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## SEAC—Review of Three Years of Operation

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### PURPOSE FOR CONSTRUCTION OF SEAC

SINCE SEPTEMBER of 1950, the National Bureau of Standards has had SEAC, a digital-automatic computer, in almost continuous daily usage. It was originally conceived as an interim-computing facility for the use of the government until a more complete computing system could replace it. Consequently, in constructing the machine, it was intended to put into productive operation as soon as possible a minimal machine that could produce computed results. However, the machine proved quite reliable, and the experiments involved in its design were sufficiently successful that SEAC was expanded and kept in operation as a perma-

nent tool at the National Bureau of Standards. It is the purpose of this paper to present some of the operating experience that has been obtained from the use of this computer and to indicate the ways in which component reliability and maintenance procedures have affected the amount of useful computation that has been obtained from SEAC.

When SEAC was first put into productive operation, the demand for its use was so great that it became necessary to schedule it for operation on a 24-hour-a-day 7-day-a-week basis. Since it was apparent that the computer would have to be expanded, at first this time was divided nearly equally between the engineering groups modifying the computer and experimenting with it, and the mathematicians who were producing computed re-

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sults for the various Government agencies. After a year of operation, the engineering time was reduced to about one-quarter of the total available time.

By the use of flexible scheduling, and largely because of the very convenient input-output facilities of SEAC, a great number of concurrent mathematical projects were able to use the computer. This kept a staff of from 30 to 40 mathematicians busy formulating and coding problems. It has at all times been possible to allow both short and long runs on the computer because the time that is involved in switching over from one problem to another can be less than 2 minutes. This has resulted in SEAC being used for over 85 different projects of varying length and of diverse natures.

Interspersed with the productive computation have been periods during which research and development have been conducted on SEAC. These engineering periods are, typically, eight hours in length. During this time, investigations have been conducted into new computer circuitry and accessory devices. As a result of this engineering work, many new features were added to the computer.

Because SEAC has been used for both computation and development, there has been some decrease in the reliability of the system from what it would have been on a SEAC that was solely a computing device. Examination of the operating record shows that since the initial period of experimentation, this loss of reliability has been small. After engineering periods, the attempt is made to restore the machine to the condition it was in prior to the period. Obviously, this is not always possible. In general, however, the engineering periods on the machine do have the effect of hastening failures that may be intermittent or marginal. Removing components, turning power on and off frequently, and physically dislocating sections of the circuitry for the duration of temporary experimental changes accelerate the failure of components that would perform satisfactorily for a longer time in ordinary operation. An analysis of machine failures, which will be given later, will show the extent to which experimentation has caused failures in machine operation.

#### OPERATING AND MAINTENANCE PROCEDURES ON SEAC

Until recently, when the 168-hour-a-week schedule was relaxed, there were four periods per week of approximately eight hours in length during which SEAC was used for engineering or during which maintenance work was performed. At all other times, the computer was operated by mathematicians. These mathematicians are responsible for the mathematical formulation of the problem, for the preparation of the code, and for operating the console during the running of the problem on the computer. In general, they are not expected to be familiar with the logical structure of the computer except insofar as it is manifest in the structure of the operation code.

When a problem is scheduled for solution on SEAC, the mathematician who has prepared it puts the problem into the computer and follows its operation during the time that it is on the machine. Since there is no automatic-checking provision in SEAC, with the exception of the memory-parity check, it is usual for the mathematician to provide program checks or to have print-outs on the teletype at sufficiently frequent intervals to enable him to monitor the operation and to detect any machine errors. It is also usual when the mathematician suspects a failure in machine operation for him to call a maintenance technician. The information that the mathematician can provide is usually sparse if not misleading. Occasionally, the mathematician gives a report simply that the machine has "hung up." The technician must then determine whether the machine has indeed made an error or whether the error is in the code. Not being familiar with the code, he often first tries to rerun the section that is claimed to have produced the error. If inconsistent results are obtained, it is fairly certain that the machine has made at least one intermittent error.

The maintenance staff of SEAC for three-shift operation consists of three engineers and five technicians. One technician is occupied full time in the construction and repair of replacement parts. At all times when the computer is in operation, there is a technician present and an engineer available for consulting purposes.

In the event of a machine error, it is desirable for the maintenance technician to be able to reproduce the machine conditions under which the error occurred. Unfortunately, the technician is generally not qualified to analyze the code that was running and to detect the immediate nature of the error. In such circumstances, it would be highly desirable if the person who operates the computer were familiar not only with the code but also with the logical organization of the computer. For a machine like SEAC, where the electronic structures are highly iterated, it is necessary only to have a machine operator who can analyze troubles from the logical standpoint and a technician familiar with the electronic nature of the circuitry in order to maintain the machine. The luxury of a standby engineering staff present for consultation in emergencies is a fortunate aspect in maintaining an experimental machine. For computer installations of a nonexperimental nature, this auxiliary staff is not available.

In the event of a failure, the computer is not always removed from problem solution. When the failure is highly intermittent, it is usually more efficient of time to allow computation to proceed until such a time as either computation becomes impossible, the error occurs frequently enough to make it possible to locate it, or a scheduled maintenance period occurs.

In the diagnosis of an error, several systematic procedures are used. The most frequently used technique is the diagnostic-test routine. There is a library of such routines available to the person doing the debugging.

In general, the test routines are predicated on the assumption that the operator has assured himself that control functions in the computer are operating properly. These routines then perform any one of a number of computations involving special parts of the computer with a diagnostic printout if an error is produced. One routine, for example, loads the acoustic memory with different word patterns and then checks the memory for the storage of these patterns. If an error is detected, the routine prints on the Teletype information that indicates to the technician operating the routine where the failure has occurred in the memory. Obviously, this indication can only be approximate, but for errors that involve such commonplace failures as those due to improper gain adjustments in the recirculation amplifiers, a test routine which will save diagnosis time for technicians is highly valuable.

There is a compensating disadvantage in unqualified use of diagnostic-test routines like this memory test. When technicians and semi-skilled maintenance personnel use these routines, they have a tendency to rely too greatly on the indications provided by the test routine. When subtle troubles occur for which the test routines were not designed, there is often a significant loss of time involved in trying to find failures where they do not exist. Despite the occasional lapses into indiscriminate use of these test routines, the amount of effort saved by allowing the computer to do its own testing is great.

Among the various diagnostic tests available for use with SEAC are those that check specific portions of the machine: the memory, either acoustic or electrostatic, the arithmetic unit, the magnetic-tape auxiliary memory, and the magnetic wire input-output. Other routines cause the computer to perform operations which result in the highly repetitive production of special patterns of standard pulses at test points. These routines are used in conjunction with an oscilloscope for observing the patterns produced. Failure is then detected visually.

Another type of test routines frequently used is written as the trouble is observed. It is usually less complicated than the diagnostic routine and is written to test for a very specific trouble. It is also more effective than the diagnostic routine for troubles that involve the control section of the computer and other troubles of a serious nature that cause radically incorrect behavior of the machine. This type of routine is also of use in the detection of highly intermittent errors where the lower-duty cycle of testing of some diagnostic routines might make the detection of the error less probable.

Another systematic procedure for the detection of computer errors, which has always been in use on SEAC, involves marginal checking. In SEAC, most of the signal outputs of tubes are coupled to the rest of the circuitry by the use of pulse transformers. By varying the dc voltage to which these transformer secondaries are returned, it is possible to vary the effective output voltage of all tube and transformer stages in the computer.

Only two such voltages need to be varied to affect almost all stages in the computer in the same manner. These two voltages can be used to provide an over-all marginal test of the computer or of individual chassis. It is often possible to set these voltages at such a point that only the single weakest stage in the computer will be effectively inoperative. It is also sometimes possible to increase the frequency of intermittent failures by this technique. The marginal check is incorporated as a part of the preventive-maintenance schedule.

With one single area of the computer failing under marginal-voltage variations, the trouble is traced to the individual component that is to blame. Note that all during this period the operation of the system would be error-free under normal voltages. This forcing of the system to fail allows trouble shooting to be performed on the computer during "cheap" time, that is, during a maintenance period rather than during time that would otherwise be scheduled for computation. For components that are approaching the failure condition gradually, as in the case of vacuum tubes whose transconductance may gradually decrease, it is possible to anticipate failures during maintenance by marginal checking. The marginal check gives a nondestructive quantitative measure of the operating tolerances under which the machine is working. Another reason for the marginal check is to allow computer troubles to be debugged one at a time. If the failures are allowed to accumulate between maintenance periods, the situation will arise where there are two or more faults present in the computer simultaneously. The difficulty in locating the source of malfunctioning under such conditions is vastly greater than the effort that would be needed to isolate them individually. The computer represents a very powerful tool for use in debugging many parts of its own internal structure. However, to allow the computer to lapse into the degree of disrepair in which more than a single trouble is present at a time is to make it generally very difficult to use this powerful debugging tool.

For over two years of operation, SEAC had no automatic-checking facilities. All checks that were performed were programmed. For example, one checking procedure that was devised enables the computer operator to minimize the amount of time that is lost in the event of the detection of an error. Once every half-hour or hour during long runs, the entire contents of the high-speed internal memory are recorded on a magnetic-wire unit. Under the control of the program, this recording is then read by the computer and a check sum of the recording is compared with the corresponding check sum of the contents of the memory. If the sums agree, it indicates that the recording has been made accurately, and the machine automatically resumes computation at the point in the main routine where it left off. The memory-recording routine requires only eight memory cells and is completed within less than two minutes when transferring the contents of the 1,024-word memory. If the operator makes use of this routine,

he can insure that in the event an error is detected, the time lost will be no more than the time since the last memory recording was made. To resume computation at the point of the last memory recording, he simply reads the recording back into the memory. In a matter of a few seconds, the computer is recalculating in the part of the routine that occurred after the last recording. Not only is this routine useful for minimizing lost time due to errors, but it enables short periods of machine time to be used effectively in the solution of long problems.

At the beginning of this year it was decided to incorporate some degree of automatic checking in one section of the computer that gave less reliable operation than other parts of the electronic circuitry. It was found that transient errors involving the change of a single binary digit would occur in the acoustic memory. Often, these errors could not be attributed to the failure of any single component. On the other hand, such errors were relatively rare in the main body of the computer which used more conventional circuitry. This was a case in which checking circuitry could be built that would have a margin of reliability considerably greater than that of the circuits being checked. The parity checker that was built incorporated standard SEAC-type tube and transformer stages with diode gating. After its initial experimental stage, this checking circuitry was able to detect the great majority of errors in the acoustic memory. Because of the experience and success gained with this addition to the computer, investigations of the possibility of incorporating automatic checking for the input-output and electrostatic-memory circuits are now under way.

#### ANALYSIS OF THE SEAC LOG

Whenever there is a failure in the operation of SEAC an entry is made in the *Operations Log*. These entries may be made either by the operator or by a technician or engineer. A record is also kept of all modifications to the computer. Because of the transient nature of some errors that the computer makes, it is not always possible to identify the cause with certainty. Therefore, it is often the case that an entry will simply record the loss of computing time with no explanation of the cause. At the end of each week, figures are obtained for the operating efficiency of the computer. Operating efficiency is defined as the ratio of productive computation during assigned time to total assigned time. The remainder of assigned time after productive computation constitutes machine errors, overrun of engineering time into scheduled operating time, and downtime due to debugging.

A graph of the operating efficiency of SEAC for three years of operation is shown in Fig. 1. The average efficiency for that time was 74 per cent. The ratio of code-checking time to productive computation time is also shown. Only a small portion of operating time is needed for code checking because of such features as the auto-

matic monitor and the high-speed wire output which enable each operation to be monitored as it is performed and to be recorded rapidly on an output unit for later transcription to printed copy with auxiliary equipment.

In order to understand the manner in which various failures have contributed to downtime on SEAC, the operation log may be analyzed. Naturally, some of the failures that are of a transient nature cannot readily be

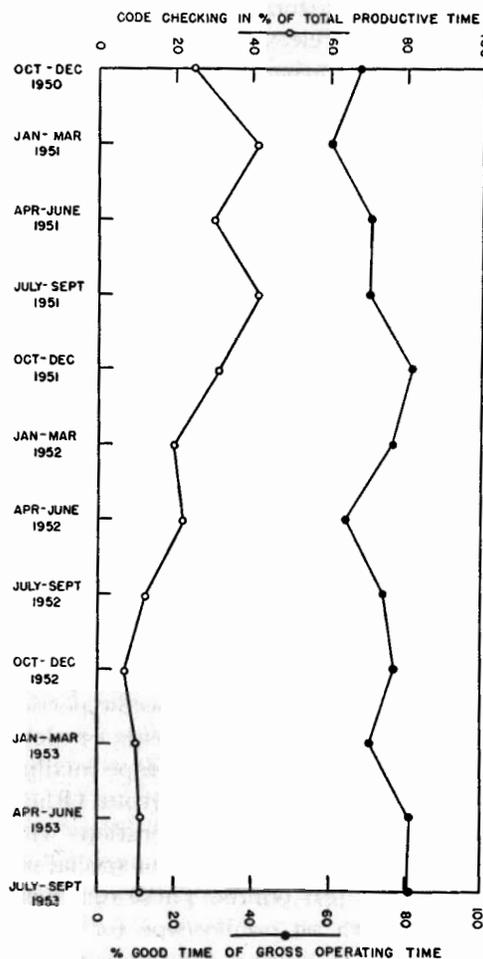


Fig. 1—Graph of operating efficiency of SEAC from October, 1950 to March, 1953.

analyzed. However, a recent period of a month has been selected during which a large percentage of the failures that occurred during scheduled operation were capable of analysis. Of a total of 477 hours scheduled for computation during that month all but 112 hours produced error-free calculation. The operating efficiency of this period was therefore 77 per cent. Only about 12 hours of lost time could not be attributed to specific faults. Data from this analysis of the operation log are in Table I.

In the first column is the cause of the failure. The second column gives the number of individual cases during which computation was delayed due to a component failure. The numbers in this column are considerably greater than the total number of times that debugging was necessary because in many cases the machine errors were of a trivial nature that were easily detected or corrected by the operator. The third column gives the

amount of downtime that was caused by these machine errors. The fourth column of the table gives an indication of the most common length of computation time lost as a result of the failure. The last column gives the number of individual components the failures of which caused the number of computer failures shown in the second column.

TABLE I  
NATURE OF FAILURES ON SEAC FOR ONE MONTH

Cause of Failure	Number of Machine Failures	Total Downtime Hrs.-Min.	Most Common Length of Downtime Hrs.-Min.	Number of Components that Failed
Diodes	8	6:05	0:30	3
Vacuum tubes				
6AN5	3	2:30	0:45	2
6AK5	3	2:35	0:45	2
Input-Output and Magnetic Tape	29	14:20	0:30	—
Pulse Transformers	14	17:30	1:00	3
Experimentation				
Parity Checker	26	11:40	0:25	—
Other	10	9:05	0:55	—
Electrical Connections	4	6:50	1:30	4
Switches	2	3:30	1:45	2
Adjustments				
Acoustic Memory	7	2:10	0:20	—
Magnetic Input-Output Units	9	5:25	0:30	—
Mechanical Equipment	13	4:45	0:20	—
Auxiliary Equipment	18	5:20	0:15	—
Miscellaneous	5	6:40	—	—
Undiagnosed	20	13:30	—	—

The table shows that during this time there were three diode failures. These were bad diodes that were not found during the preventive maintenance diode check. There were eight individual times during which these three diodes caused machine failures. All other failures among over 15,000 diodes were detected during the preventive check before they could cause machine failures.

During this period of a month there were four tube failures that caused six failures in machine operation. The two 6AN5 tubes came from standard SEAC pulse-repeater stages. They were rejected for low emission. The two 6AK5 tubes were removed from the acoustic memory.

The most frequently occurring fault in SEAC operation involved the input-output equipment. In general, no component was at fault. Rather, mechanical variations that are difficult to control in such equipment were at fault. Because there is no automatic checking for the input-output, incorrect-data input often is not even detected after the computation has progressed to the point where programmed checks occur, although for ordinary reading of program information, a checking routine is common. This minimizes the lost time from such input. The most costly input-output failures occur when the final computed results are incorrectly transferred to the output medium.

The failure rate shown for transformers is not typical in SEAC operation. It does, however, serve to indicate the extent to which certain components cause loss of computing time all out of proportion to their frequency of occurrence. The transformers that failed during this time were all of the standard type used in the SEAC

pulse-repeater stage. For over two years of operation transformer failures were so rare as to make it unnecessary to do any checking of them. Furthermore, it was correctly anticipated that the most common type of failure that would occur was catastrophic in nature, and it is not easy to anticipate such failures by testing the suspected transformers. As a result, when these three transformers developed intermittent openings or shorts in their windings, they caused a great deal of trouble before they were located.

It has already been mentioned that some failures in SEAC could be attributed to its use as an experimental machine. Shortly before the month in consideration, it was decided to install a parity checker for the acoustic memory. The new circuitry was debugged and installed in the computer. It began to detect many "errors," some spurious and others of such a nature that they would not cause computer malfunctioning. Eventually an error was found in the construction of the new unit, but not before it had caused a great deal of lost time on the computer. Now that this circuitry has been thoroughly debugged, it is performing with the reliability that was anticipated and has succeeded in locating most of the transient errors in the acoustic memory. The remainder of the downtime attributed to engineering was caused by overruns of engineering time into scheduled computation and by changes that were made during engineering that were mistakenly not restored until after the engineering period had ended.

SEAC went into operation with a number of joints unsoldered. At first, there were few malfunctionings due to these poor connections, largely because the wires involved were uncorroded. As the wires became corroded, they caused malfunctionings and were consequently located. It is safe to estimate that there are still a few of these unsoldered or rosined connections in the computer, although they are probably in uncritical areas. Most of the current troubles with connections arise from those that have become loose because of the extensive removal of components. When plug-in components are removed, there is motion of the wiring on the plugs. In addition, for many of the voltage busses, there was inadequate provision to leave slack or stress loops in the wiring so that these connections have been rather prone to coming loose. During the month under consideration, there were four bad connections discovered, a fairly typical number.

In two cases during the month faulty switches caused machine malfunctioning. In terms of lost time, these were rather costly failures because the connections involved were intermittent. Most of the switches in SEAC are rotary type and cause little failure. The push-button and toggle switches have been less reliable but only because they are used more frequently and enthusiastically.

Although the next three adjustments shown in the table are performed during the maintenance periods, it has also been necessary to perform them between maintenance periods. The failures indicated generally oc-

curred in groups in short periods before it was recognized that an adjustment was necessary, so that only about two of each type were necessary during the month.

A coincidental situation accounts for the large number of failures due to auxiliary equipment during this period. Magnetic recordings of codes and input data are generally made at times other than when the operator is scheduled to operate the computer. In this case many such recordings had been made but were not used on the computer until some time later. When the faults in the auxiliary equipment were discovered, it was too late to re-record the data and lost time resulted. As a result of this experience, it was suggested to the operators that they use another auxiliary device, the outscriber, to check all inscriptions on wire by punching paper tapes on the outscriber and comparing the output tape with the originally-punched tape. This is recommended where there are no programmed means provided for checking the input from magnetic wire.

During this month there were also five miscellaneous failures and 20 cases of machine failure not diagnosed.

#### COMPONENT RELIABILITY IN SEAC

##### *Vacuum Tubes*

There are a total of 1,424 vacuum tubes in SEAC and its associated auxiliary equipment, comprising 32 different types. However, since the type 6AN5 vacuum tube occurs more frequently than other types, discussion will be confined to this tube. A total of 1,050 6AN5 tube locations presently exist in SEAC. During the first three years of SEAC operation, approximately 2,500 6AN5's were used in the machine. Of these, 1,300 tubes were rejected for various reasons. Rejections were made almost exclusively during the preventive maintenance periods. Operational failures of 6AN5's in SEAC have been very few. During a 15-month period from February, 1952 to April, 1953, for example, it was necessary to replace only 18 tubes during computation time.

Fig. 2 shows graphically vacuum-tube survival for 1,775 6AN5's used up to March, 1953. This group does not include the approximately 700 tubes associated with the Williams memory and short experimental developments. The curve has been plotted by considering batches of tubes installed within 500 hours of the indicated average as single entities and weighting the points on a survival curve for such a group of tubes according to the number contained in each batch. This curve shows the percentage of tubes one would expect to survive after a given number of hours.

When SEAC was first placed in operation there existed considerable variation in heater voltage in various parts of the machine. Accordingly, plate currents were measured with heater voltages at 5.7 as well as 6.3 volts to allow for abnormal heater voltage during use in the computer. If there was a drastic change in plate current when the heater voltage was decreased, the tube was discarded as "heater sensitive." In addition to preventing weak tubes from being installed in stages having low

heater voltage, it was thought that heater sensitivity might provide an indication that the tube would soon be rejected for low emission. Thus, in September, 1951, heater sensitivity was formalized in a specification which called for rejection of all tubes that showed a reduction of plate current of 25 per cent or more when the heater voltage was changed from 6.3 to 5.7 volts. This part of the specification was adopted even though at that time abnormal heater voltages had been corrected on all chassis. Approximately 55 per cent of all tube rejects in SEAC until June, 1953, were made for heater sensitivity. An analysis of tube data showed that after 8,000 hours of service heater sensitivity was the main cause for replacement. (More detailed information on tubes and diodes used in SEAC is included in a Special NBS Computer Circular, which is in process of publication.)

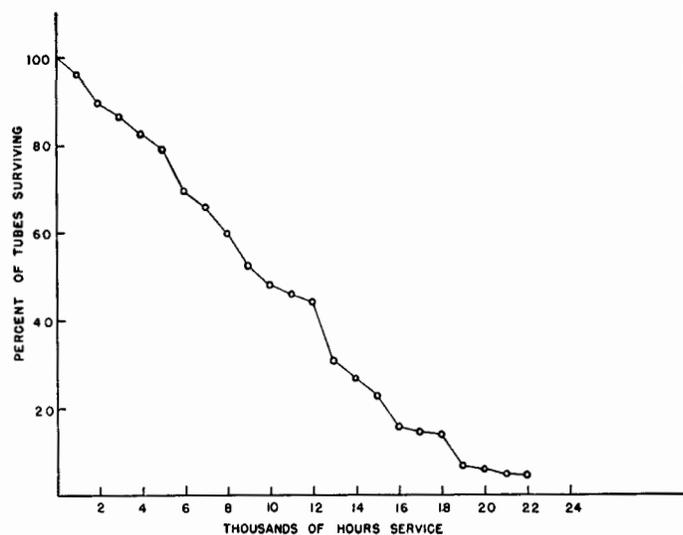


Fig. 2—Over-all tube survival versus time in service for 1,775 type 6AN5 tubes.

During June of this year, an analysis of our 6AN5 vacuum-tube experience showed that heater sensitivity increases with tube age and is some cause for alarm if heater voltages fluctuate. It is not apparent, however, that heater sensitivity provides a definite indication before a serious slump in plate current. The analysis also indicated that the median life expectancy for tubes rejected for all reasons except heater sensitivity was 10,000 to 12,000 hours, while if heater sensitivity was also included as a reject criterion, the median life appeared to be 8,700 hours. Since June of this year, the heater-sensitivity test has not been included in the vacuum-tube test for the computer. Experience does not yet show that this increase in tube-life expectancy as a result of relaxing the heater-sensitivity requirement coincides with any material increases in the incidence of tube failures during scheduled machine operation.

##### *Germanium Diodes*

The basic measure of diode reliability in SEAC is the rate at which diodes cause machine failures. Since there are over 15,000 diodes in the computer, any substantial

failure rate would be intolerable. During the three years that SEAC has been in operation, however, this failure rate has been kept so low that diodes have been a minor consideration in the production of machine failures. Over the three-year period, diodes have had an in-operation failure rate of less than two per month. Table II shows the type of diode failures that occurred during a two-year period of regular machine operation. Those diodes with high forward voltage had a voltage drop of greater than 2 volts when a current of 20 milliamperes was passed through them. High back current was indicated by more than 500 microamperes when 40 volts was applied in the reverse direction. Drift was indicated by a change of more than 300 microamperes in reverse current while the diodes were under test.

TABLE II  
OPERATIONAL FAILURES OF GERMANIUM DIODES IN SEAC  
December 1950–December 1952  
Total Diode Populations 15,676  
(Elapsed Time: 3,693 to 19,512 service hours)

Nature of Failure	Number of Diodes
High $E_f$	4
High $I_b$	14
Drift	8
Unspecified	13
Total	39

The failures of Table II are few indeed and are offset by the preventive rejects shown in Table III. The figures for the computer exclusive of acoustic memory are representative of a period that is roughly half the period covered by Table II. The diodes came from sections of the computer (other than the acoustic memory) where environmental conditions were less harsh. The figures for the acoustic memory alone show the preventive replacements for a slightly shorter period than that of the computer alone.

TABLE III  
PREVENTIVE MAINTENANCE REPLACEMENTS OF GERMANIUM DIODES IN SEAC  
December 1951–December 1952  
(Elapsed time: 10,830 to 18,905 service hours)

	Replaced for		Drift	Total Replacements	Total Population
	High $E_f$	High $I_b$			
Computer exclusive of acoustic memory	91	375	382	848	12,709
Acoustic memory	20	65	340	425	2,967

It can be seen from Table III that the diodes in the mercury memory suffered a much higher replacement rate than elsewhere in the computer. The memory data have been isolated in the tables because the conditions of inspection there were more rigorous and the conditions of operation involved higher operating temperatures than elsewhere in the machine. Inspections were

made almost twice as frequently in the memory as elsewhere in the machine, thus slightly increasing the rejection rate.

The maintenance records of Table III do not include 276 replacements made in all parts of the machine during three short periods of poor operation in the summer of 1952. The air-conditioning equipment in those periods was inoperative during weather of unusually high humidity and temperature, operating conditions for which the machine was not designed. Ambient temperatures for the diodes ranged from 45 degrees C. to 55 degrees C. It was also necessary in this time to discard an unusually large number of "spare" diodes (used for replacements in the computer), probably because of the hot and humid weather conditions.

The weakest features of performance of the diodes are their tendency towards high back current and back-current drift. Actually, SEAC circuitry is extremely tolerant of back current; currents five times greater than specifications are allowable in most places.

It has been estimated that if diode specifications had been chosen to cover specific applications in the SEAC circuitry and grouped into three or even two types, the preventive maintenance replacements shown in Table III would have been materially reduced, perhaps as much as ten-to-one. Instead, at the time SEAC was designed it was decided in the interest of simplicity to use diodes to one specification—therefore all diodes were tested to the same specification as the ones used in the most critical part of the SEAC gating structure because the mounted configurations were not identified with circuit application. This tends to make diodes appear less reliable than they might actually be if typed according to application. This consideration becomes less important if preventive checking is not practiced and diodes are sought out and replaced only when failing.

#### Miscellaneous Components

In addition to tubes and diodes, four other types of components are used extensively in SEAC, namely, resistors, electromagnetic delay lines, capacitors, and pulse transformers. Of these, only resistors, delay lines, and pulse transformers form a part of the actual computer circuitry, capacitors being used solely to bypass places where excessive noise pickup would cause the generation of spurious signals.

Resistors in SEAC circuitry are required to be within 10 per cent of their design value. A set of measurements has been initiated to determine how far, in the three years of operation, resistors have varied from their initial rated value. The information obtained so far indicates that about 1 per cent of the resistors in the computer have exceeded the rated tolerance. These are being replaced as they are discovered. No records have been kept on the number of shorted or open resistors occurring during the three years. Two or three resistors are replaced each month during preventive maintenance.

Infrequent troubles with delay lines have been due to corrosion of the solder joint connecting the fine wire of the line to its termination. About a dozen instances of this kind have been reported during the life of the computer.

Pulse transformers have caused very little trouble in SEAC until quite recently when shorted and open primary windings increased the incidence of failure. Another type of failure was caused by decrease of transformer inductance which results from spreading of the gap after failure of the clamping band. Mechanical design of the transformers has been changed to correct these troubles.

### CONCLUSION

The extent to which SEAC has served as an experimental machine during more than three years of operation is indicated by the increase in the number of vacuum tubes from about 750 to about 1,450. During a good part of this time SEAC was the only large-scale automatic digital computer available to the government. Its record of productive computation coupled with its expansion and increasing power and efficiency of operation have proved that it is possible to operate a computer for experimental purposes while obtaining useful computation from it.

The most recent of the major modifications to the computer has been the addition of automatic checking circuitry. The principle followed in the addition of this feature was that the reliability of the system should be balanced. Since the standard SEAC pulse-repeater stage has proved very reliable for continuous operation, it was the basis of construction of checking circuitry.

Maintenance procedures have had considerable effect on the reliability of the system. The large-scale removal of diodes and tubes has resulted in trouble from these sources being reduced to the point where they are among the least troublesome of the components in the computer. This has been accomplished at the expense of discarding some components that could have functioned in the computer for a longer time. If diode specifications were established on the basis of the circuit function for which use was intended, the number of rejects could probably be reduced by an order of magnitude without any loss in computer reliability. For vacuum tubes, the filament sensitivity test has proved to be too stringent, and by the elimination of this test, the number of tubes rejected can be decreased considerably.

Input-output has proved to be the least reliable of the functions that the system performs. However, recognition of this has greatly reduced this trouble by the incorporation of programmed checks into routines that involve large amounts of input-output.

New constructional techniques that have resulted from the experience with SEAC have been incorporated into DYSEAC. It is believed that the use of printed-circuit techniques will materially reduce the troubles that have resulted from the wiring methods that have been used in SEAC. In addition, the need for more rugged construction of removable components which has been indicated by SEAC experience has been incorporated into the DYSEAC design.

Three years of SEAC operation have helped make it a far more reliable machine than when first in operation. Weak elements have been eliminated, and the addition of new features have increased its power of operation.

### Discussion

**Harvey Rosenberg** (Burroughs Adding Machine Corporation): How many control relays are used? What was their reliability?

**Mr. Kirsch:** In SEAC there are about 30 control relays. Most of them are associated with the input-output equipment. Most of the relays are used for gating low voltages—that is, the voltage at the level that comes out of our step-down transformers from the pulse repeater stage. So, problems like arcing and consequent corrosion of contacts are not very common with us. I do not have actual figures on relay performance but I should say that they are an extremely reliable device as we use them.

**R. Kopp** (Headquarters, United States Air Force): If, as I understood you to say, you try to continue production after an intermittent malfunction is detected but not cured, how do you know whether the resulting production is of any value?

**Mr. Kirsch:** Here we come to a problem with a nonoperational solution. It is very often a matter of what can, for want of something better, be called judgement. We

cannot say ahead of time that we know for certain that the computer is going to be functioning well. However, if a mathematician suspects an error and if we respect the mathematician's suspicion, one thing to do is to put in a quick marginal check. This can be done quite rapidly on SEAC by the insertion of any one of several diagnostic test routines and the variation of the two voltages that I mentioned. If the failure is highly intermittent and is not one that is susceptible of increase by marginal variations, there is nothing that we can do but return the machine to the mathematician and wait until this error occurs again.

**R. E. Lyons** (Department of Defense): Has lowered filament voltage ever been used as a means of marginal checking SEAC? If so, was it an adverse effect on the 6AN5's?

**Mr. Kirsch:** Only recently did we introduce equipment into the SEAC for the variation of all the filament voltages, so we have not had any experience with that. However, in installing the 6AN5's in SEAC and in testing them during the preventive check, we used to give them a filament

voltage test which consists of lowering the filament voltage from 6.3 volts, the nominal value, to 5.7 volts, at which value we measure the change in plate current. If there is more than a 25 per cent change in plate current, we say that the tube is heater sensitive. Our tube rejections over a period of about two years during which this test was used indicated that an increase in this heater sensitivity definitely occurs as the tube gets older. However, we have not been able to find any connection whatsoever between filament sensitivity and an imminent decrease in plate current, which is the important criterion in the SEAC dynamic gating stage. This heater sensitivity test has resulted in rejecting over half of the tubes that have been rejected preventively, but it has not proved to be a valid indication of imminent failure, so we have discontinued this heater sensitivity test. That is the full extent to which we have done any filament variations on the 6AN5's. Other tubes occur in such low numbers in SEAC that we have done no extensive experimentation on them at all.