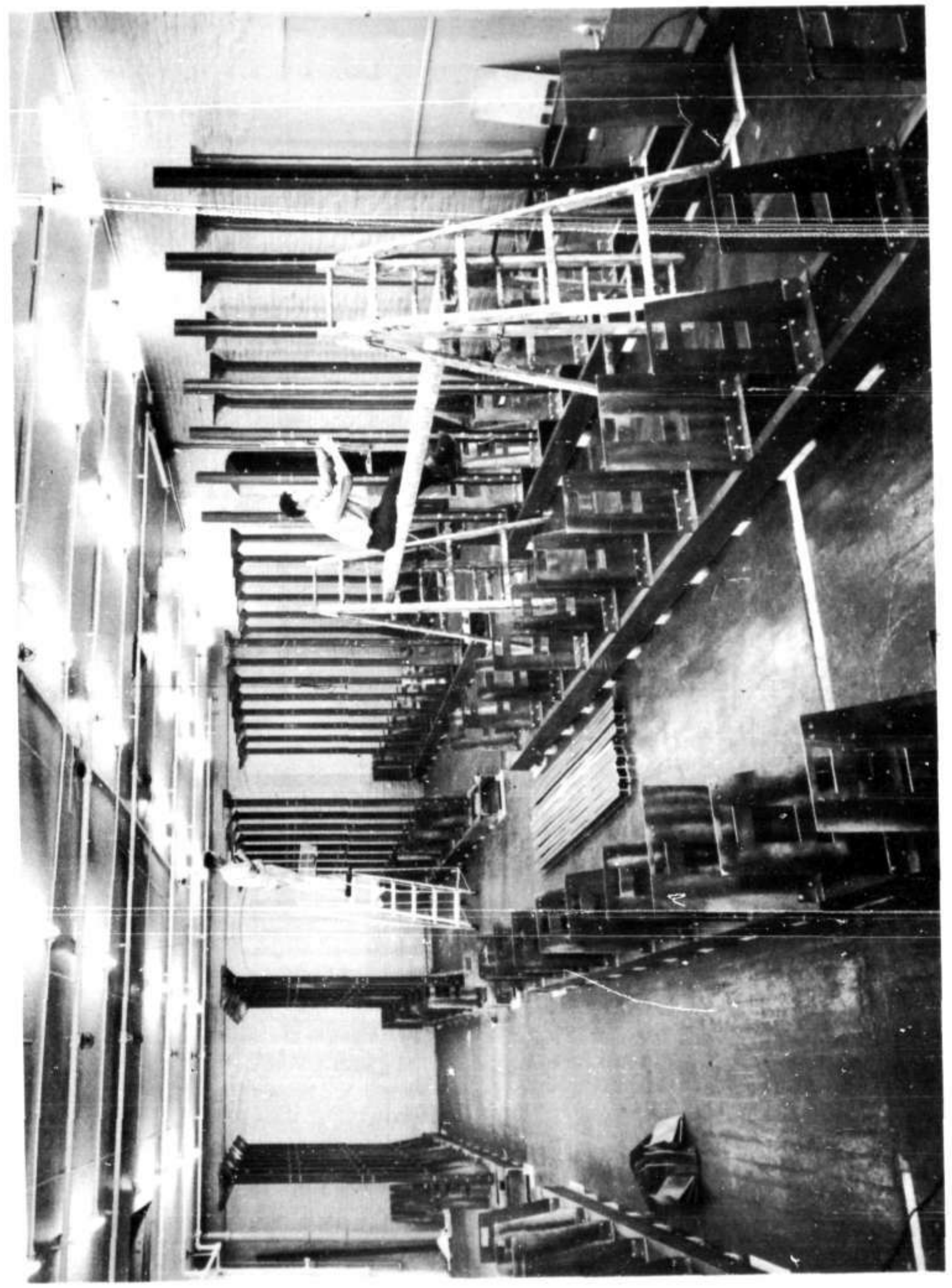
In each component such as the accumulator, A-register, and B-register of a parallel computer, the panels for most or all of the separate digits will be identical. Also, sufficient similarity exists between the A-register and program register, the B-register and in-out register, and the check register and comparison register to permit the use of interchangeable panels in these three pairs of registers. This reduces the number of different panels and increases the number of panels of a given type.

These so-called repetitive elements, of which there will be from 18 of the accumulator panels (including spares) to 140 of the control-pulse output units, are being constructed by Sylvania and are to be tested by them so as to make it as nearly certain as possible that the units will operate satisfactorily in the computer. Before construction of the repetitive units is authorized, a prototype unit is built and sent to the Project laboratory for complete testing to check the circuit design and layout.

After the prototype panel has proved to be satisfactory, general test specifications for the particular panel are drawn up for inclusion in the WWI standards book. These specifications give the



CURRENT DESIGN OF 5-INCH STORAGE TUBE



ERECTION OF RACKS IN COMPUTER ROOM

general manner in which specific parts of the circuit are to be tested and the tolerances which apply to the results of the tests. The tests are divided into two sections: first, static measurements of resistances and voltages to disclose serious errors in wiring or component size; second, dynamic measurements of output amplitudes and waveforms. The dynamic tests are subdivided into preliminary individual tests on each stage alone and so-called "semi-systems" or better "system simulation" tests in which the separate parts of the circuit are made to operate as nearly as possible as they will in the finished computer.

The specific testing procedure and the test data sheets are drawn up by Sylvania and approved by MIT. With each panel when it is delivered, there will be a sepia print of the original data sheet so that interesting data sheets may be reproduced for circulation and the original test data of each panel will be readily available if needed for trouble shooting.

APPENDIX

REPORTS AND PUBLICATIONS

The following reports and memorandums on Project Whirlwind work were among those issued during September.

No.	Title	No. of Pages	No. of Drwgs.	Date	Author
SR-10	Summary Report No. 10	22	-	7-48	
R-142	Talk Delivered by Jay W. Forrester at the Modern Calculating Machinery and Numerical Methods Symposium at the University of California, Los Angeles, July 29, 30, and 31, 1948.	7	8	8-31-48	J. W. Forrester
E-144	Basic Circuits, Revisions	3	5	9-16-48	E. S. Rich
E-145	Elimination of Common Ground Leads	3	-	9-23-48	J. A. O'Brien
E-146	Control Pulse Simulation	3	1	9-23-48	M. Hayes
E-147	The Error in the Runge-Kutta Method	4	-	9-27-48	P. Rabinowitz
M-597	Television "Readout" of Storage Surfaces Part I: System Setup	3	5	8-30-48	R. L. Sisson
M-602-1	Standard Power Connectors, WWI	2	-	9-20-48	H. S. Lee
M-603	Trip to David W. Taylor Model Basin, Aug. 31, 1948	3	-	9-3-48	E. Reich
M-604	Bi-Weekly Report, Part I, 9-3-48	17	-	9-3-48	
M-605	Bi-Weekly Report, Part II, 9-3-48	17	-	9-3-48	
M-608	Progress Report: Trouble Location in a Large-Scale Electronic Digital Computer	1	-	8-30-48	G. C. Sumner
M-609	Proposed Five-Digit Multiplier Marginal-Checking Installation	3	2	9-9-48	E. S. Rich
M-611	The Dispersion of the Holding Gun Beam Within the Collector to Target Surface Field	2	3	8-30-48	J. S. Rochefort
M-612	Accumulator Circuit Schematic	1	-	9-10-48	H. Fahnestock
M-613	Digit Interlock and Fixed Voltage Switching Panels, Revision of Schedule	1	-	9-13-48	C. W. Watt
M-615	Bi-Weekly Report, Part I, 9-17-48	13	-	9-17-48	
M-616	Bi-Weekly Report, Part II, 9-17-48	19	-	9-17-48	
M-618	Test Equipment for Production Testing of WWI Panels	2	2	9-21-48	H. Kenosian

No.	Title	No. of Pages	No. of Drwgs.	Date	Author
M-619	Installation of Equipment and Wiring in Computer Room	1	-	9-20-48	C. W. Watt
M-620	Cable Terminating Resistors	1	-	9-21-48	H. Kenosian
M-623	Present Status of Test Equipment	5	-	9-22-48	H. Kenosian
M-624	Video Busses for WWI	1	-	9-27-48	C. W. Watt
A-71	Standards Book	4	-	9-14-48	Stand. Committee
C-59	Analysis of Arithmetic Check	2	-	9-17-48	R. P. Mayer
C-60	Meetings of the Mathematics Group	3	-	9- 7-48	P. Rabinowitz
C-61	Meetings of the Mathematics Group	4	-	9-14-48	M. Daniloff
Translation					
E-142	Contribution to the Understanding of the Mechanism of Secondary Emission from the Inner Regions of Ionic Crystals - by M. Knoll, O. Hachenberg, and J. Randmer, Zeit. F. Physik, 122, 137-162, (1944)	23	9	8-31-48	M. Daniloff