TECHNICAL REPORT NO. 6

A COMPUTER PROGRAM FOR THE SIMULATION OF FAILURE – RESPONSIVE SYSTEMS

Contract NASw – 572

April 1966

Reference WGD – 38521

Westinghouse Defense and Space Center
Surface Division

P. O. BOX 1897 BALTIMORE, MD. 21203

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by
J. M. Hannigan

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I. INTRODUCTION

When analyzing the relaibility of complex electronic systems, it is usually desirable to obtain exact mathematical expressions for the reliability. This is especially true in the analysis of redundant systems, since the main goal of redundancy is increased reliability. As the complexity of redundant systems is increased, however, there is a rapid increase in the number of calculations required to determine the exact reliability expressions.

As described in an earlier report[1], failure responsive systems are multiple-line redundant systems with the added capability to partially reorganize their redundant subsystems in response to the random occurrence of internal failure patterns. Because of the added reorganizational capability, the analytical reliability expressions for these systems become extremely complex. Furthermore, a completely different reliability expression must be derived for each different reorganizational strategy class. In general, then, it is virtually impossible to analyze failure responsive systems by deriving exact mathematical reliability equations.

Because of these restrictions, a generalized computer simulation program was developed to facilitate a Monte Carlo approach to the reliability analysis problem. The simulation program may be employed in the analysis of failure responsive systems, multiple line systems, or other modularly redundant systems.

The purpose of this report is to make the simulation program available to those performing research on similar redundant systems. The report contains a complete description of the program, including input data formats, output information, a descriptive list of program variables, detailed flow diagrams, and a Fortran IV program listing. This report assumes a basic familiarity with the FORTRAN IV language and with the failure responsive system reorganization procedures.

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[1] "Analysis and Development of Failure Responsive System Organizations" by C. G. Masters, Special Technical Report No. 5 of Contract NASw-572, December, 1964.

II. GENERAL DESCRIPTION OF THE SIMULATION PROGRAM

The simulation program is capable of simulating any number of complete missions of a failure responsive or similar redundant system. It can also simulate any number of different system organizations in a given computer run by the addition of an input data deck for each system to be simulated. The program is composed of an executive routine, MAIN, and ten subroutine subprograms, all written in FORTRAN IV. A general flow diagram of the program is shown in figure 1.

A. The System Representation Matrix

The program begins simulation by setting up a three dimensional matrix representation of the system. The matrix is shown diagrammatically in figure 2. The first dimension of the matrix represents the order of redundancy, and the second dimension, the number of stages in the system. Each element of the "front" plane of the matrix therefore represents a single subsystem and each column represents one stage of the system. The third dimension, KTEMP, is used to store all the information necessary to specify the instantaneous operating state of each subsystem.

Referring to this third dimension, the first two data storage locations for each subsystem contain the limits of an interval of numbers located between zero and one. The size of the interval is determined by the ratio of the failure rate of the associated subsystem, to the sum of failure rates of all of the subsystems. Each subsystem has a different portion of the zero-to-one range, and the entire range is allocated to the system. Failures are generated by drawing a random number from a set uniformly distributed between zero and one, and designating as failed the subsystem within whose interval the number falls.

The third storage location for each subsystem in the system representation matrix stores an identification (ID) number assigned to that subsystem. The fourth location stores a "failure order" number, which indicates, if non-zero, that the subsystem has failed, plus the order of failures in each stage.

The remaining locations in the matrix contain the "spare lists," or lists of identification numbers which specify which subsystems will be used as spares for each subsystem, if it fails, as well as the order in which the "spares" will be selected.

B. The Simulation Procedure

The simulation proceeds by generating a random number, and designating the corresponding subsystem as failed. The program then determines whether or not the system is still operational, according to the operational criteria which were read in as data. For

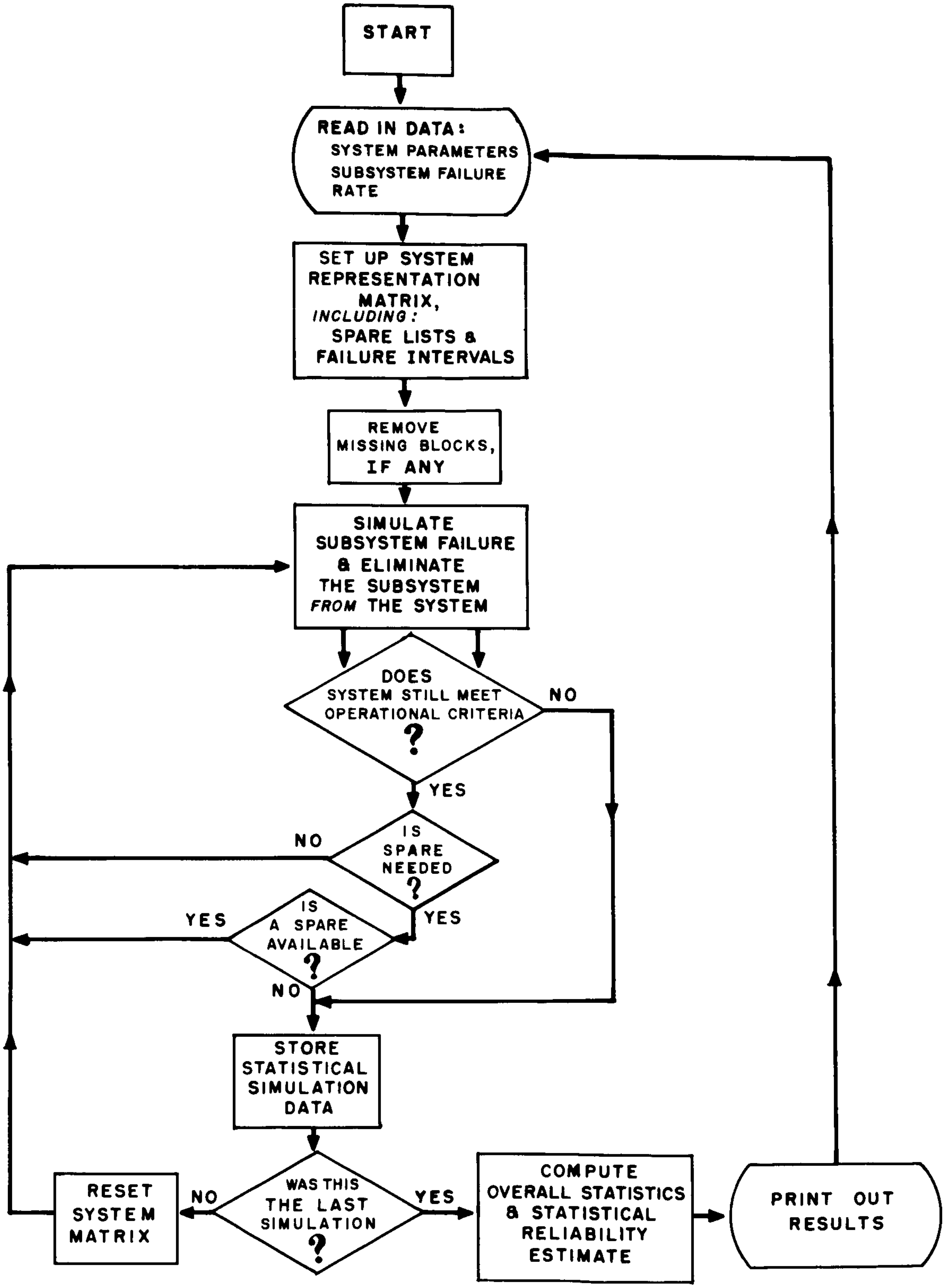


Figure 1. Summary Flow Diagram of Simulation Program

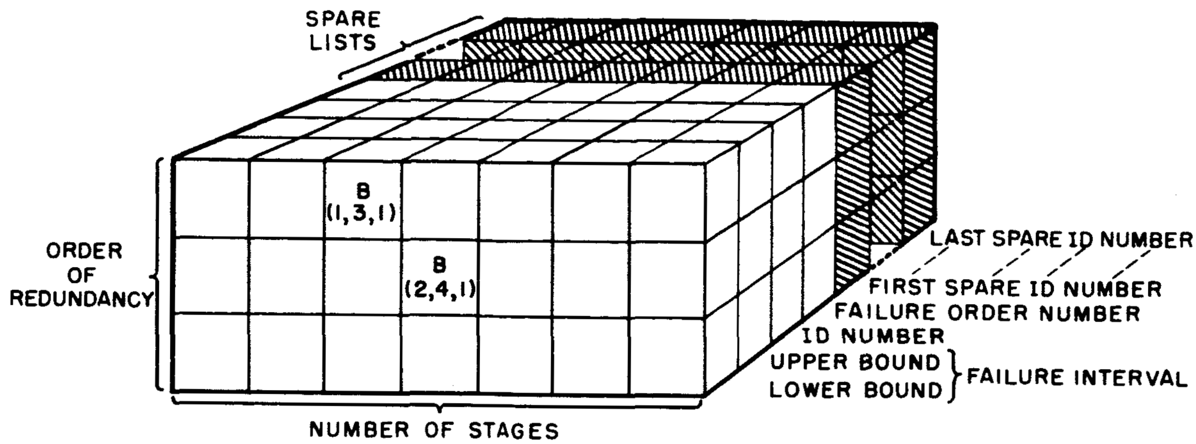


Figure 2. Diagram of System Representation Matrix

example, if the system is operational, the program determines whether the stage requires a spare subsystem from another stage in order to perform a "vote." If not, another failure is generated somewhere in the system. If the stage does require a spare, the program scans the spare list of the failed subsystem for a replacement from another stage. If none is available, the simulation terminates and a new mission simulation is begun. If a spare is available, it is moved to the new location and another simulated failure is generated.

The program contains a provision for generating a time-to-failure when a subsystem has failed. This is done by drawing a number from an exponentially distributed set of numbers. There is also an option for printing either the simulation results only, or a running synopsis of the response of the system, from time zero to failure.

C. Compilation of Results

After a predesignated number of simulations (usually 500-1000) of a system, the program computes an estimate of the reliability of the system using the results of all simulations. There is an option for computing either the 90% reliability time, or the entire reliability curve, from time = 0 to 5000 Hrs.

When the computations are completed, the program returns to its starting point and reads in the data deck specifying the next system to be simulated. If no data are remaining (the last system has been simulated), execution of the program is terminated by the attempt to read through an end-of-file. By this method, any number of systems may be simulated sequentially, simply by the addition of a data deck for each separate system.

III. DETAILED DESCRIPTIONS OF PROGRAM ROUTINES

This section contains a detailed description of the operation of the MAIN executive program, followed by descriptions of all of the subroutines, in alphabetical order.

A. The MAIN Program

This is the executive routine which sets up the system representation matrix and controls the simulation by performing the majority of subroutine calling, regulating the number of simulations, and computing the statistical results of the simulations. The operation of MAIN begins by setting up the system representation matrix. The program reads in the data which specify the system to be simulated. (Note: Most of this data is printed out, to provide a permanent record, at the beginning of the printout, of what system has been simulated.) The program then calls subroutine ALOCAT, which sets up the limits of the "failure" interval, by which random numbers simulate failures of specific subsystems. Subroutine DET is called, to assign an ID number to each subsystem.

The final operation in setting up the system matrix is the assignment of spare lists to all subsystems in the system. NRL, the Non-Repetitive List flag, controls the type of list to be set up. If NRL = 0, MAIN calls subroutine LIST, which reads in the lists for the subsystems in the last stage, and reproduces the pattern of these lists for the remainder of the subsystems. For example, figure 3(a) illustrates diagrammatically a simple list which might be read in for the last stage in a nine-stage system. The subsystems had previously been numbered consecutively from left to right, with ID numbers 1 through 9 on the top row, 10 through 18 on the second row, and 19 through 27 on the bottom row. The shaded subsystems in the last stage have the read-in spare list consisting of subsystems 8, 16, and 24, in that order. Figure 3(b) illustrates two of the reproduced spare list patterns. The second last stage has spares 7, 15, and 23, and the fourth stage has spares 3, 11, and 19. The spare list pattern would be reproduced in this manner for each of the remaining stages in the system. When NRL = 1, MAIN calls subroutine RANLIS, which generates a random spare list for each subsystem. If NRL = 2, MAIN reads in a separate list for each subsystem from input data cards.

Before the actual simulation, the program removes any "missing blocks" from the matrix. These are subsystems which are considered either failed, or simply not a part of the system at time = 0. This provision has been included in the program to provide the investigator with a wide range of system configurations different from the simple rectangular matrix. (For example, a system whose stages contain unequal orders of redundancy may be simulated with this option.) The program removes the subsystems by calling subroutine

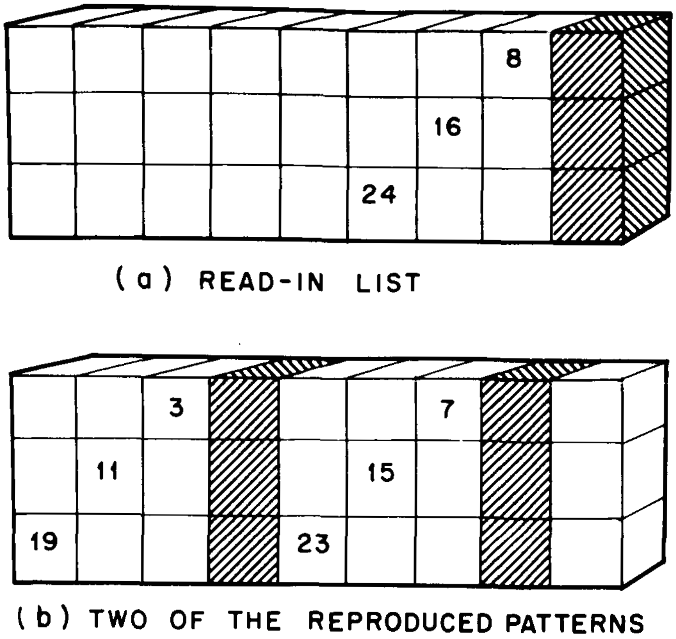


Figure 3. Example of List Pattern Reproduction

FAIL. This subroutine designates the subsystems as failed by setting their "failure order numbers" to non-zero values. FAIL then sets the subsystems' failure intervals to zero to prevent future failures of the same subsystem. The MAIN program then subtracts the failure rates of the missing blocks from the sum of the failure rates of the whole system, and computes the average failure rate for the modified system. The list of missing blocks is printed out.

To begin the simulation, MAIN sets up a duplicate matrix, C, which is used to reset the system representation matrix, B, before the next simulation. Subroutine FAIL is called to randomly generate a subsystem failure. If the failure has not caused system failure, MAIN determines if the stage that experienced the failure requires a spare to continue operation. If it does not, a new failure is generated. If it does, either subroutine SWITCH or subroutine SBACK is called to check the failed subsystem's spare list for an available spare. The determination of the proper subroutine to be called here is explained in the sections on subroutine SWITCH and subroutine SBACK. In either case, if none of the spares is available, the system is failed. If one is found, the simulation continues with the generation of another failure.

After each simulation, MAIN computes the total number of subsystem failures absorbed before system failure, and the mean time between subsystem failures. Then the system representation matrix B is reset to its initial condition and another simulation is begun. The number of simulations to be performed on a system is specified by the input data constant, NR. At the end of this specified number, the mean-time-to-system failure and the average number of subsystem failures absorbed are computed.

Using the results of all of the simulations of a system, the MAIN program computes the estimate of the system reliability, which provides a single-valued statistical estimate of system performance by which different systems may be compared. There are two options for computing the reliability. The first, which is the single-valued reliability estimate, involves the statistical estimation of the time at which the system reliability falls below 0.90. The second option is actually an extension of the first - the program computes the estimated reliability for every 100 hours between zero and 5000 hours.

1. Method of Computing the Statistical Reliability Estimate

From the results of all of the simulations, the MAIN program first computes a histogram of the frequency of systems failing with X failures absorbed, where X varies between zero and the maximum number of subsystem failures absorbed in a simulation. Each frequency is divided by the total number of simulations, resulting in a histogram of the percentage of systems failing with X subsystem failures. Each of the frequencies represents the probability that the system will fail with exactly X subsystem failures. The frequencies are then accumulated as X varies between zero and its maximum value, resulting in a list of the percentages, F(x), of systems failing with X or less subsystem failures. Each of the values is therefore the observed conditional probability that the system has failed, given that X of its subsystems have failed.

Now, the probability that exactly X subsystems have failed at time t is given by the binominal equation:

$$P(X, t) = \binom{N}{X} \left(1-e^{-\lambda t}\right)^{X} \left(e^{-\lambda t}\right)^{N-X},$$

where N represents the total number of subsystems, and λ, the average subsystem failure rate. The two conditional probabilities F(X) and P(X, t) can be combined to produce the statistical estimate of the reliability at time t,

$$R(t) = 1 - \sum_{X=0}^{N} F(X)\, P(X, t).$$

The combinational factorial $\binom{N}{X}$ is computed for each value of X, by subroutine COMFAC.

To compute the time of 0.90 reliability, the program uses a method of trial and error, computing the reliability for some time t, and readjusting the value of time for the next trial, based on the reliability estimate obtained with the first time. This process is repeated until the reliability estimate obtained is within the interval 0.90 ±.001.

The value of time used for the first trial is chosen so that the number of trials needed to complete the estimate is relatively small. The first estimate is obtained in the following manner. As mentioned above, the program contains a subroutine, TIME, which computes the time-to-failure for each subsystem failure. During the first 25 simulations, this subroutine is called after each subsystem failure is generated. This subroutine effectively draws a random number from an exponentially distributed set of numbers, based on the assumption that all subsystems have a constant failure rate. The program totals all the times between subsystem failures, obtaining, at the end of a simulation, the total system time to failure. The MAIN program stores in ascending order, the five shortest times of the first 25 simulations. Then the longest of these five, called T1, is used to compute the first approximation to the 0.90 reliability time. The actual time used in the first trial is 0.7 (T1). Subroutine TIME is not used by the program after the first 25 simulations of each system.

2. Results Printout

There are two options for the amount of printout obtainable from the simulations. The "No Sample Format" flag, NSF, specifies which option is used.

a. No Sample Format Option (NSF=1)

First, a listing of most of the input data variables and constants is printed to provide a permanent record with the results identifying the type of system simulated. Next, the portion of the spare lists which was read in as data is printed, as a further identifying record. If a "missing block" list was used, it is printed. The histogram of the number of systems failing with X subsystem failures, computed after all simulations of the system, is printed in tabular form. After each of the trials in the reliability estimation procedure, the value of time used and the probability of system failure (which is 1 - Reliability) are printed, until the 0.10 value is reached. The average number of subsystem failures per simulation is printed below the reliability computation results, followed by a final listing of the system's 0.90 reliability time.

b. Sample Format Option (NSF=0)

This printout option is used mainly as a check on the operation of the program. An extremely large amount of printout results from this option whenever more than a few simulations of a system are requested. All of the information printed under the first option just described is also printed with this option. In addition, the program prints a complete list of the contents of the system representation matrix before the simulation is begun. The first item to be printed is a list of the limits of the "failure interval" for every subsystem, followed by the ID numbers for all of the subsystems. The complete spare list for every subsystem is printed after the lists are stored in the system matrix. During the simulation, the MAIN program prints every subsystem failure which occurs, listing the location in the matrix of the failed subsystem, its ID number, the generated random number which designated the subsystem as failed, the random number specifying the time since the previous failure, and the time itself. The last two quantities will not apply after the first 25 simulations of a given system, since subroutine TIME is not used.

After the occurrence of each system failure, MAIN prints the average time between subsystem failures, the total system time-to-failure, and the total number of subsystem failures. Again, the times do not apply after the first 25 simulations of each system.

If the system fails because no spare is available for a stage in need of a spare, subroutine SWITCH prints a list of all ID numbers in the system, in the order in which they are located in the system representation matrix. This list shows where each subsystem is located in the system.

Examples of the printout obtained from both options are shown in Appendix B.

3. Program Size Limitations

The number of simulations which can be performed for each system is restricted only by the computer memory size. Results from each of the simulations are stored in memory until all simulations of a system have been completed. The results of all of the simulations are used to compute the system performance statistics. Therefore the amount of memory needed to store all individual simulation results is proportional to the number of simulations performed (NR).

The main restriction imposed by memory space is the size of the system itself. The system representation matrix, B, and its duplicate matrix C, utilize the largest portion of the computer memory when large systems are simulated. The program, listed in Appendix C, was run on a UNIVAC 1107 computer with a 32K word memory. The dimension statements at the beginning of the MAIN program provided sufficient memory for the operation of the program. Storage is provided for a twenty stage, order five system, with eleven spares per subsystem.

The computer memory size imposes no restriction on the number of systems simulated during each program run, because a new input data deck is read in for each system, cancelling the input data for the previous system.

In general, for systems much larger than the size mentioned above, and for significantly more than 500 to 1000 simulations per system, a memory larger than the 32K memory may be required.

B. Subroutine ALOCAT

Random failures are generated in the system by selecting a number from a uniformly distributed set of random numbers between zero and one. The number thus generated is used to find the "failed" subsystem by searching through the system representation matrix for the location containing an interval of numbers in which this generated number falls.

The function of subroutine ALOCAT is to assign to each subsystem the interval of numbers, the size of which is proportional to the subsystem's failure rate. The interval, F, for subsystem j, whose failure rate is λj, is given by the equation:

$$F = \frac{\lambda_j}{\sum_{i=1}^{x} \lambda_i} ,$$

where X is the total number of subsystems.

When the interval is computed for each subsystem, the limits of the interval are stored in locations B (I, J, 1) and B (I, J, 2). These two locations for each subsystem are examined when a random number is generated, until the "failed" subsystem is located.

Subroutine ALOCAT is called only by the MAIN program.

C. Subroutine COMFAC

This subroutine computes the combinational factorial,

$$\text{FACTL} = \binom{X}{Y} = \frac{X!}{Y!\,(X-Y)\,!} .$$

This factorial is used, together with the simulation results, to obtain the statistical reliability estimate. The actual variables used in the above formula are $\binom{\text{IPROD}}{\text{LL}}$, where IPROD is the total number of subsystems operating at simulated time zero, and LL is a dummy variable representing the number of subsystem failures absorbed at system failure. LL is incremented in the MAIN program from 0 to the maximum number of subsystem failures absorbed, and the combinational factorial is computed for each value of LL.

Subroutine COMFAC is called only by the MAIN program.

D. Subroutine DET

In order to identify each subsystem and to provide a means for listing different subsystems on spare lists, each subsystem carries an identification (ID) number. The function of subroutine DET is to assign an ID number to each subsystem, and store this number in the location B (I, J, 3) corresponding to the subsystem's location. For example, the subsystem in the second row of the fifth stage in matrix B, would have its ID number stored in location B (2, 5, 3).

The subsystems are numbered consecutively, starting at row one, stage one, and proceeding across row one to stage N, then to row 2, stage 1, etc.

Subroutine DET is called only by the MAIN program.

E. Subroutine FAIL

This subroutine generates the random failures throughout the system. Using a starting index, or argument, which has been read in as data, the subroutine calls UDRNRT, a FORTRAN library function for generating random numbers between zero and one. The program then searches through the system representation matrix until it locates the subsystem which has had a failure interval or range of numbers assigned to it, within which the generated random number falls. This is the subsystem which has "failed." If the program is unable to find such a subsystem, it (the subsystem) has either failed previously or is one of the "missing blocks." In this case, a new random number is generated and the search is repeated. When the "failed" subsystem is found, its failure interval is set to zero, and the program then counts the number of remaining subsystems in that stage. If the number is less than the value of input variable, MIN, the minimum number allowed before spare switching is necessary, a flag, S, is set. This will indicate to the MAIN program that a spare is needed for the stage.

The next quantity computed is the "failure order number" of the failed subsystem. Every subsystem in the system is assigned a failure order number, initially zero, stored in location B (I, J, 4). These numbers identify the order in which failures occur in each stage, by the following method. After the first failure in a given stage, the program stores a one in location B (I, J, 4) corresponding to the failed subsystem. After the second failure in the same stage, a two is stored in the corresponding B (I, J, 4), and so forth. (The "I" of this location is necessarily different from that of the failure location immediately preceding the current failure.) When a stage requires a spare, the subsystem which is replaced is not the most recently failed subsystem in the stage, but the previous failure. The failure order numbers are the means of locating this previous failure.

Subroutine FAIL also checks the number of subsystems remaining in a stage to determine whether there are any subsystems remaining in the stage. If not, the system has failed and the "system failure" flag, SYSFA, is set to one. If there is only one remaining subsystem and MIN ≥ 3, the system has failed. This is because MIN would be as large as three only in a system which could not tolerate the loss of a correct output signal, even for a single clock pulse. But the output would be temporarily incorrect if a stage were down to only one subsystem, even though a spare would be switched in to correct the output. Control of the program is then transferred to MAIN, which uses the information generated.

Subsystem FAIL is called only by the MAIN program.

F. Subroutine LIST

This subroutine reads in the spare list for a subsystem in stage N, and duplicates the pattern of spares for the rest of the system. There are two options for reading in the spare lists, controlled by MM, the common column spare list flag. If MM is zero, each of the subsystems in a column, or stage, has exactly the same spare list as the others, so a list is read in for one subsystem in stage N, and duplicated for the others. If MM equals one, a separate spare list is read in for each subsystem in stage N. For both values of MM, the spare list pattern is reproduced by the program for every subsystem in each row of the system matrix.

Subroutine LIST is called only if NRL=0, and is called only by the MAIN program.

G. Subroutine RANLIS

This subroutine generates random spare lists by calling the FORTRAN function UDRNRT (IRL)[2] which generates random numbers between zero and one. Each number is multiplied by the total number of subsystems, then increased by one, and changed to fixed point. This results in a number which is one of the subsystem ID numbers. If input variable, NOS, equals zero, a subsystem can have subsystems from its own stage on its spare list. If NOS=1, it cannot.

[2] "IRL" is any odd number.

The subroutine generates identical spare lists for all subsystems in a stage. Thus, for an N stage system, N different spare lists will be generated.

Subroutine RANLIS is called only if NRL=1, and is called only by the MAIN program.

H. Subroutine SBACK

This subroutine performs an operation called "spring-back," which in effect, calls a spare to a failed stage in order to "vote" the failed subsystem out of the system. Instead of remaining there after the subsystem is eliminated, however, the spare returns to its original location.

Subroutine SBACK is called by the MAIN program when subroutine FAIL indicates that a spare is needed in a certain stage. SBACK finds the previously failed subsystem in the stage, and scans its spare list. The subroutine contains a provision to "rescan" the spare list under weaker spare movement restraints if no available spare is found during the first scan. The scan and rescan procedure operates as follows.

An input data constant, called NOP1, specifies the number of operating subsystems which must remain in a spare's stage after a spare is taken from the stage. The program locates the first subsystem on the spare list and determines the number of remaining subsystems if the spare were switched. If it is less than NOP1, the next spare on the failed subsystem's list is examined, etc. If the program searches the entire spare list in this manner and finds no available spare, a new input data constant, NOP2, is brought into use. The program goes through the spare list once again, using NOP2 in exactly the same manner as NOP1. It is usually given a lower value. This allows the program to switch a spare from a stage with fewer operating blocks, if no spare were found available during the first scan of the spare list. (If NOP2 is equal to, or greater than, NOP1, the program does not rescan the spare list.)

If no available spare is found during either scan of a spare list, the system is failed. In this case, the system failure flag, SYSFA, is set to one, and control is returned to MAIN.

When the program does find an available spare, the spare is not actually transferred to the failed stage, but it is assumed that it has moved, that the failed subsystem has been eliminated from the voter inputs, and that the spare has returned to its original location as it would in an actual system utilizing a "spring-back" capability.

In the switching of spares, the MAIN program has a choice of two options, controlled by an input data constant, ISBAC. The first option is to call subroutine SBACK, in which case the spare is not actually switched, but simply located. This option is used when

ISBAC=1. If ISBAC=0, the second option is taken, that of calling subroutine SWITCH. In this case the spare would be moved to the failed subsystem's location and left there.

Thus, subroutine SBACK is called only when ISBAC=1, and it is called only by the MAIN program.

I. Subroutine SEARCH

This subroutine is called by subroutine SWITCH, to revise the spare lists after a spare has been switched to a new location. SEARCH performs one of two options, the choice of which is controlled by the dummy variable NREP. When NREP=0, the subroutine searches through all of the spare lists and removes ID number FAILB from every list on which it appears. When NREP=1, the subroutine removes FAILB and replaces it with ID number SPARE. FAILB is used as a dummy variable which may represent either a failed subsystem or the spare which has just replaced it in the system. The latter case would be used if each spare may replace a subsystem only once, in which case it is removed from all spare lists as soon as it has replaced a failed subsystem. SPARE represents the ID number of the spare which has just repaired a failed stage. It replaces the failed subsystem ID on all spare lists when it is desired that spares take over the repair capability of the subsystems which they are replacing.

Subroutine SEARCH may also be called by the MAIN program, if there are any missing blocks to be removed from the system before simulation is initiated. Since these subsystems are not in the system, they must be removed from the spare lists. MAIN calls SEARCH, with FAILB equal to BML(KK), the ID number of a missing block, and SPARE and NREP equal to zero. These three arguments indicate to subroutine SEARCH that ID number BML(KK) is to be removed from all spare lists on which it appears.

Subroutine SEARCH is called only by the MAIN program and subroutine SWITCH.

J. Subroutine SWITCH

This subroutine performs the search for, and switching of spare subsystems to "repair" failed stages. After switching a spare, the subroutine handles the necessary transfer of information within the system representation matrix.

SWITCH performs the search for a spare in exactly the same manner as that of subroutine SBACK. The details of this procedure can be found above, in the section on subroutine SBACK. After finding a spare, the program determines what alterations should be made to the spare lists which contain ID numbers of the failed subsystem and the spare which is replacing it. The type of alteration is controlled by the input data constant ISW2, which can have one of three values. If ISW2=0, the spare's ID number is left on the lists, and only the failed subsystem's ID is removed. When ISW2=1, both the spare and the failed subsystem are removed. If ISW2=2, the spare's ID is removed from the lists, and the failed subsystem's ID is replaced by the spare's ID. SWITCH calls subroutine SEARCH to make the actual spare list changes, using as arguments the necessary ID numbers and values for NREP. This latter variable specifies whether SEARCH should perform a removal or a replacement operation.

After revising the spare lists, SWITCH transfers the spare's information to its new location in the system representation matrix. The first four locations of the spare's information block are always transferred. These locations contain: the two limits of the failure interval computed in subroutine ALOCAT, the spare's ID number, and the spare's "failure order number." The latter location must, of course, be zero, since the spare must be an operating subsystem.

The program next alters the spare list of the spare's new location, if necessary. The input data constant ISW1 specifies which of three operations must be performed. If ISW1=0, the original spare list of the failed subsystem is retained at the location when the spare information is transferred to that location. When ISW1=1, the spare's own spare list is transferred to the new location, and the original list discarded. If ISW1=2, the spare list of the spare's new location is deleted entirely.

Next, subroutine SWITCH returns to the original location of the spare and sets its failure range, which was computed in ALOCAT, to zero. The program then computes the failure order number for the spare's original location, since, as far as that stage is concerned, the spare is essentially failed. SWITCH now returns control to the MAIN program.

As explained in the section on subroutine SBACK, subroutine SWITCH is called only when ISBAC=0; and it is called only by the MAIN program.

K. Subroutine TIME

This subroutine computes the estimated time to failure of a failed subsystem, by using a method of random number generation. Each subsystem is assumed to have a constant failure rate, λ . Thus, the probability of continuous operation of all subsystems from time $t=0$ is given by the expression,

$$R(t) = e^{-\sum_{i=1}^{N} \lambda_i t} ,$$

where N is the total number of subsystems in the system. Therefore the probability of the first failure occurring by time t is given by

$$P(1) = 1 - e^{-\sum_{i=1}^{N} \lambda_i t} .$$

In order to simulate random failures corresponding to this exponential distribution, the numbers must be chosen from an exponentially distributed set of numbers. However, it is known that a set of random numbers taken from a population uniformly distributed between zero and one may be transformed to a similar set of random numbers belonging to any other distribution. This is what is done in subroutine TIME. The FORTRAN random number generation function UDRNRT (IR) is used to draw a number at random from a set uniformly distributed between zero and one. This number, RNT, is transformed to correspond to an exponentially distributed set by the equation

$$T = \mathrm{Ln}(RNT)/(-Y),$$

where

$$Y = \sum_{i=1}^{N} \lambda_i .$$

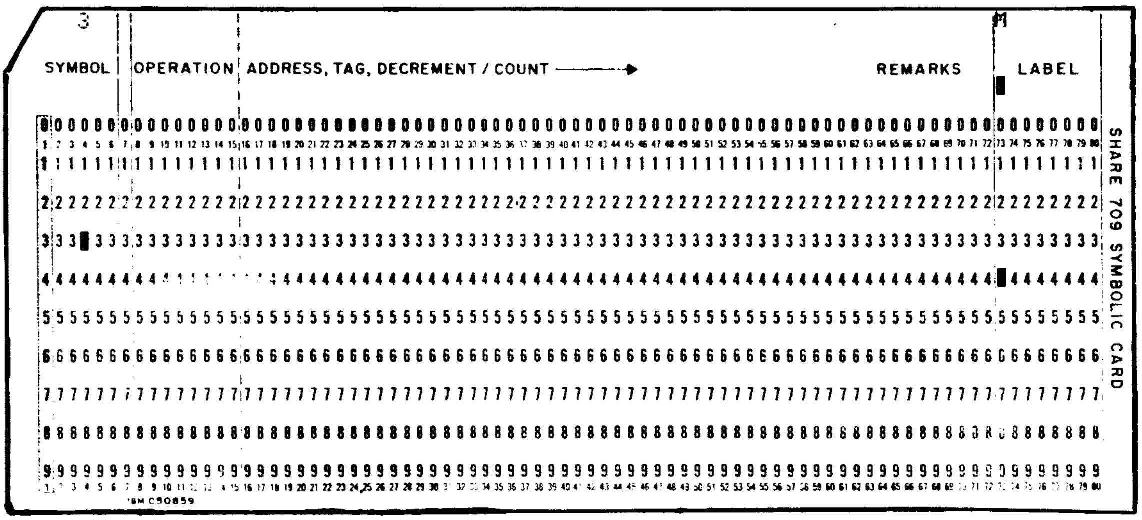
This gives the time to the failure of the first subsystem, with failure rate λ_j. Similarly, the time from the first to the second failure is generated by subtracting λ_j from Y and repeating the procedure.

Subroutine TIME is called only by the MAIN program, after a failure has been generated by subroutine FAIL.

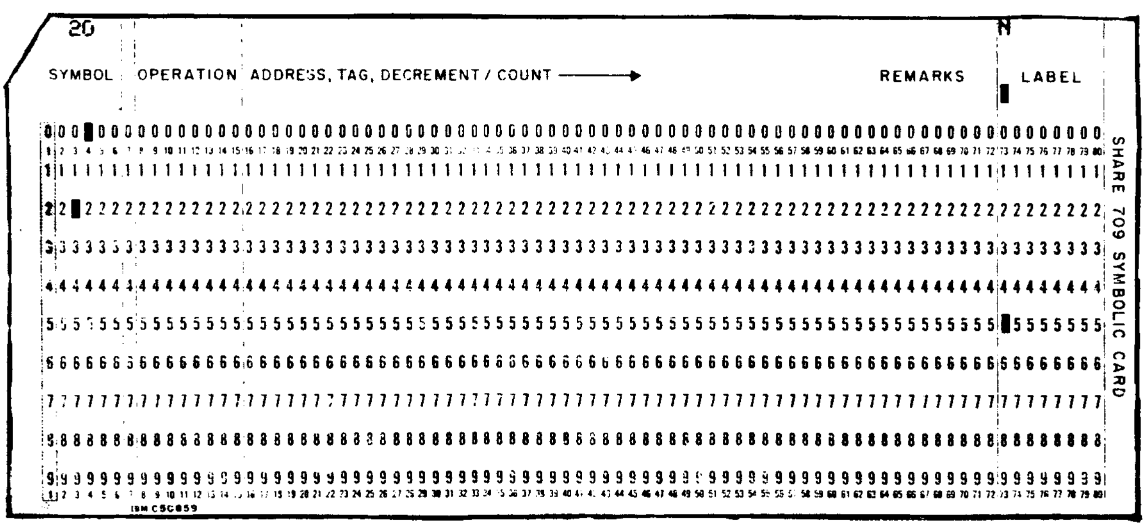
IV. INPUT DATA CARD FORMAT

This section describes the formats of all of the input data cards, in the order in which they must appear in the data deck.

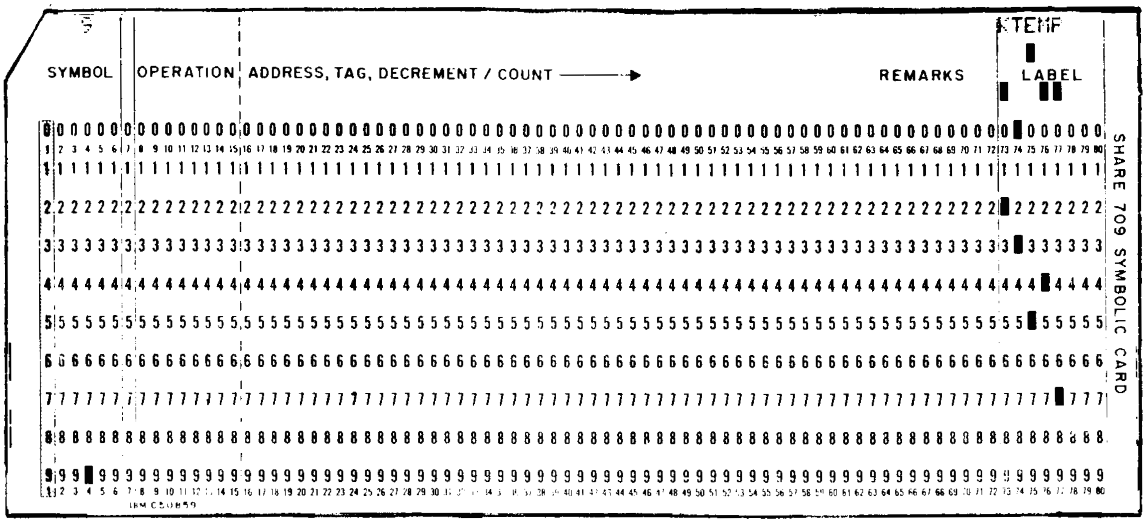
M - Format (I4), right justified. M is equal to, in general, the order of redundancy of the system being simulated. However, for systems containing fractional orders of redundancy or those in which voters or other peripheral circuitry are considered to be separate stages, M might not be equal to the order of redundancy.



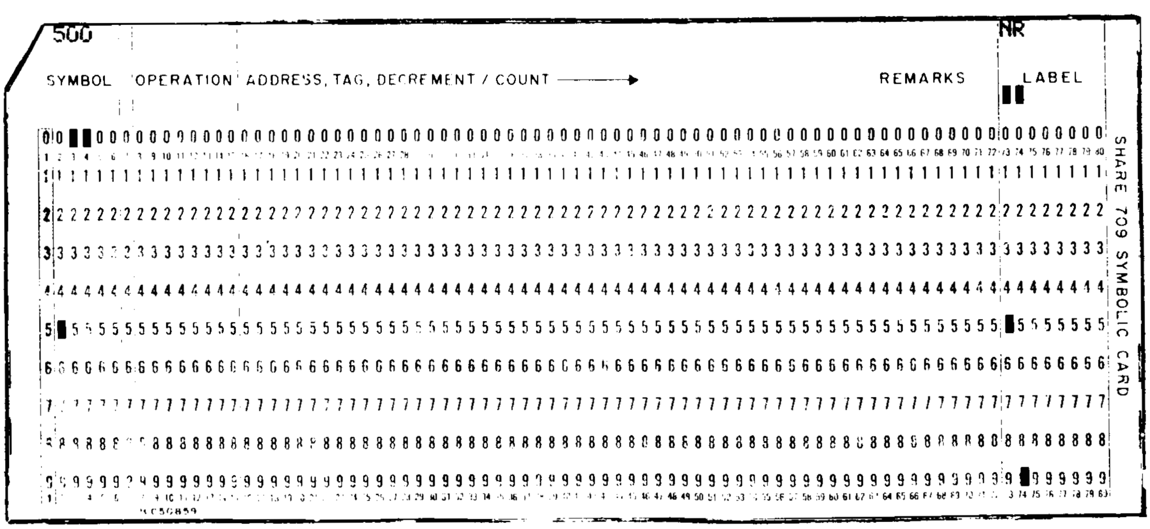
N - Format (I4), right justified. N is equal to the number of stages in the simulated system.



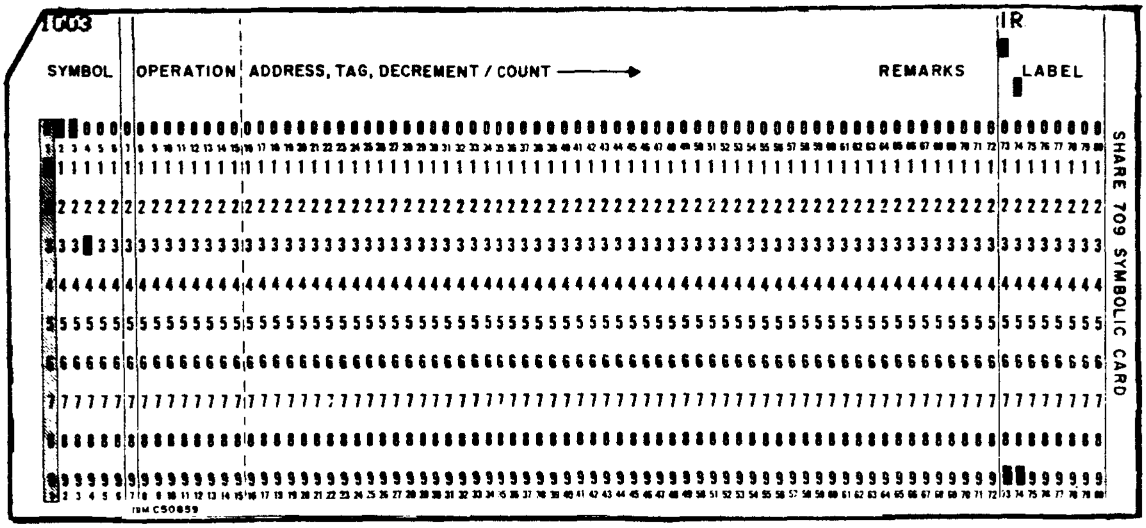
KTEMP - Format (I4), right justified. KTEMP is the third dimension of the system representation matrix B. Its value is equal to the total number of "pieces" of information to be stored for each subsystem. KTEMP = 4 + Length of the longest spare list.



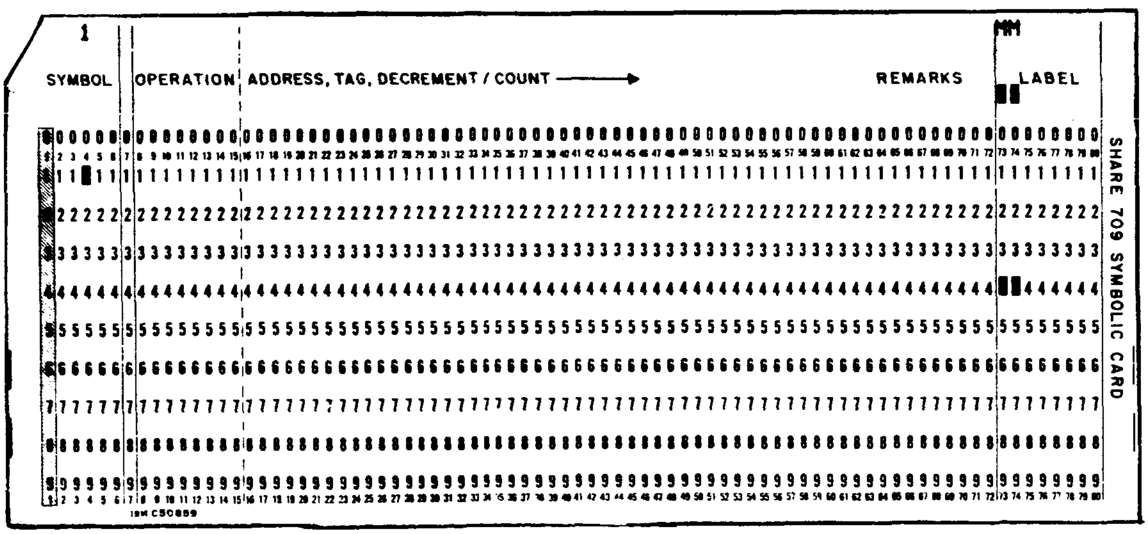
NR - Format (I4), right justified. This is the number of runs, or simulations, to be performed on the system.



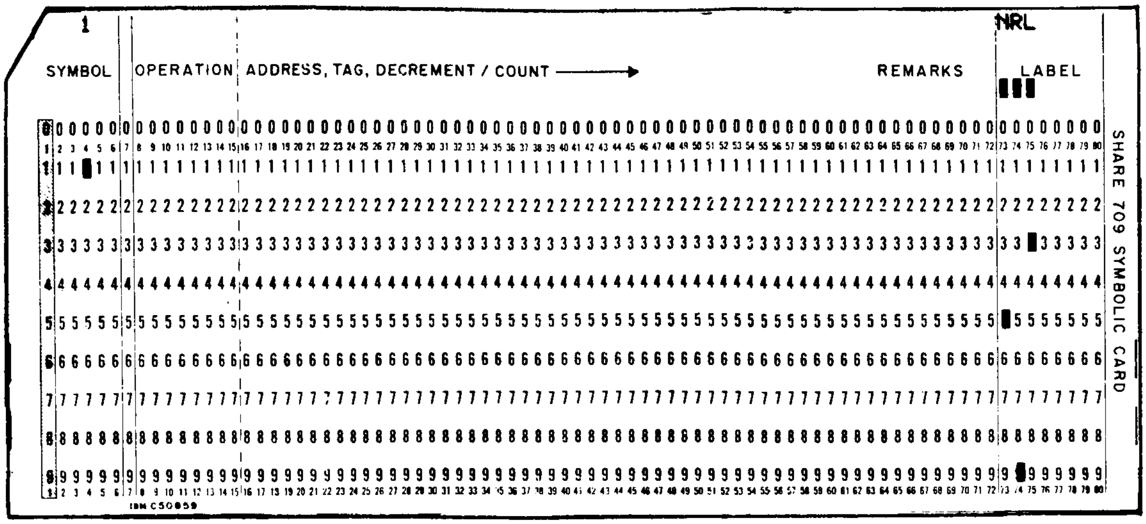
IR - Format (I4), right justified. IR is a starting number for the random number generating routine UDRNRT (IR). It must be any odd number.



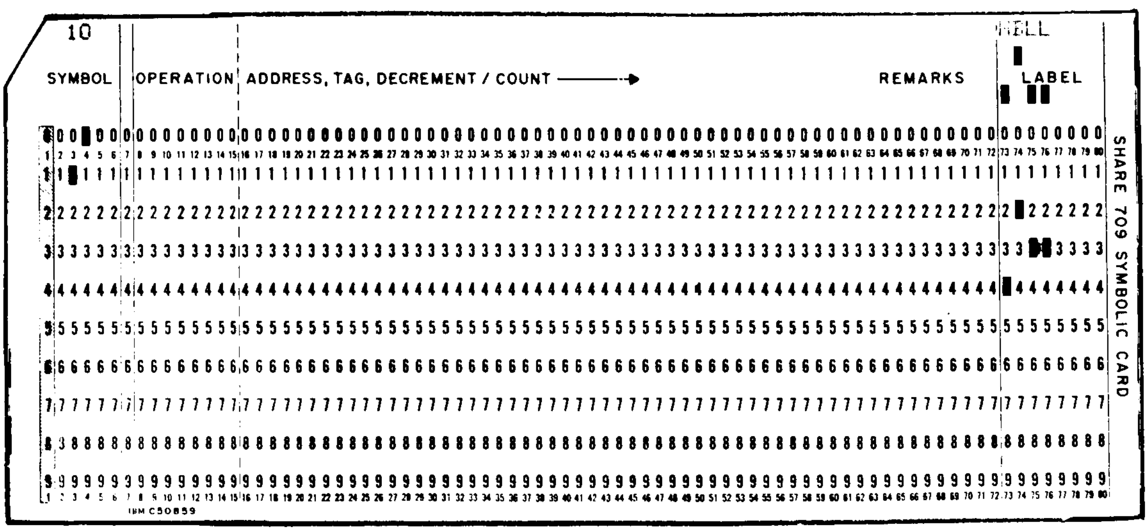
MM - Format (I4), right justified. MM is the common column spare list flag, which specifies whether or not the spares in a stage share a common spare list. MM can be either 0 or 1. The value of MM is used by the program only if NRL = 0.



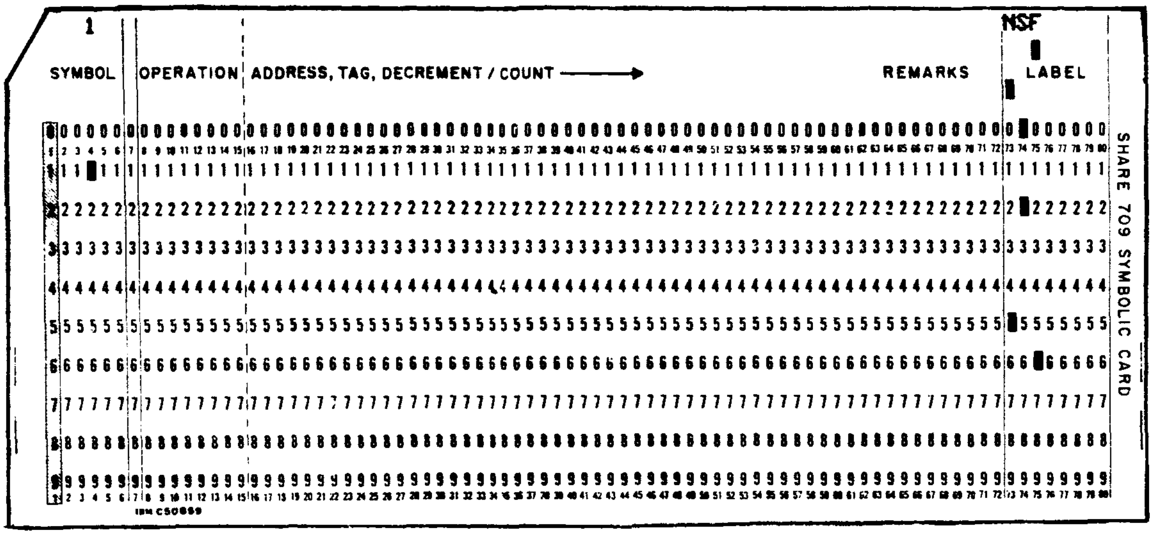
NRL - Format (I4), right justified. This is the non-repetitive list flag, which specifies whether the spare list will be read in by subroutine LIST (NRL = 0), generated by subroutine RANLIS (NRL = 1), or read in by the MAIN program (NRL = 2).



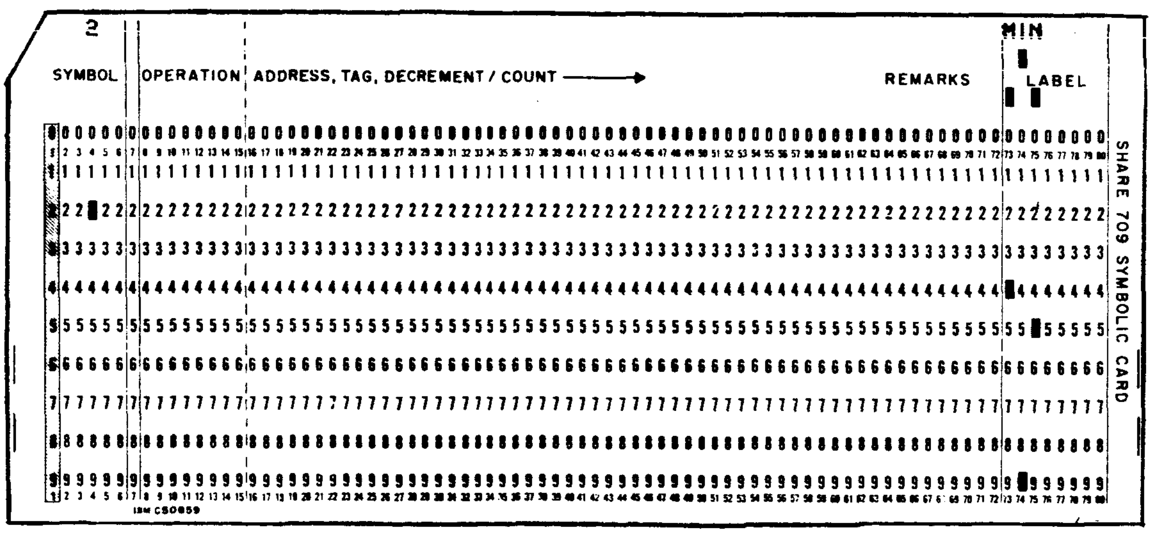
MBLL - Format (I4), right justified. MBLL is the missing block list length, which specifies the number of subsystems which are either failed or not included in the system at the start of the simulations.



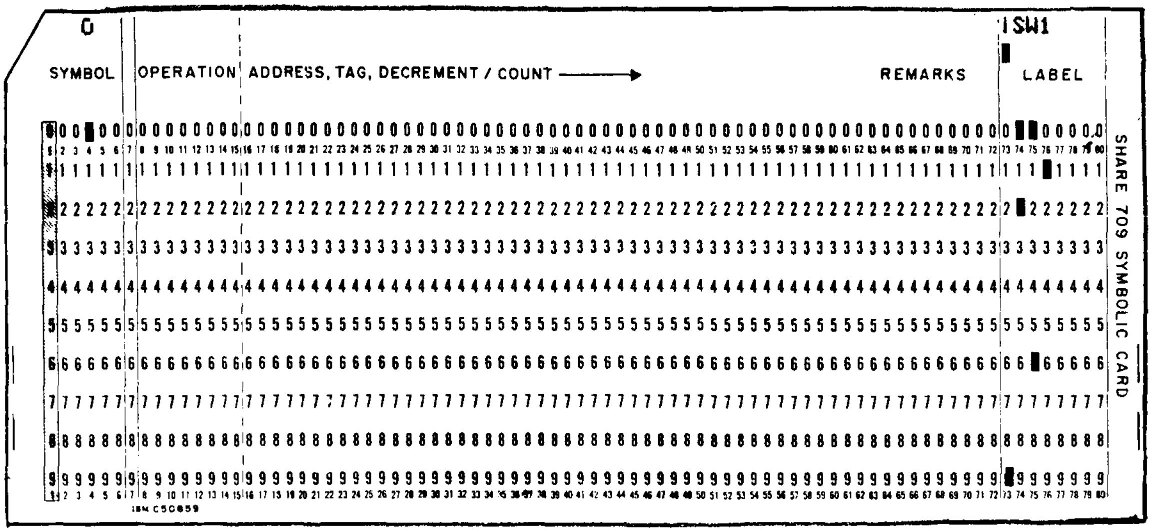
NSF - Format (I4), right-justified. NSF is the "No Sample Format" flag, which specifies whether the printout will be a complete listing of the system's failure response during every simulation (NSF = 0), or simply a listing of the statistical results of the simulations (NSF = 1).



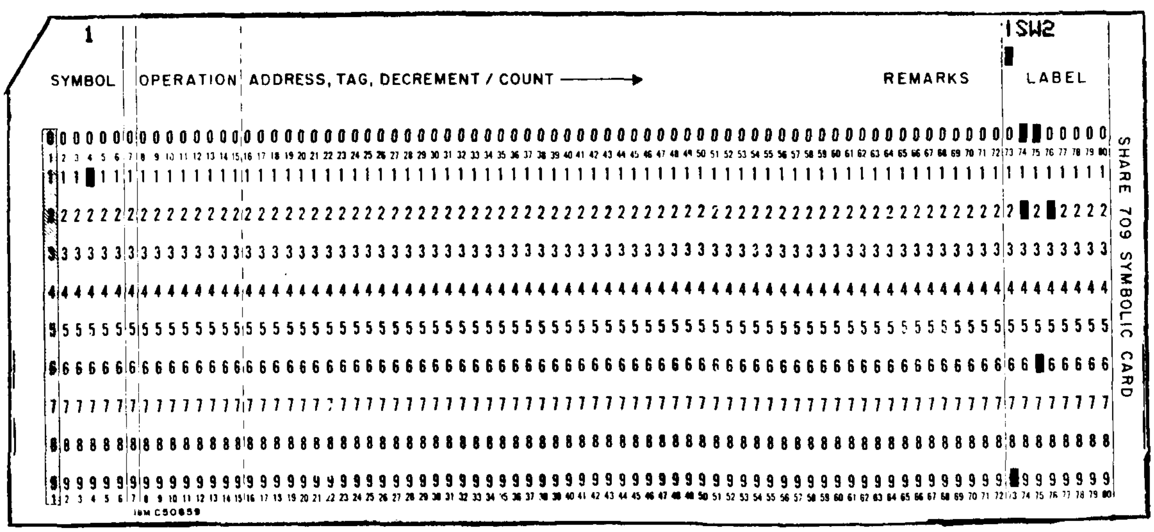
MIN - Format (I4), right-justified. This is the minimum number of operating subsystems required per stage, such that no spare switching, or reorganization, is necessary anywhere in the simulated system.



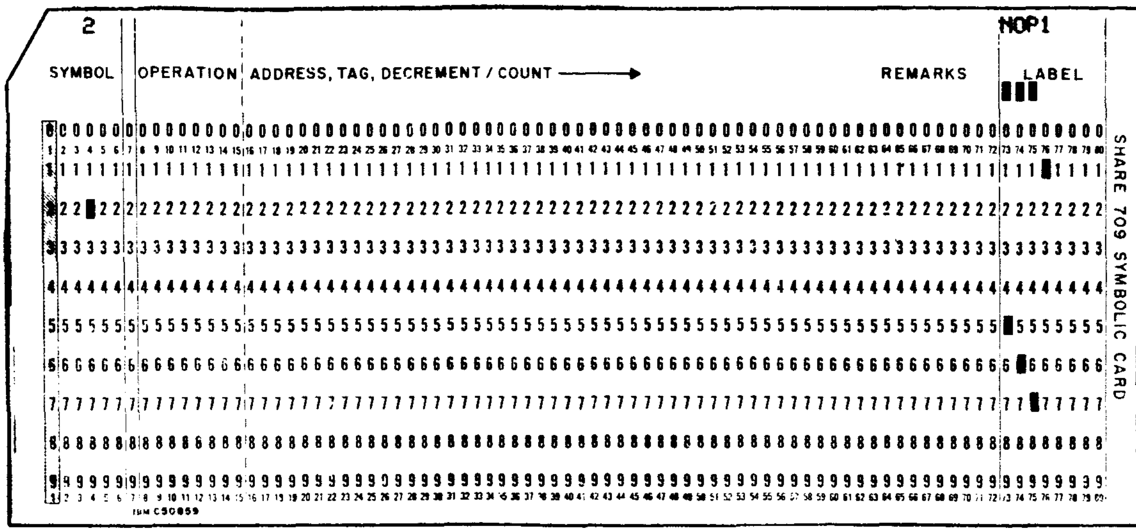
ISW1 - Format (I4), right-justified. This constant determines what the program does to the spare list of a failed location after that location obtains a spare. ISW1 may have one of three values, 0, 1, or 2, the determination of which is explained in the list of program variables and constants.



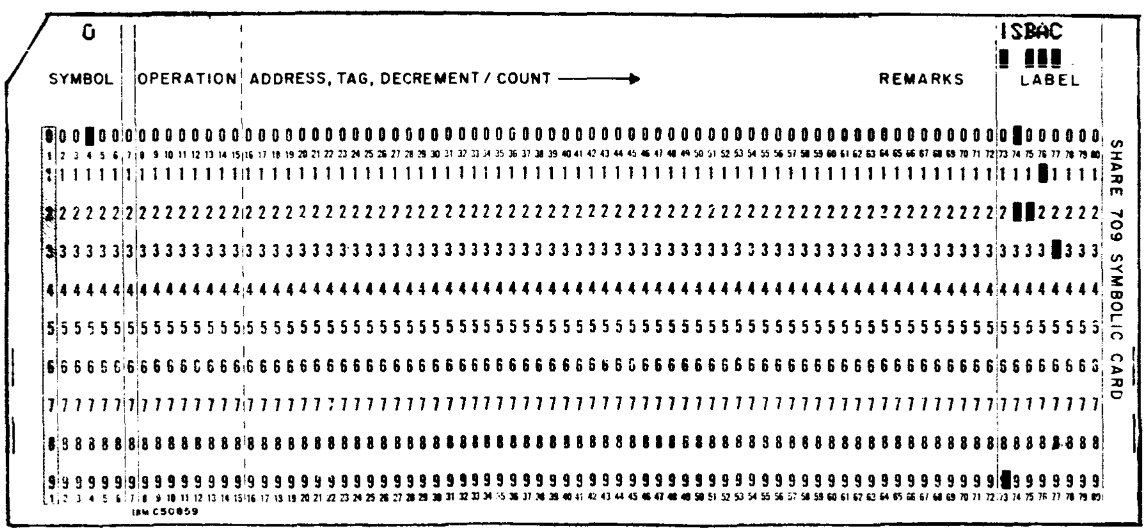
ISW2 - Format (I4), right-justified. This constant determines what the program does to the spare lists which contain the ID numbers of a failed subsystem and the spare which replaces it. The three permissable values for ISW2 are explained in the list of program variables and constants.



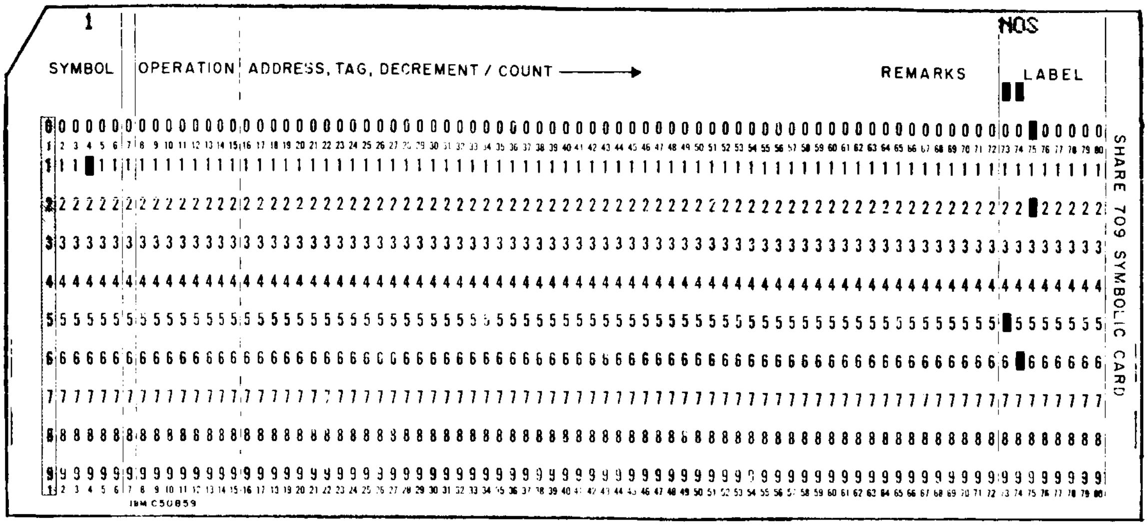
NOP1 - Format (I4), right-justified. NOP1 is used during the first "scan" of a failed location's spare list. It is the minimum number of operating subsystems which can be left in a stage if a spare is taken from that stage.



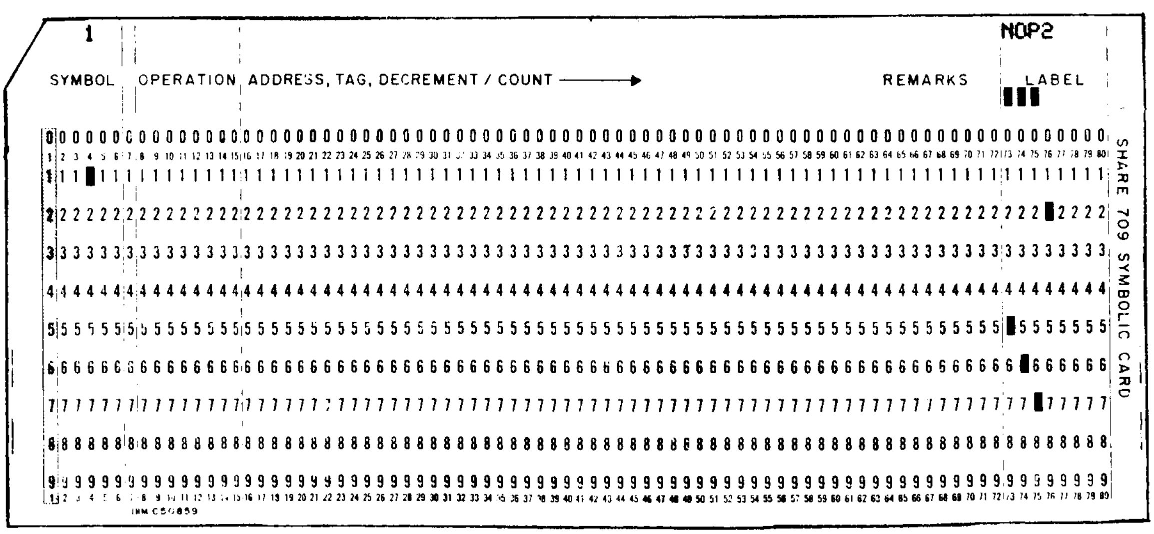
ISBAC - Format (I4), right-justified. This constant determines if available spares are switched to different locations as needed (ISBAC = 0), or if they are simply found, but left where they are (ISBAC = 1).



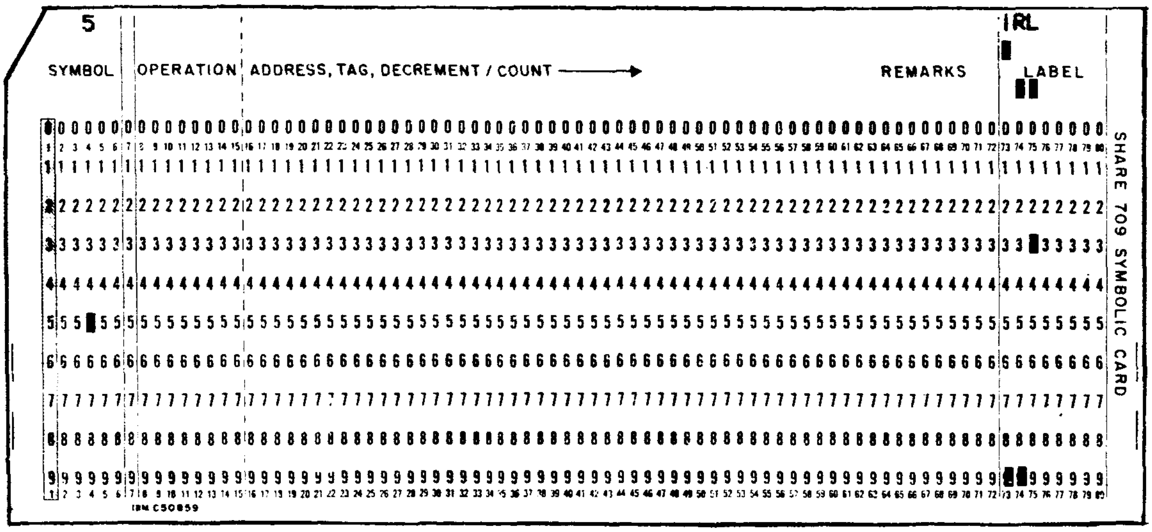
NOS - Format (I4), right-justified. This is the "No Own-Stage Spare" flag used in the random spare list generation routine, RANLIS. NOS determines whether a subsystem may have a subsystem from its own stage on its spare list (NOS = 0), or may not (NOS = 1). The value of NOS is used by the program only if NRL = 1.



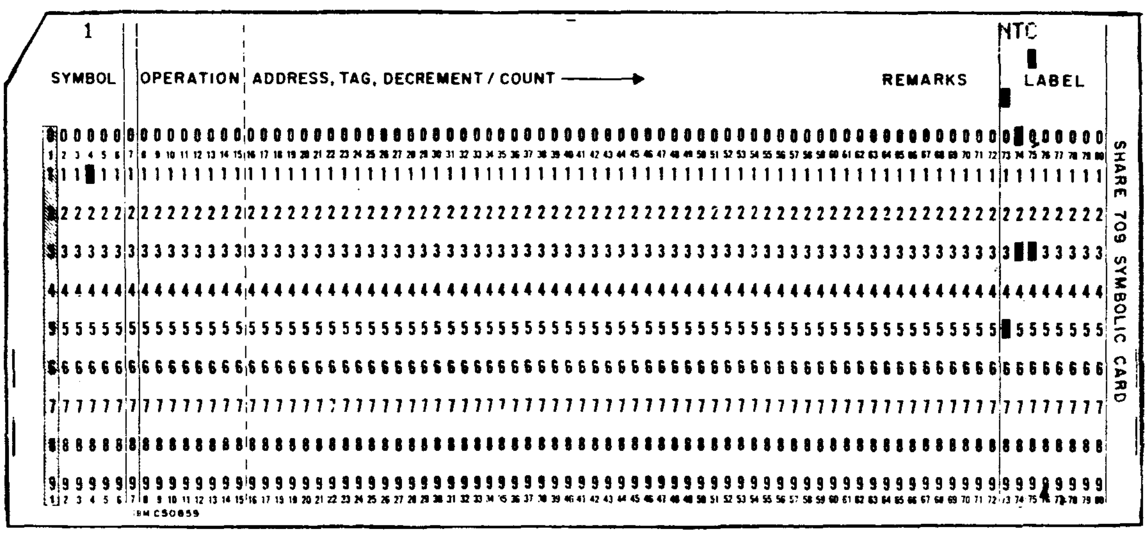
NOP 2 - Format (I4), right-justified. NOP2 is used during a "rescan" of a failed location's spare list. The list is rescanned only if no spares were available with the NOP1 criterion during the first scan. NOP2 is the minimum number of operating subsystems which can be left in a stage if a spare is taken from that stage during a rescan.



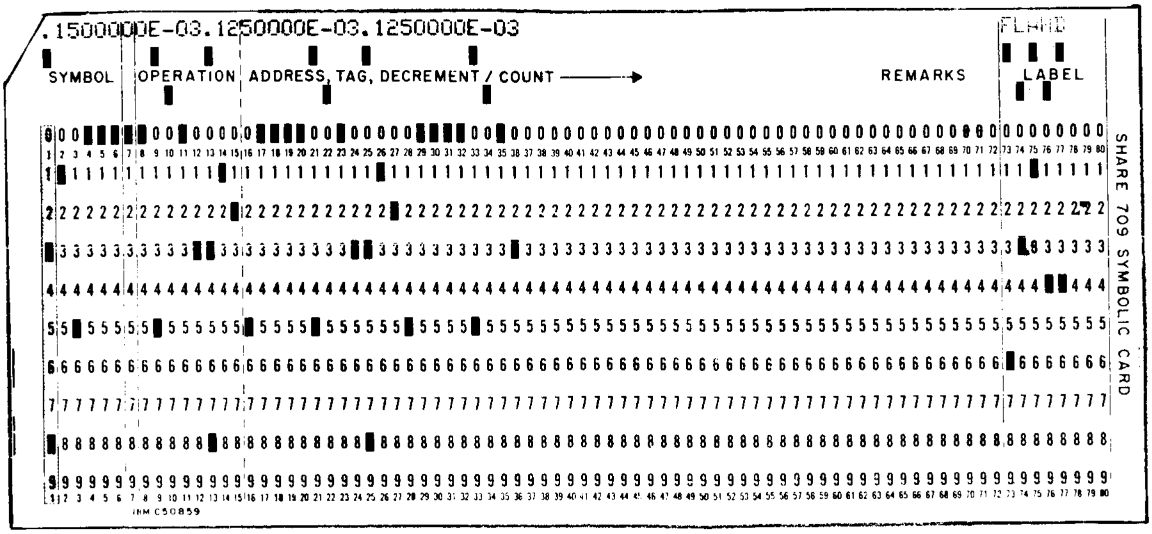
IRL - Format (I4), right-justified. This is the starting index for the random spare list generating routine UDRNRT (IRL), used in subroutine RANLIS. IRL must be any odd number.



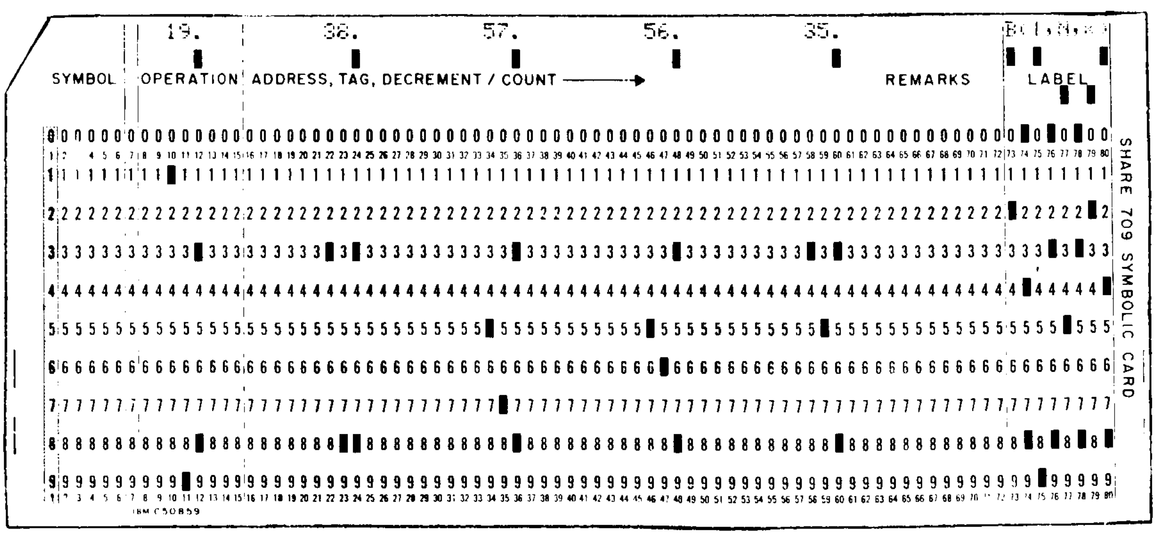
NTC - Format (I4), right-justified. This is the "No-Time-Curve" flag, which determines whether the program will compute and print out the Reliability-vs-Time curve, over Time from 0 to 5000 units (NTC = 0), or just the 90% Reliability Time or "Useful Life" (NTC = 1).



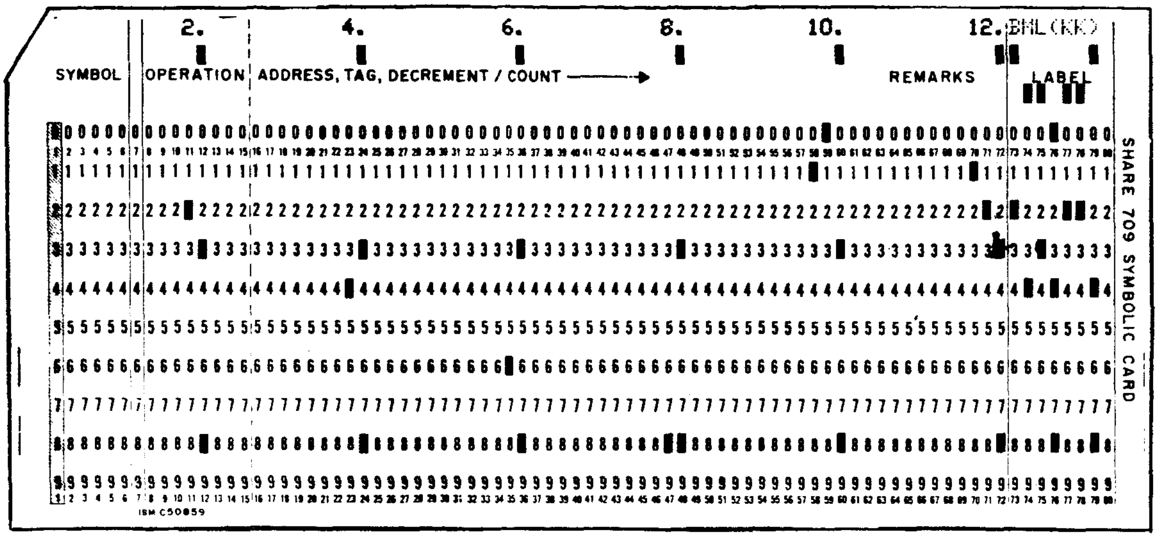
FLAMD(I), I = 1, M. Format (5E12.6), including decimal points. FLAMD(I) is the failure rate of the subsystems in the I^{th} row of the system representation matrix, together with their associated circuitry.



B(I, N, K), K = 5, KTEMP. Format (6 F12.0), including decimal points. This is the spare list for the subsystem in row I, column N of the system representation matrix. The values read in are the ID numbers of the subsystems which will be called, in the order in which they appear on the list, to replace the subsystem.



BML(KK), KK = 1, MBLL. Format (6 F12.0), including decimal points. This is the list of "missing blocks"; that is, ID numbers of subsystems which are to be considered by the program as either failed or not included in the system at simulated time zero.



V. LIST OF PROGRAM VARIABLES AND CONSTANTS

AMEAN - Non-subscripted variable-equal to the mean-time-to-failure of a given system, computed from all of the simulations of that system.

AUGT - Non-subscripted variable-equal to the average time between subsystem failures in a given system.

AVLAMD - Non-subscripted variable-equal to the sum of the failure rates of all subsystems in a given system.

B - Subscripted variable matrix which stores a mathematical model of the system being simulated, together with information specifying the instantaneous "state" of the system.

BML - Subscripted variables, equal to the identification numbers of the "missing blocks", which are subsystems considered either failed or not included in the system at time = 0.

C - Subscripted variable - matrix which stores the initial condition of matrix B during the simulation. This information is used to reset matrix B before another simulation of the same system is initiated.

CON - Non-subscripted variable - Average of the failure rates of all subsystems which are operational at time = 0.

CNT - Non-subscripted variable-equal to the total number of operational subsystems at the beginning of a simulation.

FAILB - Non-subscripted variable-equal to the identification number of the most recently failed subsystem.

FAL - Non-subscripted variable - value denotes the "failure order number" of the second most recently failed subsystem in the stage of the most recent failure. If a "repair" is necessary, this subsystem is replaced, not the most recent failure.

FAVGF - Non-subscripted variable-equal to the average number of subsystems failing per system simulation, computed from all of the simulations of a given system.

FLAMD - Subscripted constants - equal to the failure rates of the subsystems, plus those of their associated switching circuitry. All subsystems in the same row have the same failure rate.

IR - Non-subscripted variable - indexing number for the random number routine UDRNRT (IR). IR is initially an odd integer starting number for the routine.

IRL - Non-subscripted variable - starting index for the random spare list generating routine UDRNRT (IRL). IRL is initially an odd integer.

IRR - Non-subscripted variable - used to update IR after every simulation. This provides the generation of a different failure pattern for each simulation.

ISBAC - Non-subscripted constant - Determines whether or not available spares are switched. If ISBAC equals 0, spares are switched to new locations as needed. If it is 1, the program determines the availability of the spares, but does not switch them.

ISW1 - Non-subscripted constant, which determines what the program does to the spare list of a "repaired" location. The constant may have one of three values:

0 - Retain spare list of failed location

1 - Substitute spare list of spare's old location

2 - Delete spare list completely.

ISW2 - Non-subscripted constant, which determines what the program does to the spare lists which contain either a failed subsystem or the spare which replaced it. The constant may have one of three values.

0 - Leave spare's ID number on lists, and remove failed subsystem's.

1 - Remove spare's ID number from lists, and remove failed subsystem's.

2 - Remove spare's ID number from lists, and replace failed subsystem's ID with spare's ID number.

IW - Non-subscripted variable - equal to the instantaneous number of failed subsystems in a given system during simulation.

IWF - Subscripted variable - stores the total number of failed subsystems for each simulation of a particular system.

IWFT - Non-subscripted variable - stores the cumulative total number of failed subsystems for all simulations of a particular system.

KTEMP - Non-subscripted constant - equal to one dimension of matrix B, which stores the information specifying the instantaneous state of each subsystem, such as ID numbers, spare lists, failure order numbers, etc. Information for each subsystem is stored in locations B(I, J, K), where K = 1, ... KTEMP, and I and J are fixed.

M - Non-subscripted constant - equal to the order of redundancy of the system being simulated. M is one dimension of matrix B.

MBLL - Non-subscripted constant - Missing block list length; i. e. , the number of subsystems which are considered either failed or not included in the simulated system at t = 0.

MIN - Non-subscripted constant - equal to the minimum number of operating subsystems required in each stage of a particular system, so that no spares are required anywhere in the system.

MM - Non-subscripted constant - Common column spare list flag, which specifies one of two conditions:

MM = 0 - all subsystems have the same spare list pattern, but none has a spare list identical to that of another subsystem.

MM = 1 - all subsystems have the same spare list pattern, and all subsystems in a stage have identical (common) spare lists.

MR - Non-subscripted variable - equal to the instantaneous total number of simulations which have been performed on a given system.

N - Non-subscripted constant - equal to the number of stages in the simulated system. N is one dimension of matrix B, which stores the system state information.

NI - Non-subscripted variable - equal to the "row" in the system in which a subsystem to be replaced is located. (Row refers to the row in matrix B).

NJ - Non-subscripted variable - equal to the stage in the system in which a subsystem to be replaced is located. (A stage is represented by a column in matrix B).

NOP1 - Non-subscripted constant - Minimum number of operating subsystems which can be left in a stage if a spare is taken from that stage. NOP1 is used during the first "scan" of a failed subsystem's spare list.

NOP2 - Non-subscripted constant - Minimum number of operating subsystems which can be left in a stage if a spare were taken from that stage, during a rescan of a failed subsystem's spare list. NOP2 is generally lower than NOP1. (Rescan is only performed if no spares are available during the first scan).

NOS - Non-subscripted constant - "No own-stage spare" flag, which is used in the random spare list generation routine RANLIS. NOS may have one of two values:

0 - Any subsystem may have a subsystem from its own stage on its spare list.

1 - No subsystem may have a subsystem from its own stage on its spare list.

NR - Non-subscripted constant - equal to the number of simulations, or runs, which the program is directed to perform on a given system.

NRL - Non-subscripted constant - Non-repetitive list flag, which specifies to the program the method of spare list generation to be used. NRL may have one of three values:

0 - A number of spare lists are read in and their patterns reproduced for the remainder of the lists, by subroutine LIST.

1 - Completely random spare lists are generated by subroutine RANLIS.

2 - A separate, non-repetitive spare list is read in for each subsystem, by the MAIN program.

NSF - Non-subscripted constant - "No sample format" flag, which controls the amount of printout obtained from the simulations. NSF may have one of two values:

0 - The contents of the entire system representation matrix B at the beginning of the simulation are printed out, plus the entire sequence of failures and repairs, and results of the simulation.

1 - A brief listing of simulation results is printed.

In both cases, the input data specifying the system to be simulated is printed.

NTC - Non-subscripted constant - No-time-curve flag, which specifies the amount of statistics to be compiled from the simulation results. NTC may have one of two values:

0 - The program computes and prints out the complete reliability-vs.-time curve for values of time from 0 to 5000 hours, in 100 hour intervals. The values are computed from the statistical results of all of the simulations.

1 - The program computes and prints out only the "useful life" of the system.

OPRT - Non-subscripted variable - equal to the running total of the system operating times during the first 25 simulations of a given system.

P - Subscripted variable - Before the overall simulation results are computed, P equals a histogram of the frequency of systems failing with exactly x sub-system failures. During overall results computation, P is converted to a list of the conditional probabilities that the system has failed, given that there are x subsystem failures.

PFAT - Non-subscripted variable - equal to the probability that the simulated system has failed at some time, t. (PFAT = f(t)). PFAT is computed from the statistical results of all simulations of a given system.

RNT - Non-subscripted variable - The random number in subroutine TIME, chosen from a uniformly distributed set of random numbers, and used to generate the time to failure of each failed subsystem.

S - Non-subscripted variable - generated by subroutine FAIL, and indicates, if non-zero, that the most recently generated failure has created a need for a spare.

SUM - Non-subscripted variable - equal to the sum of the failure rates of all sub-systems operating at the start of a simulation.

SUMT - Subscripted variable - equal to the running totals of the operating times of a particular system for every simulation of the system.

SYSFA - Non-subscripted variable - indicates to the program, if non-zero, that the system being simulated has failed.

T - Subscripted variable - A matrix used to store, in ascending order, the running times of the five shortest-lived of the first twenty-five simulations. The largest of the five is used in computing the first approximation to the "useful life" of the simulated system.

TI - Non-subscripted variable - the time used in the equations for computing the useful life or the reliability curve of the simulated system.

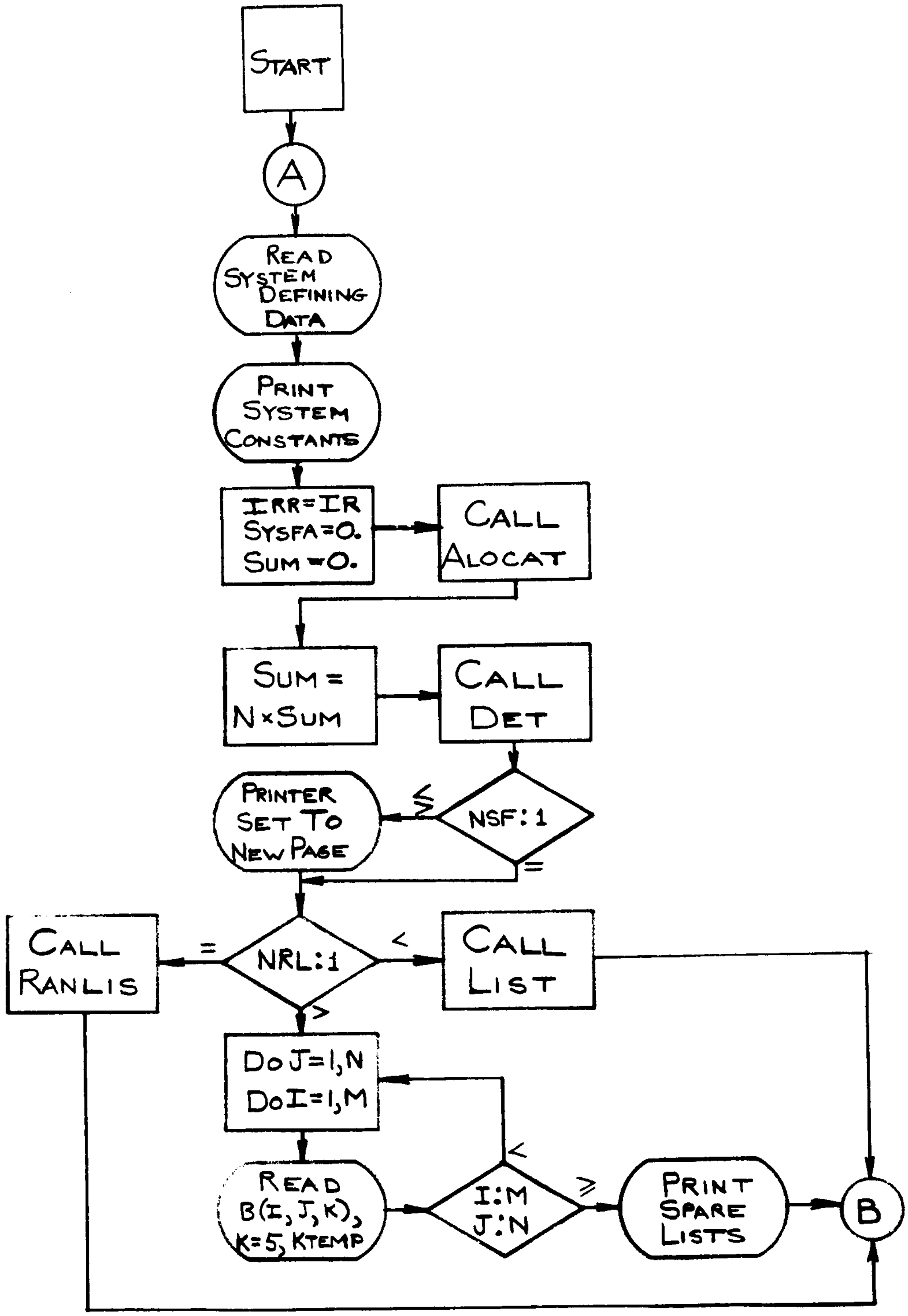
TT - Subscripted variable - Equal to the times between the subsystem failures for a given system simulation.

X - Non-subscripted variable - a random number generated in subroutine FAIL, which designates the subsystem which has failed. X is chosen from a uniformly distributed set of random numbers between zero and one.

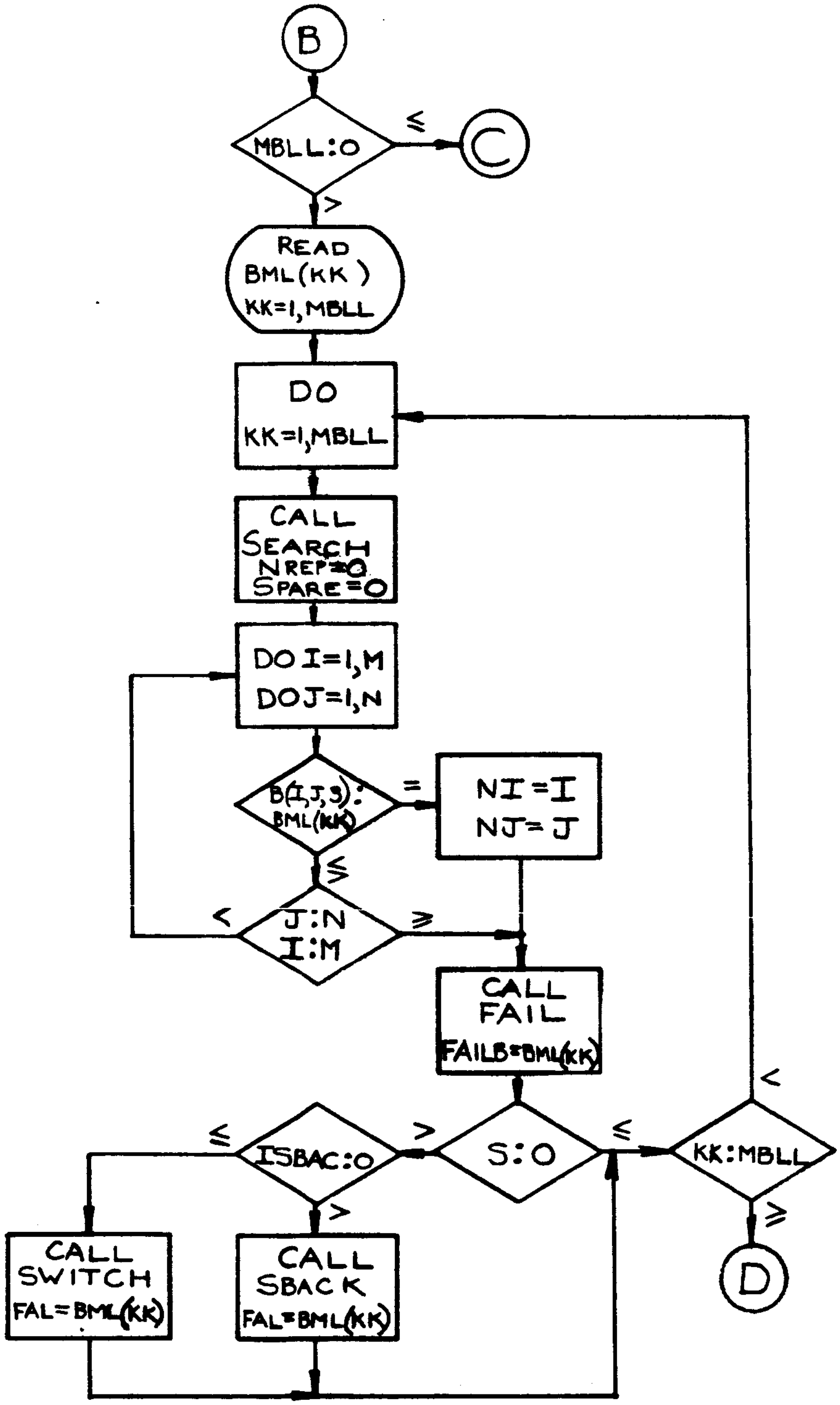
APPENDIX A

DETAILED FLOW DIAGRAMS

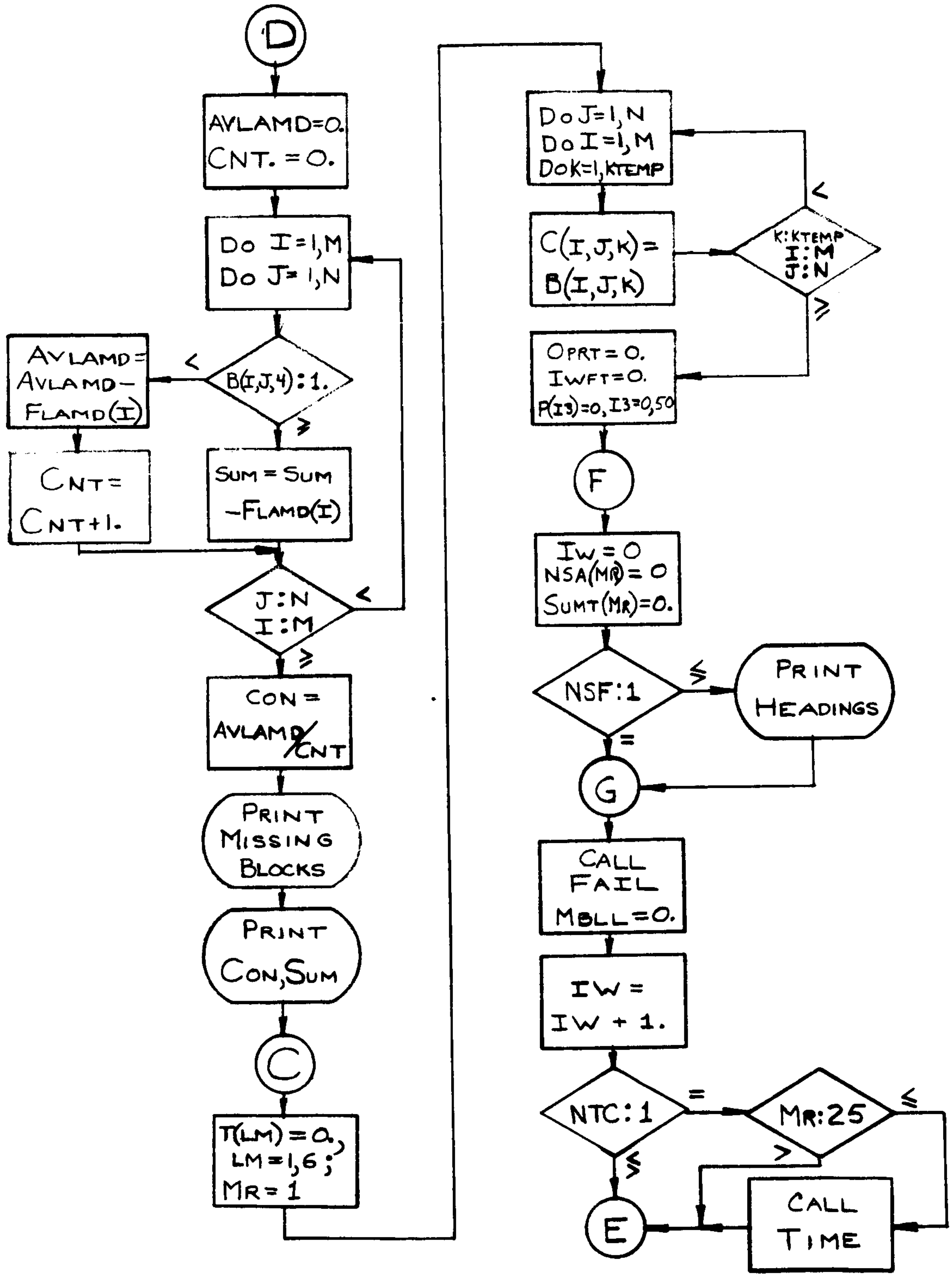
This section contains, first, a detailed flow diagram of the MAIN executive program, followed by flow diagrams of each of the ten subroutines, in alphabetical order.



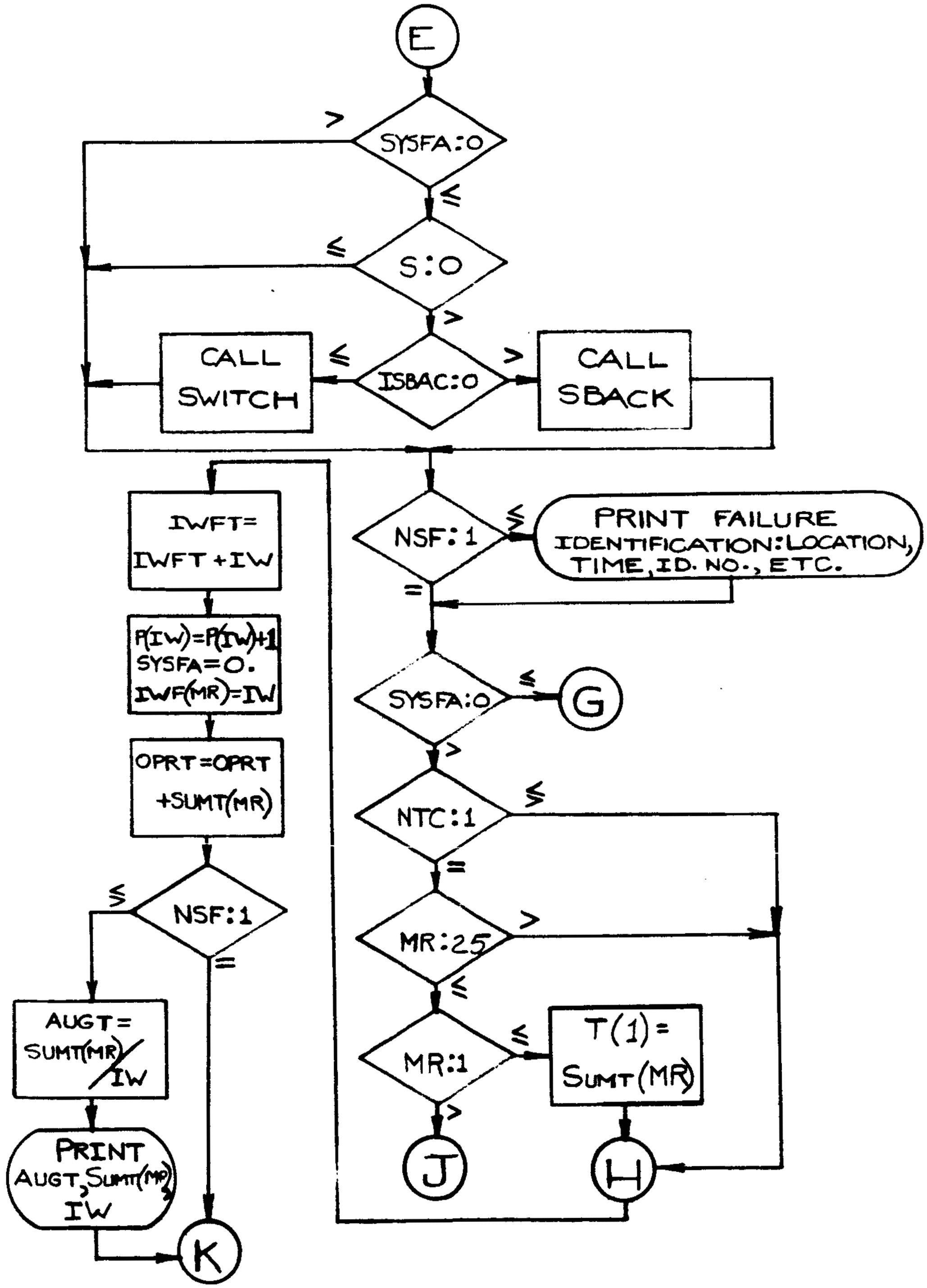
MAIN PROGRAM



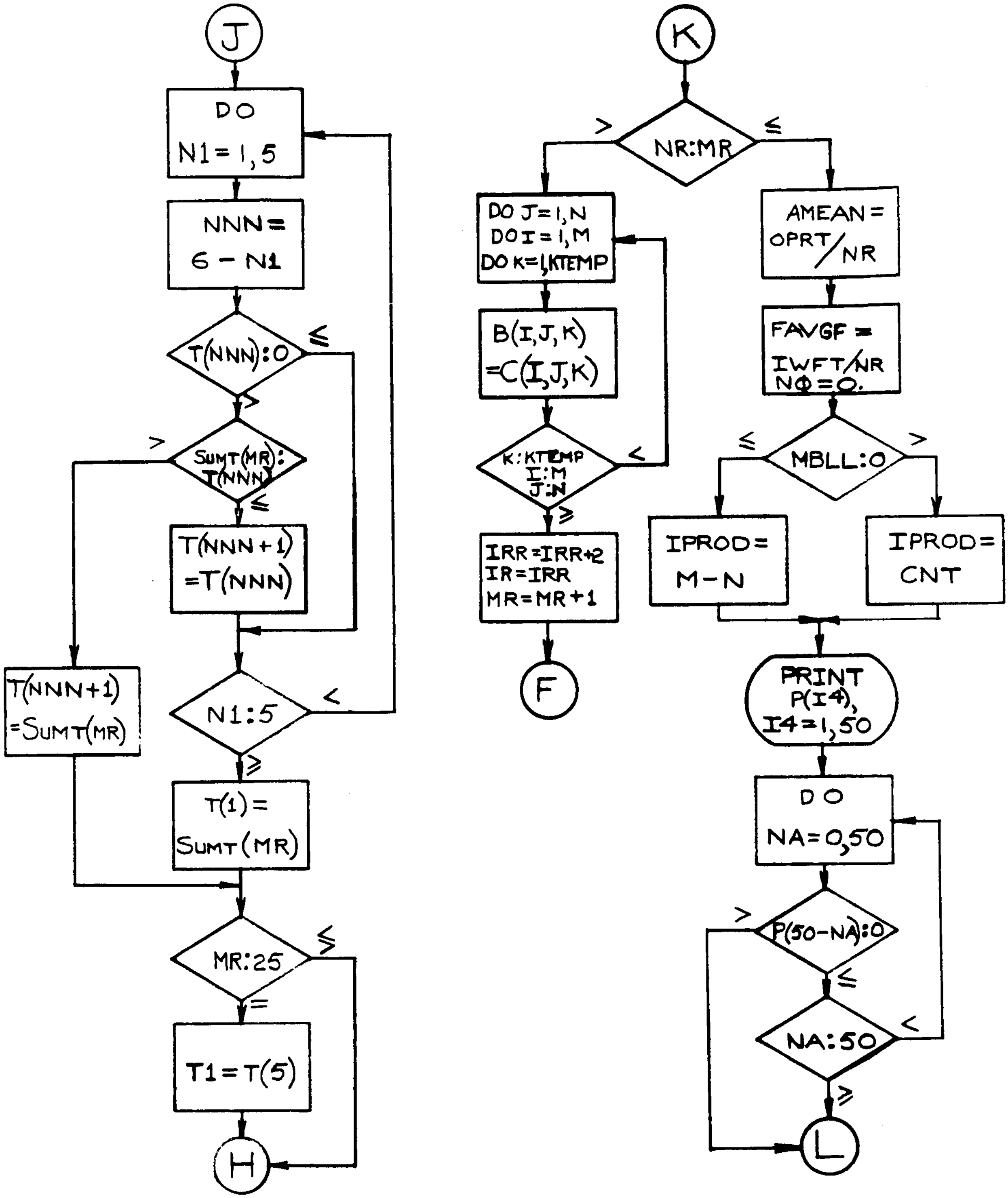
MAIN PROGRAM (CONT.)



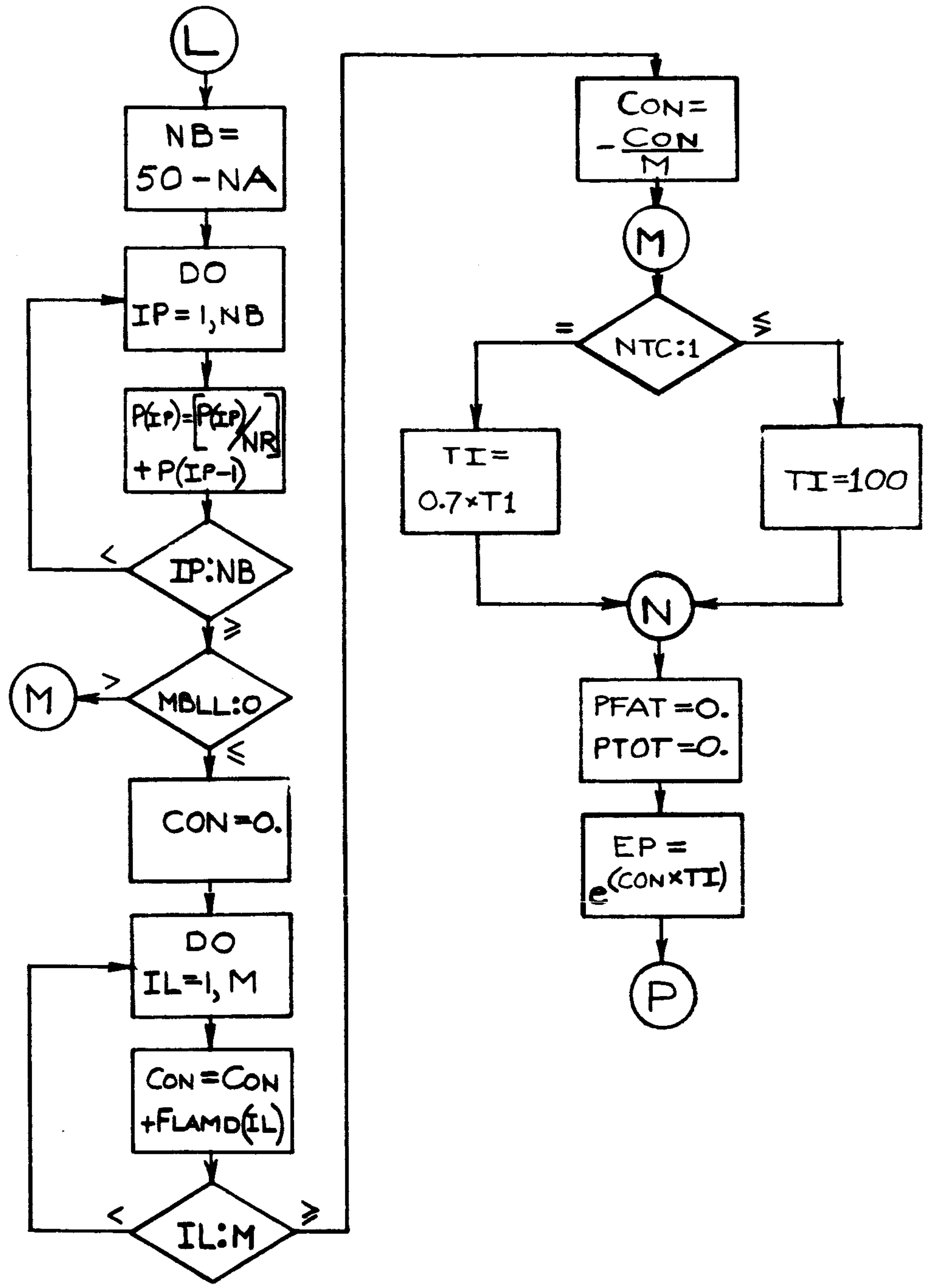
MAIN PROGRAM (CONT.)



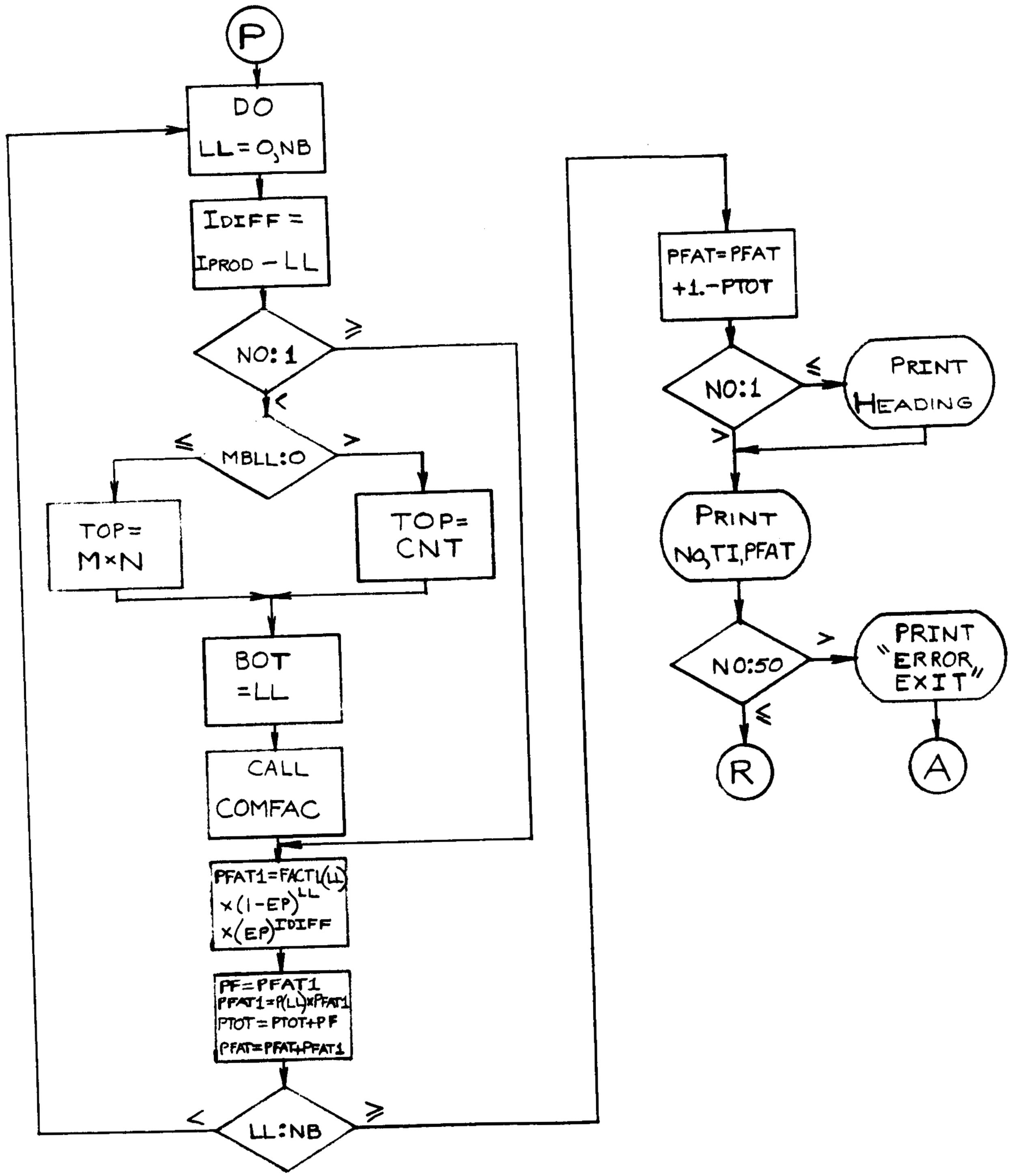
MAIN PROGRAM (CONT.)



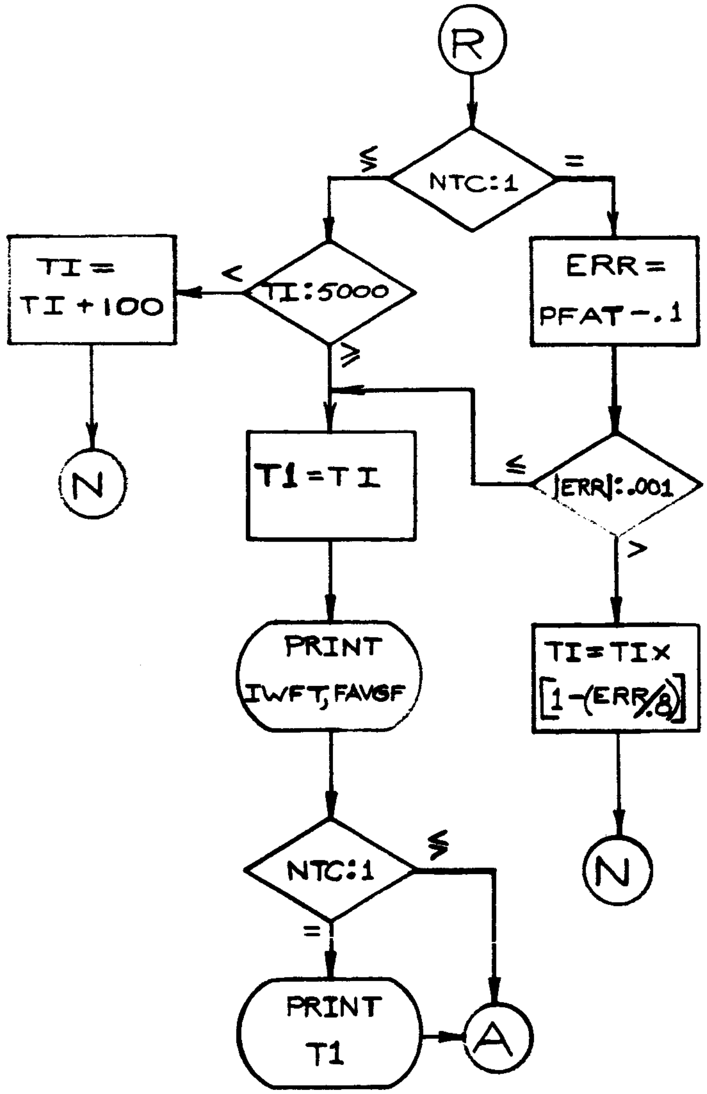
MAIN PROGRAM (CONT.)



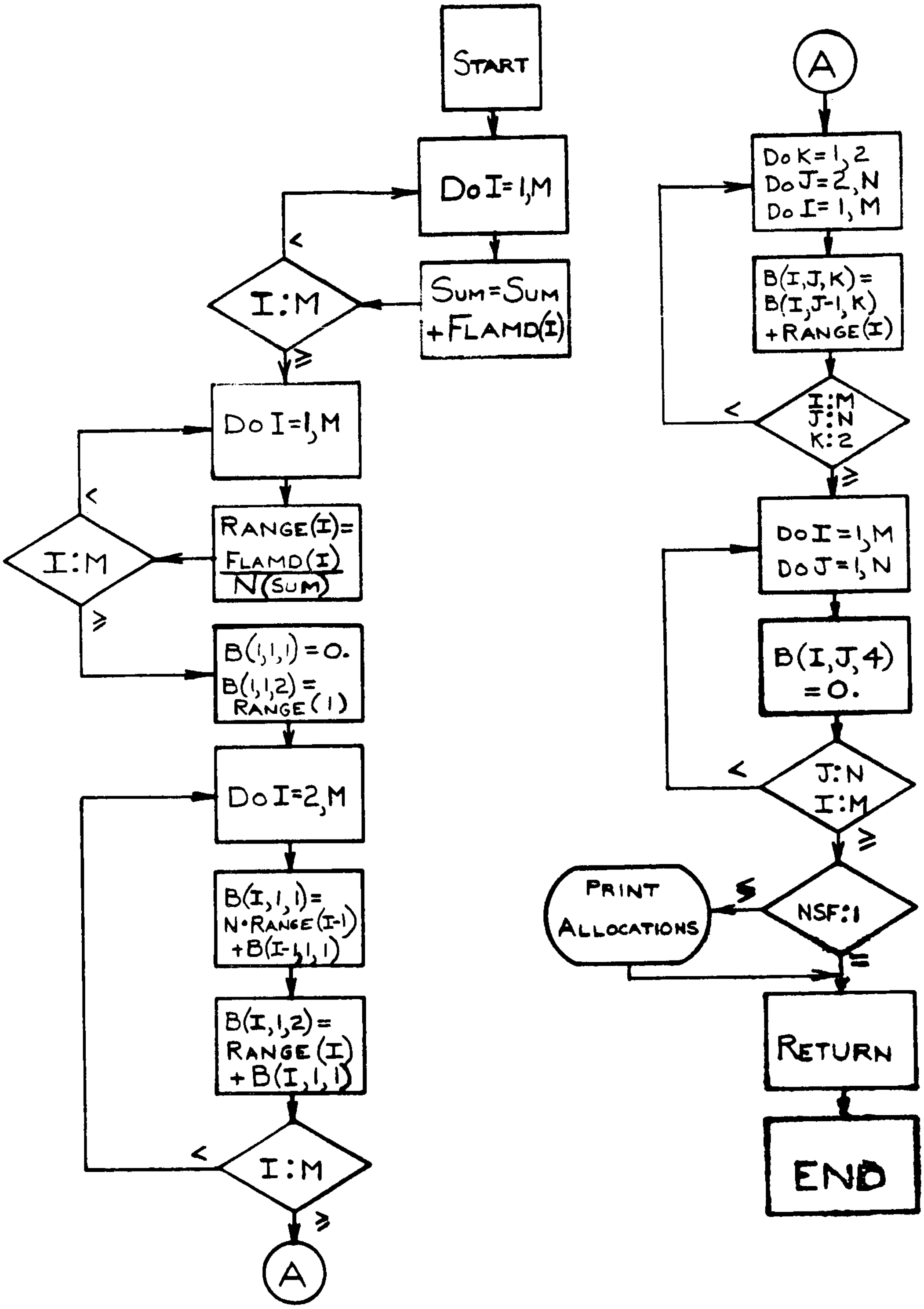
MAIN PROGRAM (CONT.)



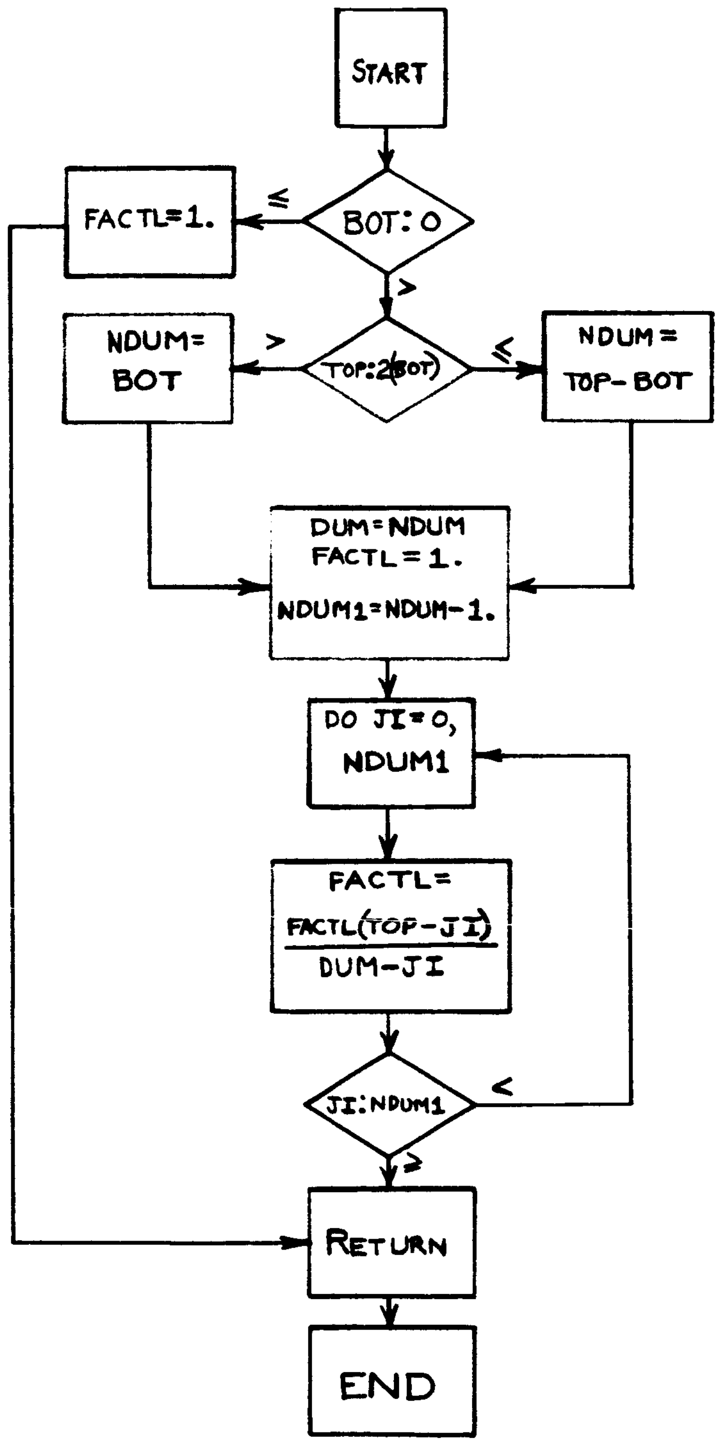
MAIN PROGRAM (CONT.)



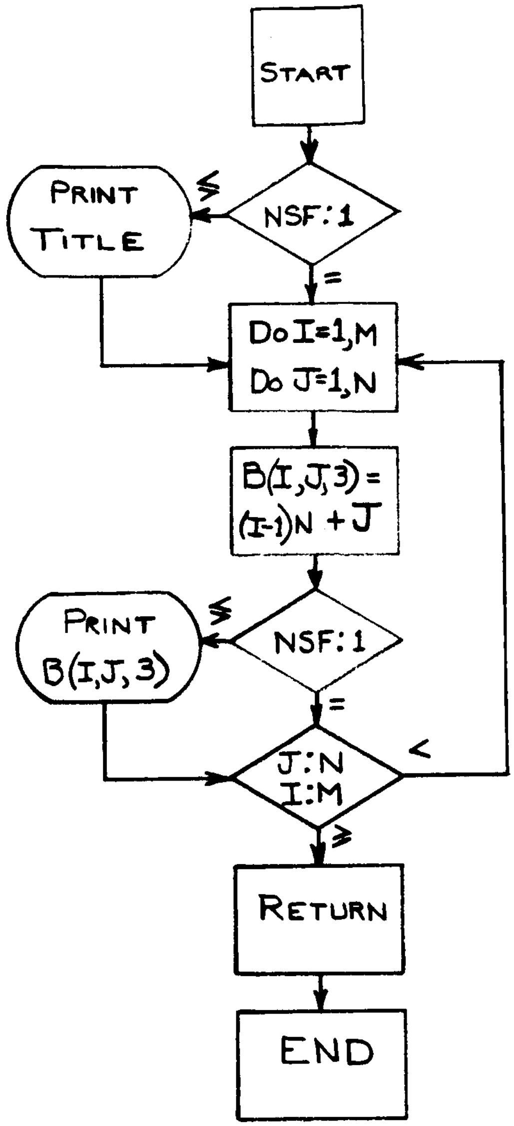
MAIN PROGRAM (CONT.)



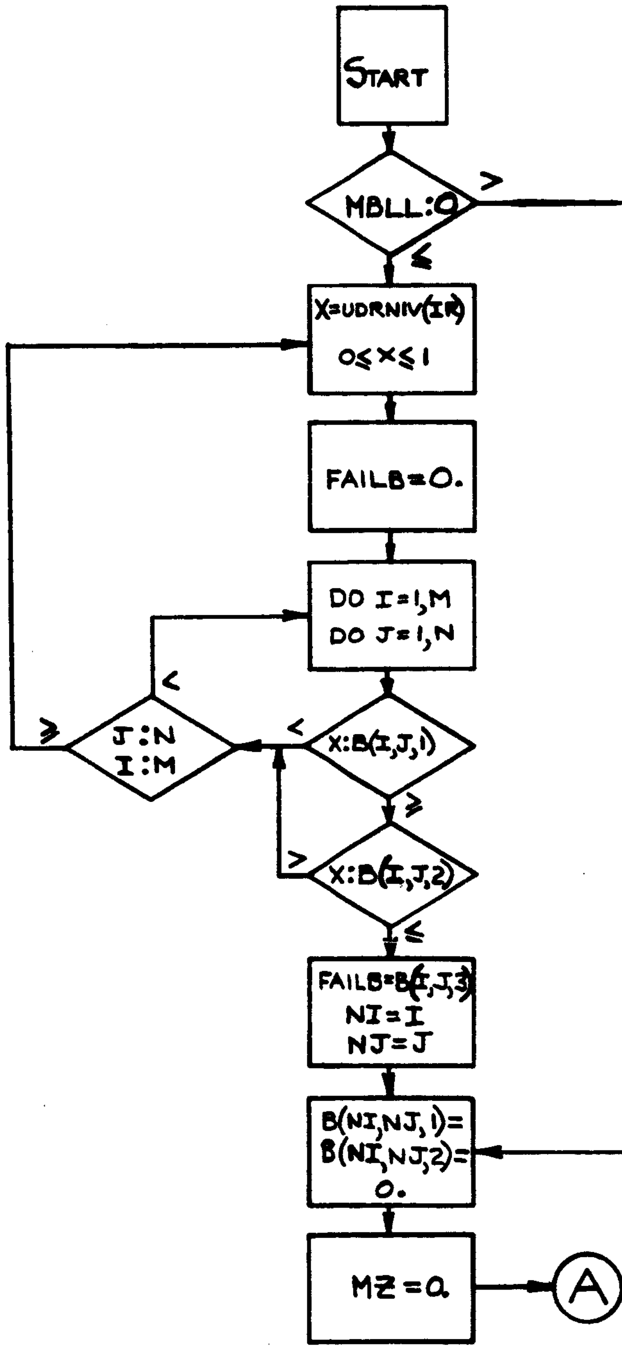
SUBROUTINE ALOCAT



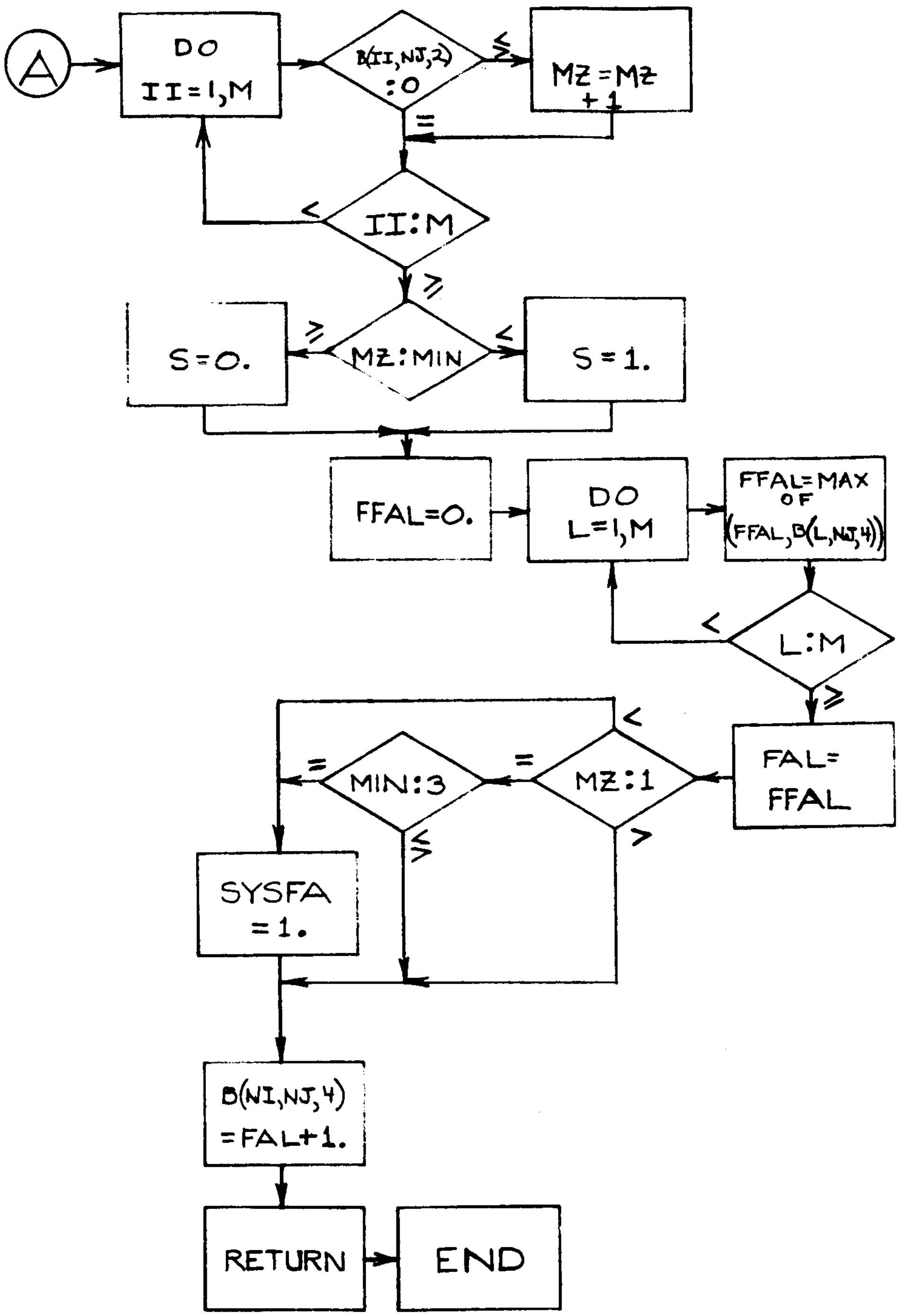
SUBROUTINE COMFAC



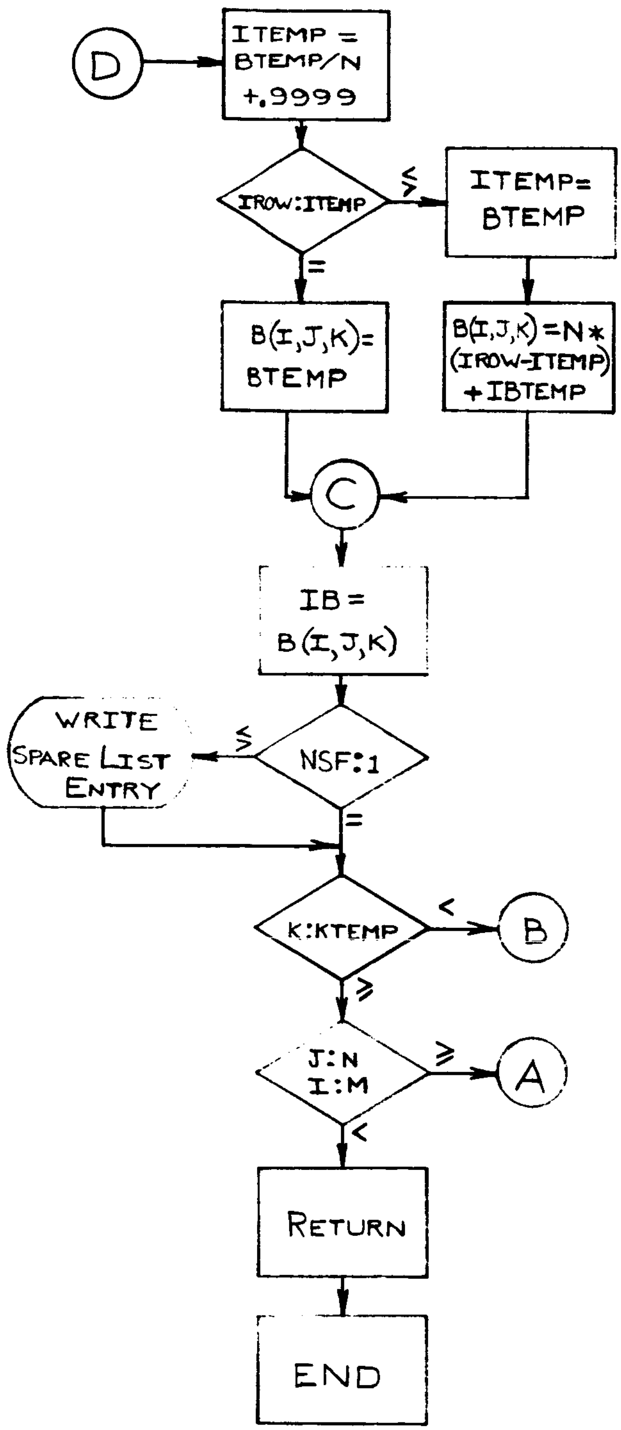
SUBROUTINE DET



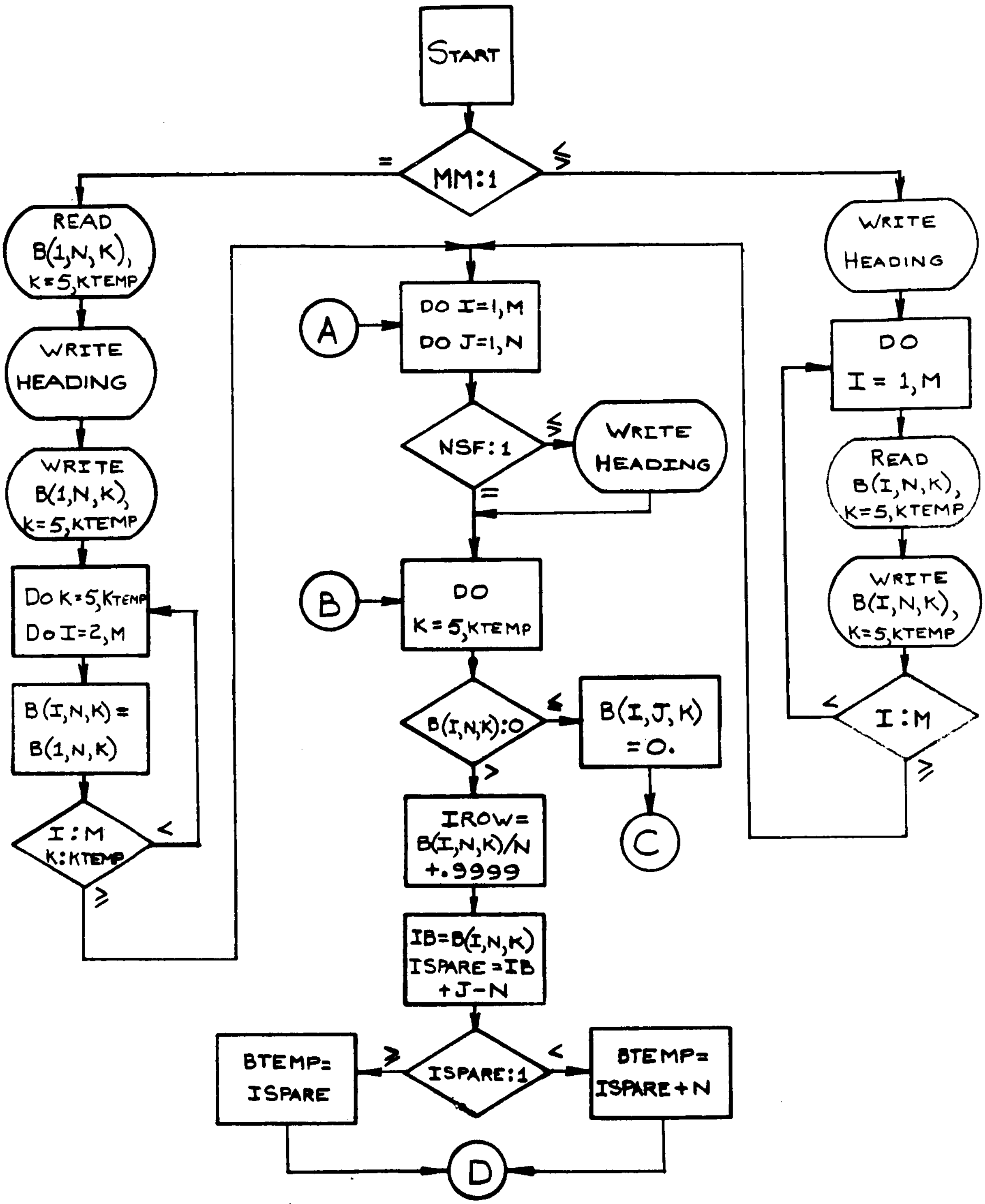
SUBROUTINE FAIL



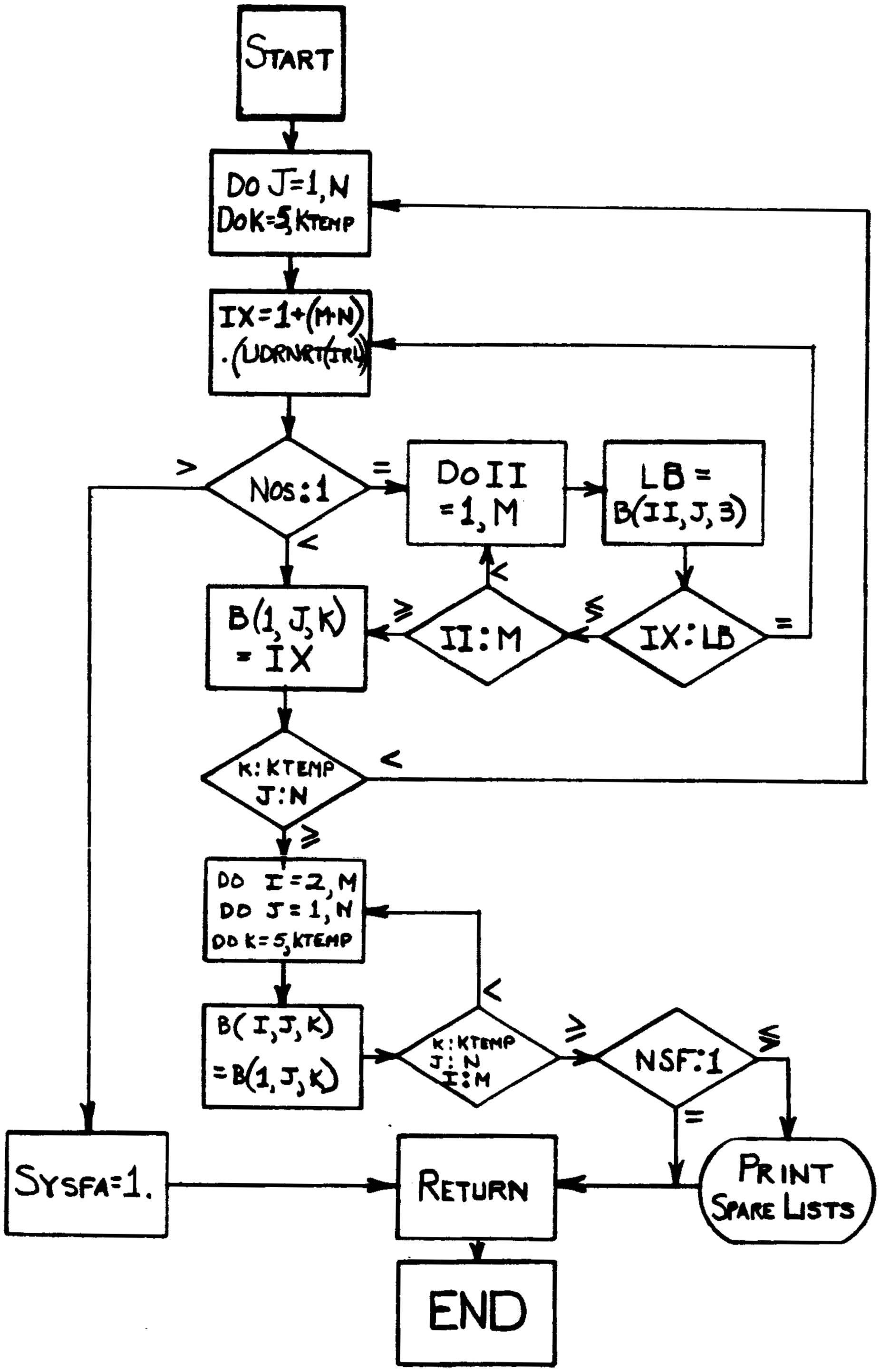
SUBROUTINE FAIL (CONT.)



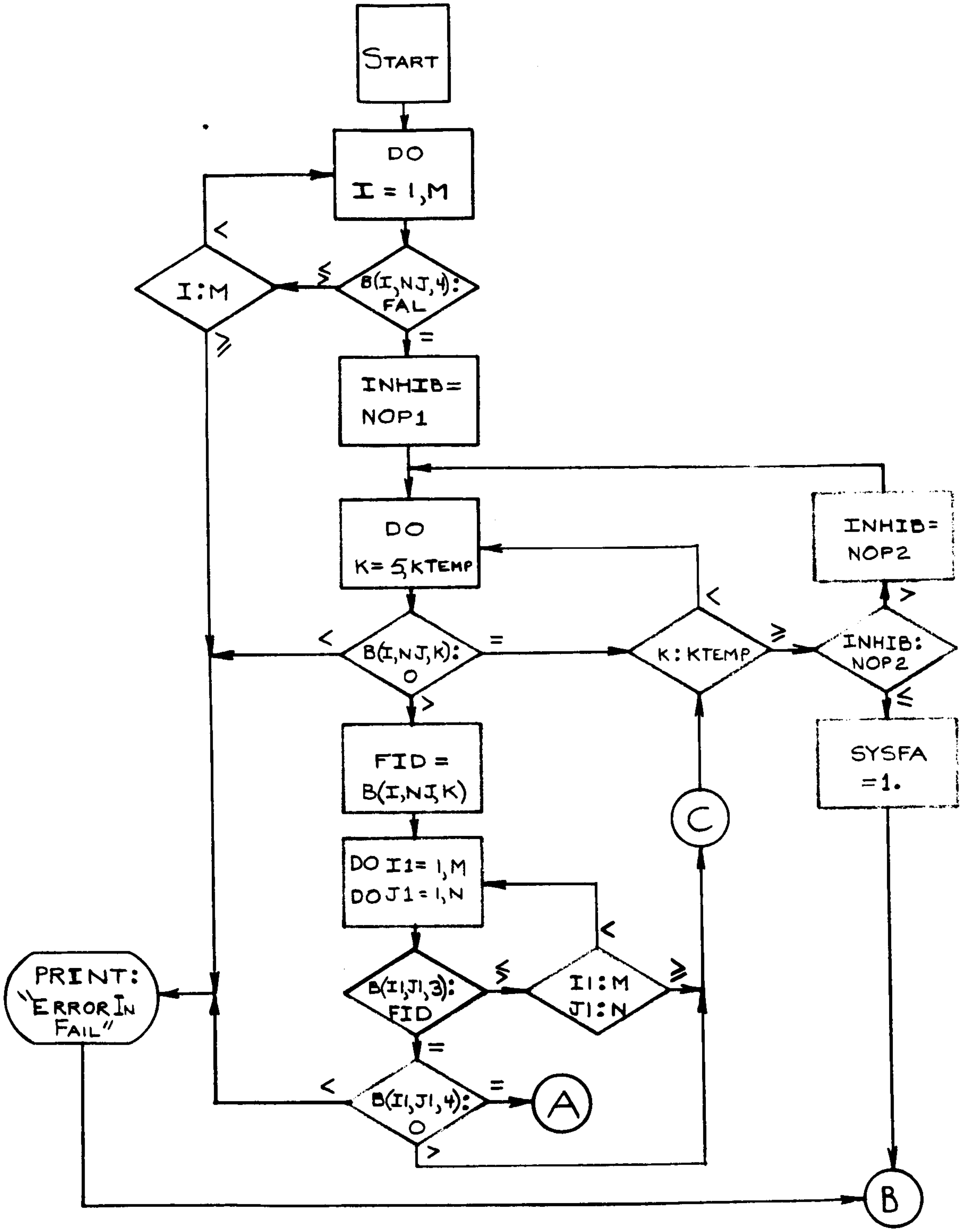
SUBROUTINE LIST (CONT)



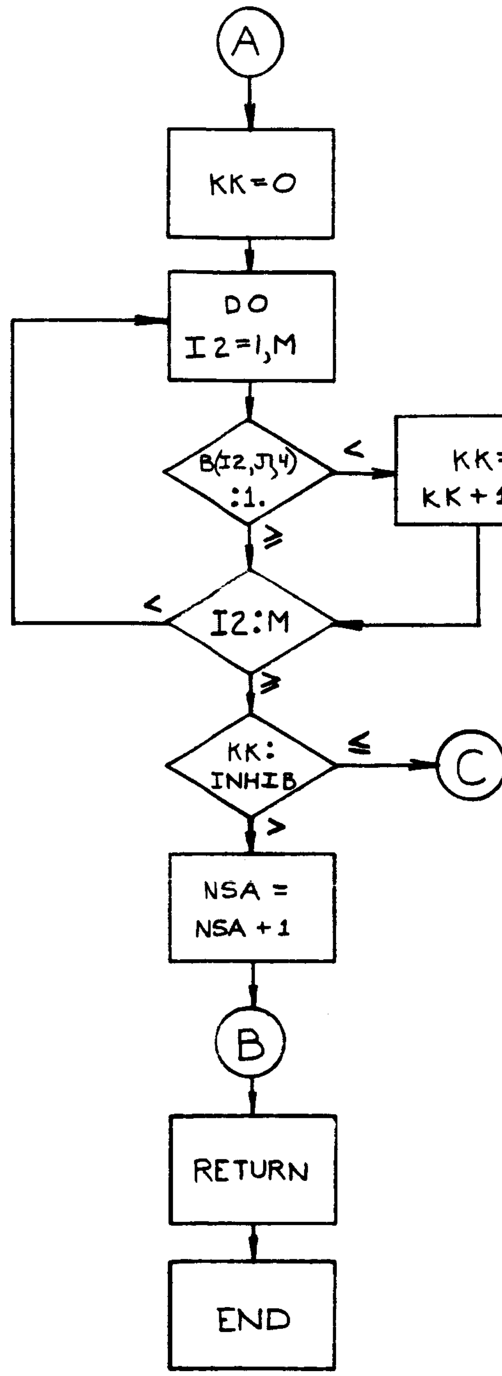
SUBROUTINE LIST



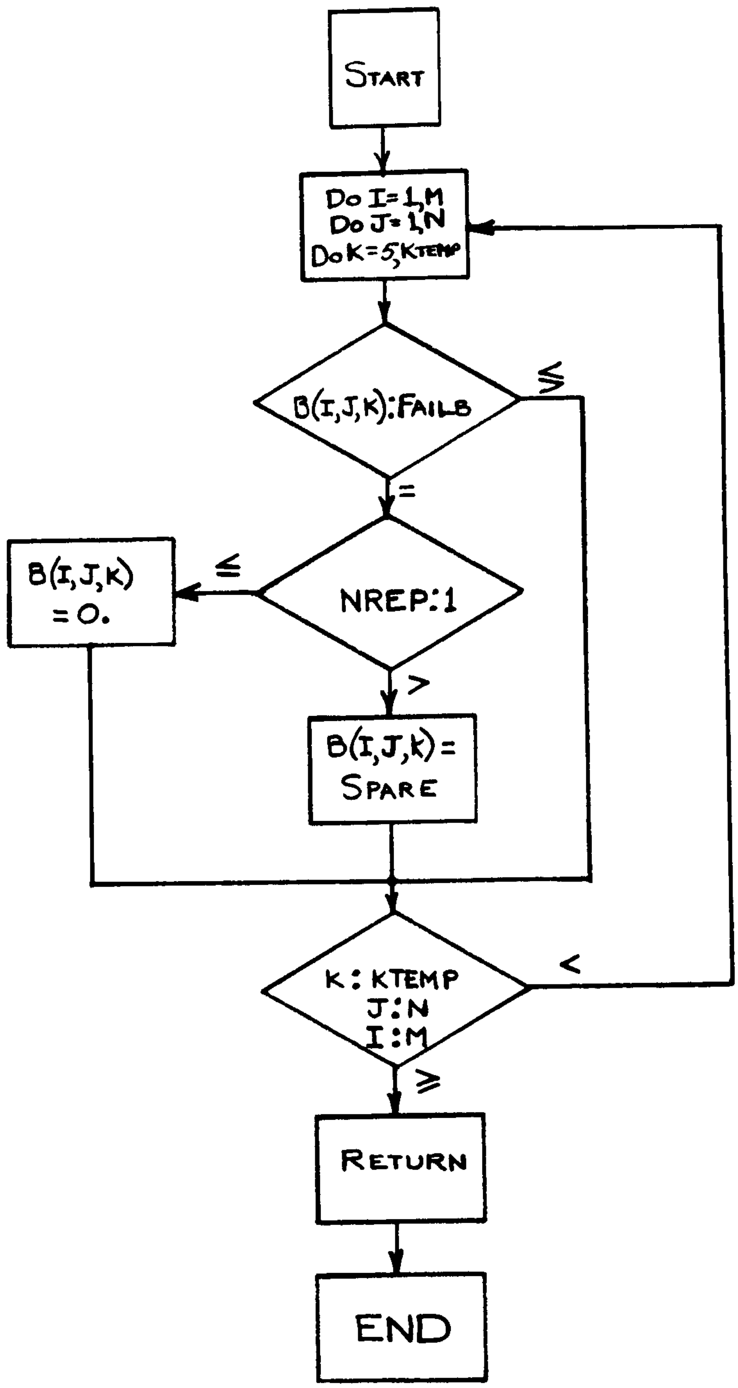
SUBROUTINE RANLIS



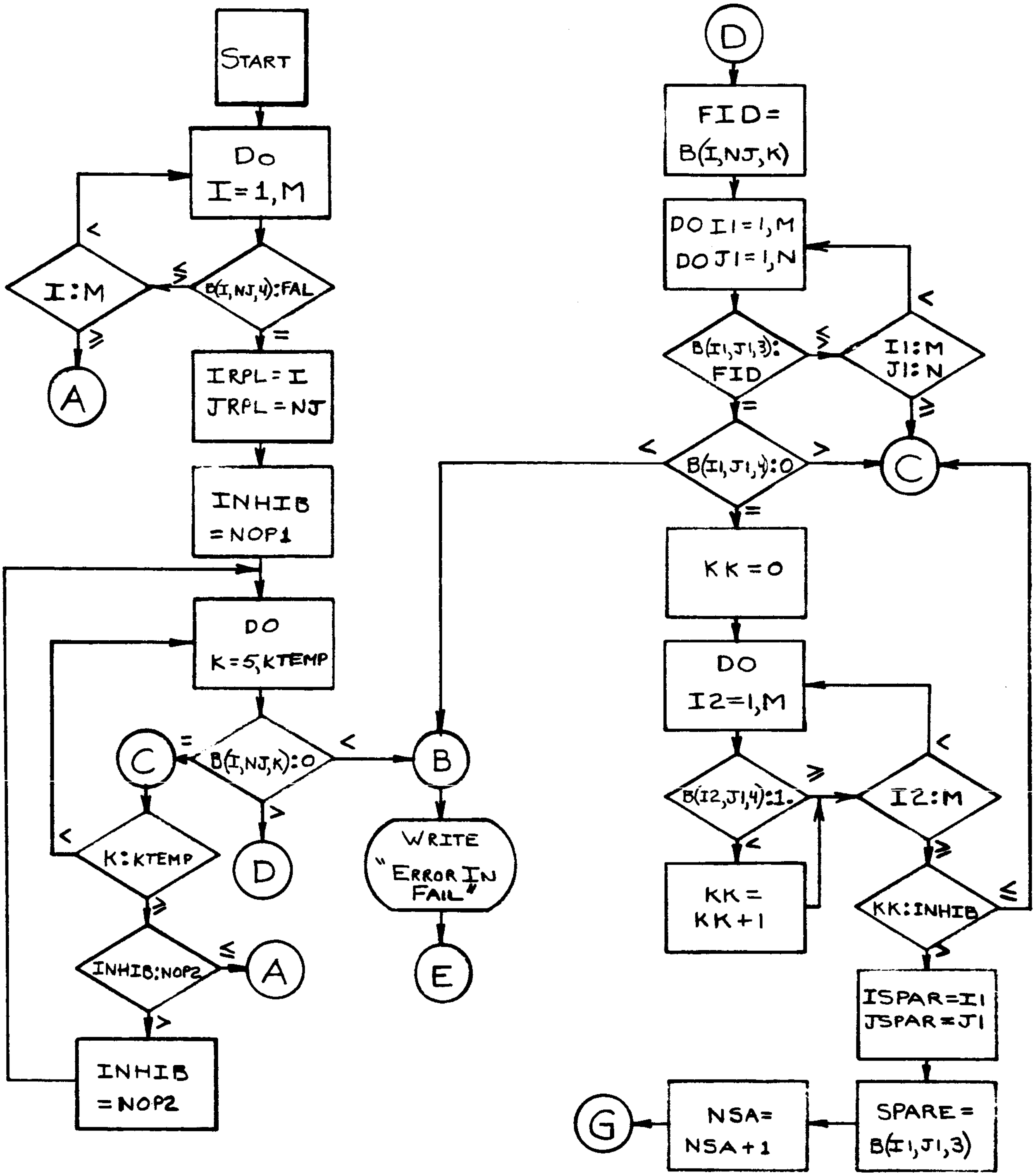
Subroutine Sback



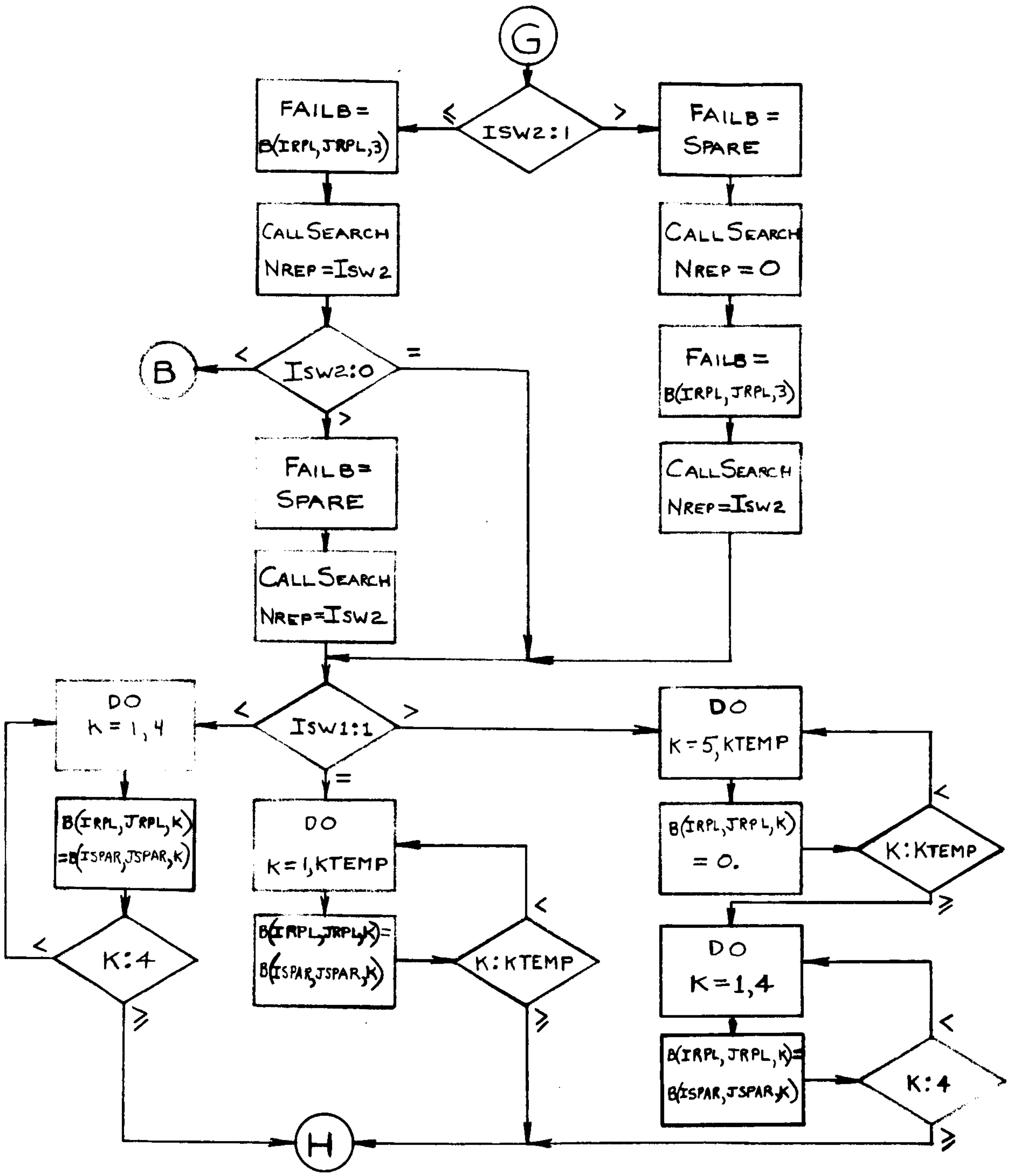
SUBROUTINE SBACK (CONT.)



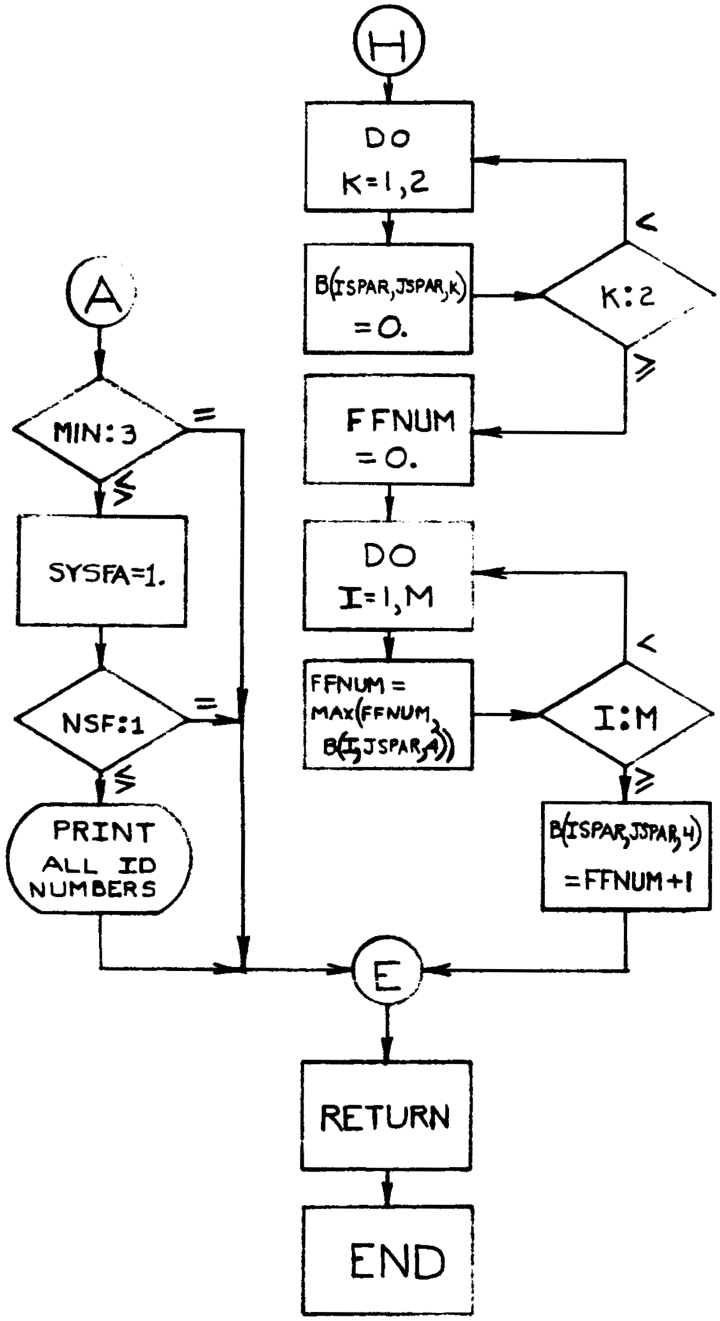
SUBROUTINE SEARCH



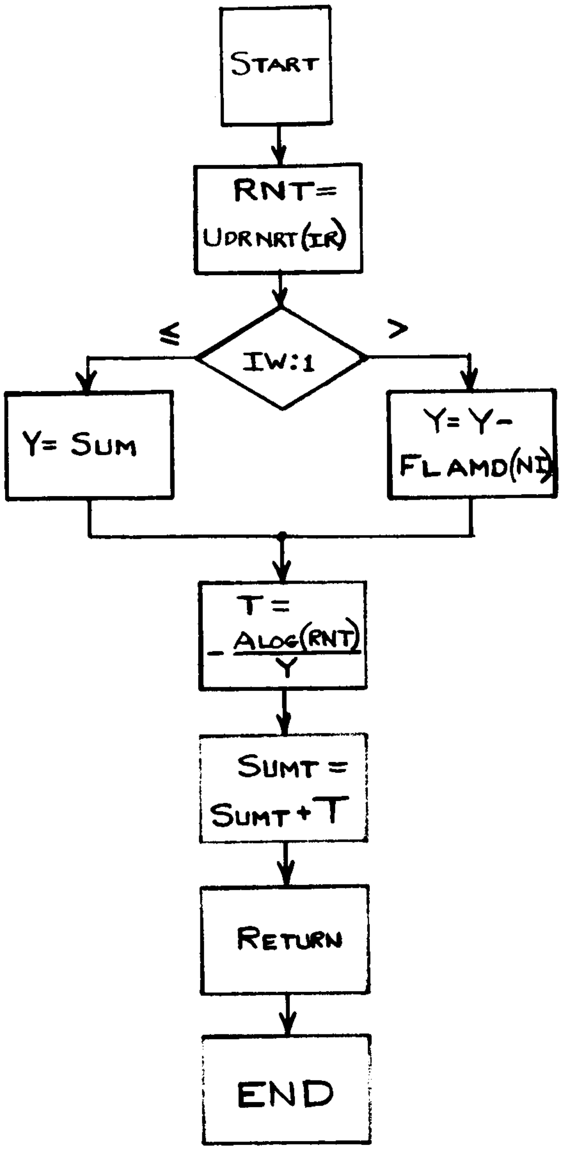
Subroutine Switch



Subroutine Switch (Cont.)



SUBROUTINE SWITCH (CON.T.)



SUBROUTINE TIME

APPENDIX B

EXAMPLES OF THE PRINTOUT OPTIONS

This section contains examples of the printout obtained with the two printout options: NSF = 0, no-sample-format; and NSF = 1, sample-format. The no-sample-format printout is the complete printout obtained from 500 simulation of a typical failure responsive system. The sample format printout was obtained from only 5 simulations of a typical system, so that the form of the printout could be shown without producing an inordinately large amount of printout. Therefore the results obtained for this system are not particularly meaningful.

```
FAILURE RESPONSIVE SYSTEM ORGANIZATION

STRATEGY DESCRIPTION


CONTROL CONSTANTS

LAMDA=  .150000-03
LAMDA=  .125000-03
LAMDA=  .125000-03
    M=   3
    N=  20
KTEMP=  10
   NR= 500    (NUMBER OF RUNS)
   IR=1003    (RANDOM NUMBER SET)
   MM=   1    (COMMON SPARE LIST FLAG)
  NRL=   0    (NON REPETITIVE LIST FLAG)
  MIN=   2    (OPR. BLOCKS REQ. TO RESOLVE ERROR)
 MBLL=   0    (MISSING BLOCK LIST LENGTH)
  NSF=   1    (NO SAMPLE FORMAT FLAG)
 ISW1=   0
 ISW2=   1
 NOP1=   2
 NOP2=   1
ISBAC=   0
  NOS=   1
  NTC=   1
SPARE LIST
        19.          38.          57.          16.          35.          54.
```

-X-	FREQUENCY OF FAILURES WITH X FAILED SUBSYSTEMS
1	0.
2	0.
3	0.
4	0.
5	0.
6	0.
7	0.
8	0.
9	0.
10	0.
11	0.
12	0.
13	0.
14	3.
15	0.
16	1.
17	7.
18	7.
19	16.
20	12.
21	22.
22	30.
23	56.
24	38.
25	55.
26	71.
27	53.
28	52.
29	34.
30	26.
31	15.
32	1.
33	1.
34	0.
35	0.
36	0.
37	0.
38	0.
39	0.
40	0.
41	0.
42	0.
43	0.
44	0.
45	0.
46	0.
47	0.
48	0.
49	0.
50	0.

COMPUTATION	TIME	PROB. OF FAILURE
1	2062.6	.201783-01
2	2268.4	.359277-01
3	2450.1	.561257-01
4	2584.5	.755035-01
5	2663.6	.888326-01
6	2700.8	.956030-01
7	2715.7	.983978-01
8	2721.1	.994349-01

AVG. NO. OF FAILURES= 25.15

10 PERCENT FAILED AT 2721.1

NSF = 0

```
FAILURE RESPONSIVE SYSTEM ORGANIZATION

STRATEGY DESCRIPTION


CONTROL CONSTANTS

LAMDA=  .150000-03
LAMDA=  .125000-03
LAMDA=  .125000-03
    M=   3
    N=  20
KTEMP=  10
   NR=   5     (NUMBER OF RUNS)
   IR=1003     (RANDOM NUMBER SET)
   SM=   1     (COMMON SPARE LIST FLAG)
  NRL=   0     (NON REPETITIVE LIST FLAG)
  MIN=   2     (OPR. BLOCKS REQ. TO RESOLVE ERROR
 MBLL=   0     (MISSING BLOCK LIST LENGTH)
  NSF=   0     (NO SAMPLE FORMAT FLAG)
 ISW1=   0
 ISW2=   1
 NOP1=   2
 NOP2=   1
ISBAC=   0
  NOS=   1
  NTC=   1
```

```
LLOCATIONS
( 1 , 1 , 1 )=      .000000
( 1 , 1 , 2 )=      .018750
( 1 , 2 , 1 )=      .018750
( 1 , 2 , 2 )=      .037500
( 1 , 3 , 1 )=      .037500
( 1 , 3 , 2 )=      .056250
( 1 , 4 , 1 )=      .056250
( 1 , 4 , 2 )=      .075000
( 1 , 5 , 1 )=      .075000
( 1 , 5 , 2 )=      .093750
( 1 , 6 , 1 )=      .093750
( 1 , 6 , 2 )=      .112500
( 1 , 7 , 1 )=      .112500
( 1 , 7 , 2 )=      .131250
( 1 , 8 , 1 )=      .131250
( 1 , 8 , 2 )=      .150000
( 1 , 9 , 1 )=      .150000
( 1 , 9 , 2 )=      .168750
( 1 ,10 , 1 )=      .168750
( 1 ,10 , 2 )=      .187500
( 1 ,11 , 1 )=      .187500
( 1 ,11 , 2 )=      .206250
( 1 ,12 , 1 )=      .206250
( 1 ,12 , 2 )=      .225000
( 1 ,13 , 1 )=      .225000
( 1 ,13 , 2 )=      .243750
( 1 ,14 , 1 )=      .243750
( 1 ,14 , 2 )=      .262500
( 1 ,15 , 1 )=      .262500
( 1 ,15 , 2 )=      .281250
( 1 ,16 , 1 )=      .281250
( 1 ,16 , 2 )=      .300000
( 1 ,17 , 1 )=      .300000
( 1 ,17 , 2 )=      .318750
( 1 ,18 , 1 )=      .318750
( 1 ,18 , 2 )=      .337500
( 1 ,19 , 1 )=      .337500
( 1 ,19 , 2 )=      .356250
( 1 ,20 , 1 )=      .356250
( 1 ,20 , 2 )=      .375000
( 2 , 1 , 1 )=      .375000
( 2 , 1 , 2 )=      .390625
```

```
( 2 , 2 , 1 )=     .390625
( 2 , 2 , 2 )=     .406250
( 2 , 3 , 1 )=     .406250
( 2 , 3 , 2 )=     .421875
( 2 , 4 , 1 )=     .421875
( 2 , 4 , 2 )=     .437500
( 2 , 5 , 1 )=     .437500
( 2 , 5 , 2 )=     .453125
( 2 , 6 , 1 )=     .453125
( 2 , 6 , 2 )=     .468750
( 2 , 7 , 1 )=     .468750
( 2 , 7 , 2 )=     .484375
( 2 , 8 , 1 )=     .484375
( 2 , 8 , 2 )=     .500000
( 2 , 9 , 1 )=     .500000
( 2 , 9 , 2 )=     .515625
( 2 ,10 , 1 )=     .515625
( 2 ,10 , 2 )=     .531250
( 2 ,11 , 1 )=     .531250
( 2 ,11 , 2 )=     .546875
( 2 ,12 , 1 )=     .546875
( 2 ,12 , 2 )=     .562500
( 2 ,13 , 1 )=     .562500
( 2 ,13 , 2 )=     .578125
( 2 ,14 , 1 )=     .578125
( 2 ,14 , 2 )=     .593750
( 2 ,15 , 1 )=     .593750
( 2 ,15 , 2 )=     .609375
( 2 ,16 , 1 )=     .609375
( 2 ,16 , 2 )=     .625000
( 2 ,17 , 1 )=     .625000
( 2 ,17 , 2 )=     .640625
( 2 ,18 , 1 )=     .640625
( 2 ,18 , 2 )=     .656250
( 2 ,19 , 1 )=     .656250
( 2 ,19 , 2 )=     .671875
( 2 ,20 , 1 )=     .671875
( 2 ,20 , 2 )=     .687500
( 3 , 1 , 1 )=     .687500
( 3 , 1 , 2 )=     .703125
( 3 , 2 , 1 )=     .703125
( 3 , 2 , 2 )=     .718750
( 3 , 3 , 1 )=     .718750
```

```
( 3 , 3 , 2 )=     .734375
( 3 , 4 , 1 )=     .734375
( 3 , 4 , 2 )=     .750000
( 3 , 5 , 1 )=     .750000
( 3 , 5 , 2 )=     .765625
( 3 , 6 , 1 )=     .765625
( 3 , 6 , 2 )=     .781250
( 3 , 7 , 1 )=     .781250
( 3 , 7 , 2 )=     .796875
( 3 , 8 , 1 )=     .796875
( 3 , 8 , 2 )=     .812500
( 3 , 9 , 1 )=     .812500
( 3 , 9 , 2 )=     .828125
( 3 ,10 , 1 )=     .828125
( 3 ,10 , 2 )=     .843750
( 3 ,11 , 1 )=     .843750
( 3 ,11 , 2 )=     .859375
( 3 ,12 , 1 )=     .859375
( 3 ,12 , 2 )=     .875000
( 3 ,13 , 1 )=     .875000
( 3 ,13 , 2 )=     .890625
( 3 ,14 , 1 )=     .890625
( 3 ,14 , 2 )=     .906250
( 3 ,15 , 1 )=     .906250
( 3 ,15 , 2 )=     .921875
( 3 ,16 , 1 )=     .921875
( 3 ,16 , 2 )=     .937500
( 3 ,17 , 1 )=     .937500
( 3 ,17 , 2 )=     .953125
( 3 ,18 , 1 )=     .953125
( 3 ,18 , 2 )=     .968750
( 3 ,19 , 1 )=     .968750
( 3 ,19 , 2 )=     .984375
( 3 ,20 , 1 )=     .984375
( 3 ,20 , 2 )=    1.000000
```

```
ID NUMBERS
( 1 , 1 ,3)=   1.
( 1 , 2 ,3)=   2.
( 1 , 3 ,3)=   3.
( 1 , 4 ,3)=   4.
( 1 , 5 ,3)=   5.
( 1 , 6 ,3)=   6.
( 1 , 7 ,3)=   7.
( 1 , 8 ,3)=   8.
( 1 , 9 ,3)=   9.
( 1 ,10 ,3)=  10.
( 1 ,11 ,3)=  11.
( 1 ,12 ,3)=  12.
( 1 ,13 ,3)=  13.
( 1 ,14 ,3)=  14.
( 1 ,15 ,3)=  15.
( 1 ,16 ,3)=  16.
( 1 ,17 ,3)=  17.
( 1 ,18 ,3)=  18.
( 1 ,19 ,3)=  19.
( 1 ,20 ,3)=  20.
( 2 , 1 ,3)=  21.
( 2 , 2 ,3)=  22.
( 2 , 3 ,3)=  23.
( 2 , 4 ,3)=  24.
( 2 , 5 ,3)=  25.
( 2 , 6 ,3)=  26.
( 2 , 7 ,3)=  27.
( 2 , 8 ,3)=  28.
( 2 , 9 ,3)=  29.
( 2 ,10 ,3)=  30.
( 2 ,11 ,3)=  31.
( 2 ,12 ,3)=  32.
( 2 ,13 ,3)=  33.
( 2 ,14 ,3)=  34.
( 2 ,15 ,3)=  35.
( 2 ,16 ,3)=  36.
( 2 ,17 ,3)=  37.
( 2 ,18 ,3)=  38.
( 2 ,19 ,3)=  39.
( 2 ,20 ,3)=  40.
( 3 , 1 ,3)=  41.
( 3 , 2 ,3)=  42.
```

```
( 3 , 3 ,3)=  43.
( 3 , 4 ,3)=  44.
( 3 , 5 ,3)=  45.
( 3 , 6 ,3)=  46.
( 3 , 7 ,3)=  47.
( 3 , 8 ,3)=  48.
( 3 , 9 ,3)=  49.
( 3 ,10 ,3)=  50.
( 3 ,11 ,3)=  51.
( 3 ,12 ,3)=  52.
( 3 ,13 ,3)=  53.
( 3 ,14 ,3)=  54.
( 3 ,15 ,3)=  55.
( 3 ,16 ,3)=  56.
( 3 ,17 ,3)=  57.
( 3 ,18 ,3)=  58.
( 3 ,19 ,3)=  59.
( 3 ,20 ,3)=  60.
```

SPARE LIST

19. 38. 57. 16. 35. 54.

B(1 , 1)	K
20	5
39	6
58	7
17	8
36	9
55	10

B(1 , 2)	K
1	5
40	6
59	7
18	8
37	9
56	10

B(1 , 3)	K
2	5
21	6
60	7
19	8
38	9
57	10

B(1 , 4)	K
3	5
22	6
41	7
20	8
39	9
58	10

B(1 , 5)	K
4	5
23	6
42	7
1	8
40	9
59	10

B(1 , 6)	K
5	5
24	6
43	7
2	8
21	9
60	10

B(1 , 7)	K
6	5
25	6
44	7
3	8
22	9
41	10

B(1 , 8)	K
7	5
26	6
45	7
4	8
23	9
42	10

B(1 , 9)	K
8	5
27	6
46	7
5	8
24	9
43	10

B(1 ,10)	K
9	5
28	6
47	7
6	8
25	9
44	10

B(1 ,11)	K
10	5

29	6
48	7
7	8
26	9
45	10
B(1 ,12)	K
11	5
30	6
49	7
8	8
27	9
46	10
B(1 ,13)	K
12	5
31	6
50	7
9	8
28	9
47	10
B(1 ,14)	K
13	5
32	6
51	7
10	8
29	9
48	10
B(1 ,15)	K
14	5
33	6
52	7
11	8
30	9
49	10
B(1 ,16)	K
15	5
34	6
53	7
12	8

31	9
50	10
B(1 ,17)	K
16	5
35	6
54	7
13	8
32	9
51	10
B(1 ,18)	K
17	5
36	6
55	7
14	8
33	9
52	10
B(1 ,19)	K
18	5
37	6
56	7
15	8
34	9
53	10
B(1 ,20)	K
19	5
38	6
57	7
16	8
35	9
54	10
B(2 , 1)	K
20	5
39	6
58	7
17	8
36	9
55	10

B(2 , 2)	K
1	5
40	6
59	7
18	8
37	9
56	10
B(2 , 3)	K
2	5
21	6
60	7
19	8
38	9
57	10
3(2 , 4)	K
3	5
22	6
41	7
20	8
39	9
58	10
B(2 , 5)	K
4	5
23	6
42	7
1	8
40	9
59	10
B(2 , 6)	K
5	5
24	6
43	7
2	8
21	9
60	10
B(2 , 7)	K
6	5
25	6

44	7
3	8
22	9
41	10
B(2 , 8)	K
7	5
26	6
45	7
4	8
23	9
42	10
B(2 , 9)	K
8	5
27	6
46	7
5	8
24	9
43	10
B(2 ,10)	K
9	5
28	6
47	7
6	8
25	9
44	10
B(2 ,11)	K
10	5
29	6
48	7
7	8
26	9
45	10
B(2 ,12)	K
11	5
30	6
49	7
8	8
27	9

46	10
B(2 ,13)	K
12	5
31	6
50	7
9	8
28	9
47	10
B(2 ,14)	K
13	5
32	6
51	7
10	8
29	9
48	10
B(2 ,15)	K
14	5
33	6
52	7
11	8
30	9
49	10
B(2 ,16)	K
15	5
34	6
53	7
12	8
31	9
50	10
B(2 ,17)	K
16	5
35	6
54	7
13	8
32	9
51	10
B(2 ,18)	K

17	5
36	6
55	7
14	8
33	9
52	10
B(2 ,19)	K
18	5
37	6
56	7
15	8
34	9
53	10
B(2 ,20)	K
19	5
38	6
57	7
16	8
35	9
54	10
B(3 , 1)	K
20	5
39	6
58	7
17	8
36	9
55	10
B(3 , 2)	K
1	5
40	6
59	7
18	8
37	9
56	10
B(3 , 3)	K
2	5
21	6
60	7

19	8
38	9
57	10

B(3 , 4)	K
3	5
22	6
41	7
20	8
39	9
58	10

B(3 , 5)	K
4	5
23	6
42	7
1	8
40	9
59	10

B(3 , 6)	K
5	5
24	6
43	7
2	8
21	9
60	10

B(3 , 7)	K
6	5
25	6
44	7
3	8
22	9
41	10

B(3 , 8)	K
7	5
26	6
45	7
4	8
23	9
42	10

B(3 , 9)	K
8	5
27	6
46	7
5	8
24	9
43	10

B(3 ,10)	K
9	5
28	6
47	7
6	8
25	9
44	10

B(3 ,11)	K
10	5
29	6
48	7
7	8
26	9
45	10

B(3 ,12)	K
11	5
30	6
49	7
8	8
27	9
46	10

B(3 ,13)	K
12	5
31	6
50	7
9	8
28	9
47	10

B(3 ,14)	K
13	5

32	6
51	7
10	8
29	9
48	10

B(3 ,15)	K
14	5
33	6
52	7
11	8
30	9
49	10

B(3 ,16)	K
15	5
34	6
53	7
12	8
31	9
50	10

B(3 ,17)	K
16	5
35	6
54	7
13	8
32	9
51	10

B(3 ,18)	K
17	5
36	6
55	7
14	8
33	9
52	10

B(3 ,19)	K
18	5
37	6
56	7
15	8
34	9
53	10

B(3 ,20)	K
19	5
38	6
57	7
16	8
35	9
54	10

SEQUENCE OF FAILURES

RUN NO.	FAILURE I.D.			FAILURE RAN. NO.	TIMERAN. NO.	HOURS BETWEEN FAILURES	FAILURE NO.
1							
	2	17	37.	.633718	.118438	266.7	1
	1	19	19.	.345467	.169745	225.9	2
	1	12	12.	.222605	.001718	826.8	3
	1	18	18.	.327796	.125551	274.8	4
	3	4	44.	.739773	.720780	44.1	5
	2	1	21.	.377195	.761279	37.4	6
	2	10	30.	.528732	.601157	70.9	7
	1	20	20.	.363486	.838925	25.0	8
	3	17	57.	.949500	.111992	317.3	9
	2	14	34.	.583859	.350528	154.7	10
	3	10	50.	.835967	.212533	232.9	11
	1	6	6.	.100626	.640186	68.6	12
	3	1	41.	.690897	.023837	586.1	13
	1	17	17.	.317138	.748940	46.4	14
	3	12	52.	.871381	.946510	9.0	15
	1	4	4.	.071656	.285400	210.7	16
	3	2	42.	.704080	.349497	180.5	17
	2	5	25.	.450313	.053273	514.4	18
	3	4	3.	.049669	.449307	143.5	19
	2	8	28.	.489722	.697681	66.1	20
	2	11	31.	.539377	.438329	154.9	21
	1	15	15.	.266802	.701153	68.6	22
	1	5	5.	.086711	.377772	193.7	23
	1	10	10.	.182648	.897724	22.1	24

1.	55.	41.
2.	22.	42.
3.	23.	43.
22.	24.	3.
5.	23.	45.
6.	26.	46.
7.	27.	47.
8.	28.	48.
9.	29.	49.
10.	9.	47.
7.	31.	51.
11.	32.	52.
13.	33.	53.
14.	34.	54.
15.	35.	14.
16.	36.	56.
17.	16.	13.
18.	38.	58.
19.	39.	59.
20.	40.	60.

3 10 47. .788687 .411827 186.8 25

AVG. TIME= 197.1 TOTAL OPERATING TIME= 4928.1 TOTAL FAILURES= 25

SEQUENCE OF FAILURES

RUN NO.	FAILURE I.D.			FAILURE RAN. NO.	TIMERAN. NO.	HOURS BETWEEN FAILURES	FAILURE NO.
2							
	3	2	42.	.704772	.917278	10.8	1
	3	3	43.	.729007	.305677	150.5	2
	1	9	9.	.157247	.823257	25.2	3
	2	17	37.	.629546	.666180	53.4	4
	2	3	23.	.411238	.108060	297.7	5
	2	10	30.	.525505	.137673	269.8	6
	2	4	24.	.431131	.239656	197.7	7
	2	9	29.	.509774	.594337	73.3	8
	3	20	60.	.986289	.269743	187.9	9
	1	12	12.	.218124	.640359	65.3	10
	1	18	18.	.335142	.641670	66.5	11
	2	18	38.	.642202	.897694	16.5	12
	1	10	10.	.182985	.047219	477.0	13
	1	17	17.	.311996	.790978	37.5	14
	3	16	56.	.923952	.620822	77.8	15
	3	6	46.	.767436	.296354	202.7	16
	2	13	33.	.570303	.794444	39.2	17
	1	14	14.	.253839	.846704	29.1	18
	1	3	3.	.044407	.424644	153.6	19
	1	11	11.	.199954	.374048	181.3	20
	2	2	22.	.397896	.117721	403.7	21
	2	6	26.	.462135	.456796	151.4	22
	3	3	21.	.389833	.021073	764.3	23
	2	11	31.	.535054	.780075	50.4	24
	2	14	51.	.858530	.339127	225.3	25

```
         1.        21.        41.
         2.        22.         1.
         2.        19.        21.
         4.        24.        44.
         5.        25.        45.
         6.        26.         5.
         7.        27.        47.
         8.        28.        48.
         8.        29.        49.
        10.        47.        50.
        48.        31.        45.
        12.        32.        52.
        13.        33.        53.
        13.        51.        54.
        15.        35.        55.
        16.        34.        56.
        17.        35.        57.
        36.        38.        58.
        19.        39.        59.
        20.        40.        60.
               1    6     6.          .110097             .518007           141.5                 26
AVG. TIME=     167.3                                      TOTAL OPERATING TIME= 4349.2   TOTAL FAILURES= 26
```

SEQUENCE OF FAILURES

RUN NO.	FAILURE I.D.			FAILURE RAN. NO.	TIMERAN. NO.	HOURS BETWEEN FAILURES	FAILURE NO.
3							
	3	6	46.	.775827	.716119	41.7	1
	1	7	7.	.112547	.441609	104.1	2
	1	5	5.	.091888	.644796	57.0	3
	3	16	56.	.931297	.206809	208.0	4
	2	8	28.	.495339	.673814	53.0	5
	2	9	29.	.514066	.125521	283.3	6
	3	17	57.	.950581	.216715	212.4	7
	2	18	38.	.656062	.349748	148.5	8
	1	2	2.	.023077	.427494	122.7	9
	3	11	51.	.852389	.930191	10.6	10
	3	10	50.	.834316	.070808	396.7	11
	1	10	10.	.183779	.155202	285.5	12
	3	19	59.	.979369	.571691	87.4	13
	1	18	18.	.334449	.527542	102.3	14
	3	14	54.	.891060	.331011	180.5	15
	3	10	44.	.744110	.530766	105.6	16
	2	19	39.	.663490	.646197	74.3	17
	1	4	4.	.068951	.303488	208.3	18
	3	8	48.	.803598	.343912	190.6	19
	3	18	58.	.962578	.035540	609.5	20
	1	14	14.	.258375	.596774	96.9	21
	3	1	41.	.696065	.485940	138.8	22
	1	16	16.	.288551	.140857	388.1	23
	1	20	20.	.368954	.862225	30.3	24
	2	14	34.	.591543	.873795	28.3	25
	2	5	25.	.449660	.775613	54.6	26
	3	20	60.	.990237	.918953	18.7	27

```
         1.        21.        41.
         2.        22.        42.
         3.        23.        43.
         4.        24.         3.
        23.        25.        45.
         6.        26.        46.
         7.        27.        47.
         8.        28.        48.
         9.        29.        49.
         9.        30.        44.
        11.        31.        51.
        12.        32.        52.
        13.        33.        53.
        32.        34.        13.
        15.        35.        55.
        16.        36.        15.
        17.        37.        57.
        52.        55.        58.
        19.        39.        53.
        19.        40.        60.
               1  14    32.          .547922          .128546              468.9            28
 AVG. TIME=    168.1                                  TOTAL OPERATING TIME= 4706.7   TOTAL FAILURES= 28
```

SEQUENCE OF FAILURES

RUN NO.	FAILURE I.D.			FAILURE RAN. NO.	TIMERAN. NO.	HOURS BETWEEN FAILURES	FAILURE NO.
4							
	3	11	51.	.846881	.514959	83.0	1
	2	8	28.	.496088	.577541	69.7	2
	1	2	2.	.026529	.466334	98.8	3
	1	13	13.	.233047	.747438	38.4	4
	3	5	45.	.754168	.882619	16.8	5
	3	9	49.	.822124	.890460	15.8	6
	2	19	39.	.661506	.024494	515.2	7
	3	8	48.	.802351	.105160	318.3	8
	1	4	4.	.059866	.585244	77.4	9
	1	12	12.	.220022	.333490	162.1	10
	3	3	43.	.725355	.412710	133.1	11
	3	6	46.	.775753	.096163	358.9	12
	3	17	57.	.950804	.743088	46.4	13
	3	20	60.	.991141	.484597	115.4	14
	1	8	8.	.137579	.364587	164.7	15
	2	12	32.	.559545	.996041	.7	16
	2	13	33.	.567598	.812531	35.3	17
	1	19	19.	.353356	.841119	30.2	18
	1	10	10.	.174593	.701247	63.7	19
	1	13	31.	.546321	.584554	99.0	20
	1	15	15.	.274408	.509745	127.7	21
	2	8	7.	.120306	.891882	22.2	22
	1	12	30.	.529614	.202855	319.1	23

```
         1.        21.        41.
         2.        22.        42.
         3.        23.        43.
         4.        24.        44.
         5.        25.        45.
         6.        26.        46.
         7.        27.        47.
        23.         7.        26.
         9.        29.        49.
        10.         9.        50.
        11.        31.        51.
        30.        27.        52.
        31.        50.        53.
        14.        34.        54.
        15.        35.        55.
        16.        36.        56.
        17.        37.        57.
        18.        38.        58.
        19.        18.        59.
        20.        40.        60.
                 2  12   27.         .469908            .843959             34.8              24
AVG. TIME=     122.8                                    TOTAL OPERATING TIME= 2946.6   TOTAL FAILURES= 24
```

SEQUENCE OF FAILURES

RUN NO.	FAILURE I.D.			FAILURE RAN. NO.	TIMERAN. NO.	HOURS BETWEEN FAILURES	FAILURE NO.
5							
	3	15	55.	.917935	.313799	144.9	1
	3	13	53.	.879628	.713472	42.9	2
	3	18	58.	.961171	.287873	160.7	3
	2	11	31.	.534798	.288068	163.2	4
	2	4	24.	.425634	.269899	174.6	5
	3	19	59.	.970433	.266853	179.1	6
	2	9	29.	.514302	.372430	136.2	7
	3	10	50.	.832273	.948639	7.4	8
	3	12	52.	.860571	.096655	333.8	9
	3	4	44.	.742995	.120918	307.3	10
	3	16	56.	.929083	.266932	195.7	11
	2	19	39.	.670218	.572137	84.3	12
	2	16	36.	.620635	.567158	87.2	13
	1	5	5.	.091223	.638184	70.7	14
	2	1	21.	.390561	.744393	47.4	15
	1	13	13.	.236469	.455599	129.4	16
	1	19	19.	.345884	.066245	458.1	17
	2	19	18.	.321575	.903115	17.6	18
	2	7	27.	.474842	.017806	709.8	19
	2	12	32.	.549567	.451894	143.1	20
	1	2	2.	.027027	.495868	129.9	21
	2	20	40.	.677883	.852752	30.2	22
	3	17	57.	.952061	.642907	85.8	23
	2	17	16.	.283885	.036756	657.4	24

```
        1.         21.         41.
        2.         22.         42.
        3.         23.         43.
        4.          3.         44.
        5.         25.         45.
        6.         26.         46.
        7.         27.         47.
        8.         23.         48.
        9.         29.         49.
       10.         30.         50.
       11.         31.         51.
       12.         32.         46.
       13.         33.         28.
       14.         34.         54.
       15.         35.         55.
       16.         36.         34.
       17.         16.         54.
       18.         38.         58.
       15.         18.         37.
       20.         40.         60.
               1   19     15.         .275596          .096375                     479.9                     25
AVG. TIME=     199.1                                    TOTAL OPERATING TIME= 4976.7    TOTAL FAILURES= 25
```

-X-	FREQUENCY OF FAILURES WITH X FAILED SUBSYSTEMS
1	0.
2	0.
3	0.
4	0.
5	0.
6	0.
7	0.
8	0.
9	0.
10	0.
11	0.
12	0.
13	0.
14	0.
15	0.
16	0.
17	0.
18	0.
19	0.
20	0.
21	0.
22	0.
23	0.
24	1.
25	2.
26	1.
27	0.
28	1.
29	0.
30	0.
31	0.
32	0.
33	0.
34	0.
35	0.
36	0.
37	0.
38	0.
39	0.
40	0.

41	0.
42	0.
43	0.
44	0.
45	0.
46	0.
47	0.
48	0.
49	0.
50	0.

COMPUTATION	TIME	PROB. OF FAILURE
1	1904.8	.664029-03
2	2141.3	.292749-02
3	2401.1	.107953-01
4	2668.8	.313202-01
5	2898.0	.650688-01
6	3024.5	.917853-01
7	3055.6	.992891-01

AVG. NO. OF FAILURES= 25.60

10 PERCENT FAILED AT 3055.6

APPENDIX C

FORTRAN IV PROGRAM LISTING

```
@TIP    FOR  MAIN
COMPILATION BY UNIVAC 1107 FORTRAN-IV DATED      FEB. 10,1965 F4003
THIS COMPILATION WAS DONE ON 20 OCT 65 AT 16:10:59

   MAIN PROGRAM           ENTRY POINT 000000

   STORAGE USED (BLOCK, NAME, LENGTH)

         0001    *CODE    001742
         0000    *DATA    006170
         0002    *BLANK   002741


   EXTERNAL REFERENCES (BLOCK, NAME)

         0003    ALOCAT
         0004    DET
         0005    LIST
         0006    RANLIS
         0007    SEARCH
         0010    FAIL
         0011    SWITCH
         0012    SBACK
         0013    TIME
         0014    DEXP
         0015    COMFAC
         0016    NRDU$
         0017    NI01$
         0020    NI02$
         0021    NWDU$
         0022    NEXP9$
         0023    NSTOP$
         0024    NCDP$


   STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001   001703 104L      0001   000341 13L      0001   000060 134G      0001   000711 14L      0001
    0001   000776 17L       0001   001234 19L      0001   000565 2L        0001   001100 200L     0001
    0001   000760 22L       0001   000423 23L      0001   000363 262G      0001   000364 265G     0001
```

```
0001   000370 271G      0001   000514 28L       0001   000406 302G      0001   000407 305G      0001
0001   001223 306L      0001   001220 309L      0001   001227 310L      0001   000413 311G      0001
0001   000444 331G      0001   000473 335G      0001   000476 340G      0001   001343 35L       0001
0001   000625 375G      0001   001152 40L       0000   005567 400F      0000   005570 401F      0000
0000   005575 403F      0000   005600 404F      0000   005603 405F      0000   005612 406F      0000
0000   005631 408F      0000   005641 409F      0000   005643 413F      0000   005652 414F      0000
0001   000662 415G      0000   005702 416F      0000   005703 417F      0000   005711 418F      0000
0000   005737 420F      0000   005751 421F      0000   005762 422F      0000   005772 423F      0000
0000   006000 425F      0000   006003 427F      0000   006006 428F      0000   006011 429F      0000
0000   006026 431F      0000   006032 432F      0000   006035 433F      0001   000733 433G      0000
0000   006042 435F      0001   001127 44L       0000   006046 441F      0001   000741 441G      0000
0001   000742 444G      0000   006077 445F      0000   006110 446F      0001   000743 447G      0000
0000   006116 452F      0000   006120 454F      0000   006123 456F      0001   001275 46L       0001
0001   001423 502L      0001   001047 51L       0001   001471 53L       0001   000644 550L      0001
0001   000641 555L      0001   001200 563G      0001   001541 568L      0001   001543 569L      0001
0001   001374 572L      0001   001714 58L       0001   001661 583L      0001   000313 61L       0001
0001   001323 634G      0001   001324 637G      0001   001636 66L       0001   001401 666G      0001
0001   001555 68L       0001   001434 705G      0001   001447 717G      0001   000327 74L       0001
0001   000000 93L       0001   000601 94L       0001   001112 96L       0000 R 005545 AMEAN     0000 F
0000 R 005524 AVLAMD    0002 R 000000 B         0000 R 002734 BML       0000 R 005564 BOT       0000 F
0000 R 005525 CNT       0000 R 005526 CON       0000 D 005400 CONN      0014 R 000000 DEXP      0000 D
0000 R 005566 ERR       0000 D 005222 FACTL     0000 R 005535 FAILB     0000 R 005521 FAL       0000 F
0000 R 005546 FIWFT     0002 R 002734 FLAMD     0000 R 005544 FLONR     0000 R 005557 FM        0000 F
0000 I 005507 I         0000 I 005562 IDIFF     0000 I 005556 IL        0000 I 005555 IP        0000 I
0000 I 005471 IR        0000 I 005505 IRL       0000 I 005510 IRR       0000 I 005502 ISBAC     0000 I
0000 I 005500 ISW2      0000 I 005534 IW        0000 I 004230 IWF       0000 I 005532 IWFT      0000 I
0000 I 005552 I4        0000 I 005514 J         0000 I 005515 K         0000 I 005516 KK        0000 I
0000 I 005561 LL        0000 I 005527 LM        0000 I 005465 M         0000 I 005474 MBLL      0000 I
0000 I 005472 MM        0000 I 005530 MR        0000 I 005466 N         0000 I 005553 NA        0000 I
0000 I 005517 NI        0000 I 005520 NJ        0000 I 005540 NNN       0000 I 005550 NO        0000 I
0000 I 005504 NOP2      0000 I 005503 NOS       0000 I 005470 NR        0000 I 005473 NRL       0000 I
0000 I 005506 NTC       0000 I 005537 N1        0000 R 005531 OPRT      0000 R 005402 P         0000 F
0000 D 005370 PFAT      0000 D 005372 PFAT1     0000 D 005374 PTOT      0000 R 005536 RNT       0000 F
0000 R 005512 SUM       0000 R 003244 SUMT      0000 R 005511 SYSFA     0000 R 005214 T         0000 F
0000 R 005563 TOP       0000 R 003100 TT        0000 R 005541 T1        0000 R 005542 W         0000 F
```

```
00100    1.   CMAIN
00101    2.         DIMENSION C(5,20,15),BML(100),TT(100),
00101    3.        CSUMT(500),IWF(500),T(6)
00103    4.         DOUBLE PRECISION FACTL,PFAT,PFAT1,PTOT,EP,CONN
```

```
00104        DIMENSION B(5,20,15),FLAMD(5),P(51),FACTL(51)
00105        COMMON B, FLAMD
00106     93 READ(5,400) M,N,KTEMP,NR,IR,MM,NPL,MRLL,NSF,MIN,ISW1,ISW2,NOP1,
00106       CISBAC,NOS,NOP2,IRL,NTC
00132        READ(5,401)(FLAMD(I),I=1,M)
00140        WRITE (6,429)
00142        WRITE (6,430)
00144        WRITE (6,431)
00146        WRITE(6,404)(FLAMD(I),I=1,M)
00154        WRITE(6,402)M
00157        WRITE(6,403)N
00162        WRITE (6,419)KTEMP
00165        WRITE(6,405)NR
00170        WRITE(6,406)IP
00173        WRITE(6,407)MM
00176        WRITE(6,408)NRL
00201        WRITE(6,420)MIN
00204        WRITE(6,421)MRLL
00207        WRITE(6,422)NSF
00212        WRITE(6,424)ISW1
00215        WRITE(6,425)ISW2
00220        WRITE(6,427)NOP1
00223        WRITE(6,432) NOP2
00226        WRITE(6,428)ISBAC
00231        WRITE (6,423) NOS
00234        WRITE(6,454)NTC
00237        IRR=IR
00240        SYSFA=0.
00241        SUM=0.0
00242        CALL ALOCAT(M,N,KTEMP,FN,SUM,NSF)
00243        SUM=FN*SUM
00244        CALL DET   (M,N,KTEMP,NSF)
00245        IF(NSF-1) 60,61,60
00250     60 WRITE(6,433)
00252     61 IF(NRL-1)12,74,13
00255     12 CALL LIST(MM,M,N,KTEMP,NSF)
00256        GO TO 23
00257     74 CALL RANLIS(M,N,KTEMP,NOS,IRL,SYSFA,NSF)
00260        GO TO 23
00261     13 DO 24 J=1,N
00264        DO 24 I=1,M
00267     24 READ(5,409)(B(I,J,K),K=5,KTEMP)
00277        WRITE(6,450)
```

```
00301          DO 25 J=1,N
00304          DO 25 I=1,M
00307     25   WRITE(6,409)(B(I,J,K),K=5,KTEMP)
00317     23   IF(MBLL)14,14,16
00322     16   READ(5,409)(BML(KK),KK=1,MBLL)
00330          DO 94 KK=1, MBLL
00330   C      REMOVE MISSING BLOCKS FROM SPARE LISTS
00333          CALL SEARCH(BML(KK),0.,0,M,N,KTEMP)
00334          DO 27 I=1,M
00337          DO 27 J=1,N
00342          IF(B(I,J,3)-BML(KK))27,26,27
00345     26   NI=I
00346          NJ=J
00347          GO TO 28
00350     27   CONTINUE
00353     28   CALL FAIL (M,N,KTEMP,IR,MBLL,NJ,NI,FAL,BML(KK),MIN,X,S,SYSFA)
00354          IF(S)94,94,20
00357     20   IF(ISBAC)1,1,2
00362     1    CALL SWITCH(M,N,KTEMP,NJ,ISW1,ISW2,BML(KK),SYSFA,NOP1,
00362         1NOP2,NSF,MIN)
00363          GO TO 94
00364     2    CALL SBACK(M,N,KTEMP,NJ,BML(KK),SYSFA,NOP1,NOP2)
00365      94  CONTINUE
00367          AVLAMD=0.
00370          CNT=0.
00371          DO 550 I=1,M
00374          DO 550 J=1,N
00377          IF(B(I,J,4)-1.)551,555,555
00402     551  AVLAMD=AVLAMD-FLAMD(I)
00403          CNT=CNT + 1.
00404          GO TO 550
00405     555  SUM=SUM-FLAMD(I)
00406     550  CONTINUE
00411          CON=AVLAMD/CNT
00412          WRITE(6,434)
00414          DO 81 KK=1,MBLL
00417      81  WRITE(6,435) KK,BML(KK)
00424          WRITE(6,404)CON
00427          WRITE(6,404)SUM
00432     14   DO 82 LM=1,6
00435     82   T(LM)=0.
00435   C      SET UP DUPLICATE MATRIX C(I,J,K)
00437          MR=1
```

```
00440         DO 15 J=1,N
00443         DO 15 I=1,M
00446         DO 15 K=1,KTEMP
00451    15   C(I,J,K)=P(I,J,K)
00455         OPRT=0.
00456         IWFT=0
00457         DO 29 I3=0,50
00462    29   P(I3)=0.
00464    22   IW=0
00465         SUMT(MR)=0.
00466         IF(NSF-1)42,17,42
00471    42   WRITE(6,414)
00473         WRITE(6,415)
00475    17   CALL FAIL(M,N,KTEMP,IR,    0,NJ,NI,FAL,FAILB,MIN,X,S,SYSFA)
00476         IW=IW+1
00477         IF(NTC-1)51,54,51
00502    54   IF(MR-25)50,50,51
00505    50   CALL TIME(IR,FN,SUM,IW,RNT,TT(IW),SUMT(MR),NI)
00506    51   IF(SYSFA)97,97,96
00511    97   IF(S)96,96,98
00514    98   IF(ISBAC)100,100,200
00517   100   CALL SWITCH(M,N,KTEMP,NJ,ISW1,ISW2,FAL,SYSFA,NOP1,NOP2,NSF,MIN)
00520         GO TO 96
00521   200   CALL SBACK(M,N,KTEMP,NJ,FAL,SYSFA,NOP1,NOP2)
00522    96   IF(NSF-1) 91,40,91
00525    91   IF(IW-1)43,43,44
00530    43   WRITE(6,416)MR
00533    44   WRITE(6,417)  NI,NJ,FAILB,X,RNT,TT(IW),IW
00544    40   IF(SYSFA)17,17,52
00547    52   IF(NTC-1)19,59,19
00552    59   IF(MR-25)303,303,19
00555   303   IF(MR-1)304,304,305
00560   304   T(1)=SUMT(MR)
00561         GO TO 19
00561   C     LIST FIRST  5 OF 25 IN ORDER
00562   305   DO 306 N1=1,5
00565         NNN=6-N1
00566         IF(T(NNN ))306,306,307
00571   307   IF(SUMT(MR)-T(NNN ))309,309,308
00574   308   T(NNN+1)=SUMT(MR)
00575         GO TO 310
00576   309   T(NNN+1)=T(NNN )
00577   306   CONTINUE
```

```
00601              T(1)=SUMT(MR)
00602        310   IF(MR-25)19,312,19
00605        312   T1=T(5)
00605       C      COMPUTE INDIVIDUALRUN STATISTICS
00606         19   IWFT=IWFT+IW
00607              W=IW
00610              P(IW)=P(IW)+1.
00611              SYSFA=0.
00612              IWF(MR)=IW
00613              OPRT=OPRT+SUMT(MR)
00614              IF(NSF-1) 45,46,45
00617         45   AUGT=SUMT(MR)/W
00620              WRITE(6,418)(AUGT,SUMT(MR),IW)
00625         46   IF(NR-MR)35,35,37
00625       C      RESET SYSTEM
00630         37   DO 36 J=1,N
00633              DO 36 I=1,M
00636              DO 36 K=1,KTEMP
00641         36   B(I,J,K)=C(I,J,K)
00645              IRR=IRR+2
00646              IR=IRR
00647              MR=MR+1
00650              GO TO 22
00650       C      COMPUTE OVERALL STATISTICS
00651         35   FLONR=NR
00652              AMEAN=OPRT/25.
00653              FIWFT=IWFT
00654              FAVGF=FIWFT/FLONR
00655              NO=0
00656              IF(MBLL)570,570,571
00661        570   IPROD=M*N
00662              GO TO 572
00663        571   IPROD=CNT
00664        572   WRITE(6,444)((I4,P(I4)),I4=1,50)
00673              DO 500 NA=0,50
00676              IF(P(50-NA)) 500,500,502
00701        500   CONTINUE
00703        502   NB=50-NA
00704              DO 102 IP=1,NB
00707              P(IP)=(P(IP)/FLONR)+P(IP-1)
00710        102   CONTINUE
00712              IF(MBLL)552,552,553
00715        552   CON=0.
```

```
00716          DO 105 IL=1,N
00721    105   CON=CON+FLAMD(IL)
00723          FN=N
00724          CON=(-CON)/FN
00725    553   IF(NTC-1)202,201,202
00730    201   TI=0.7*TI
00731          GO TO 53
00732    202   TI=100
00733    53    PFAT=0.
00734          PTOT=0.
00735          CONN=CON*TI
00736          EP=DEXP(CONN)
00737          DO 56 LL=0,NB
00742          IDIFF=IPROD-LL
00743          IF(NO-1)67,68 ,68
00746    67    IF(MBLL)567,567,568
00751    567   TOP=M*N
00752          GO TO 569
00753    568   TOP=CNT
00754    569   BOT=LL
00754   C      COMPUTE COMBINATIONAL FACTORIAL
00755          CALL COMFAC(TOP,BOT,FACTL(LL))
00755   C      COMPUTE PROBABILITY OF FAILURE AT TI
00756    68    PFAT1=FACTL(LL)*((1.-EP)**LL)*(EP**IDIFF)
00757          PF=PFAT1
00760          PFAT1=P(LL)*PFAT1
00761          PTOT=PTOT+PF
00762          PFAT=PFAT+PFAT1
00763    56    CONTINUE
00765          PFAT=PFAT+1.-PTOT
00766          NO=NO+1
00767          IF(NO-1)65,65,66
00772    65    WRITE(6,445)
00774    66    WRITE(6,446)NO,TI,PFAT
01001          IF(NO-50)583,583,993
01004    993   WRITE(6,456)
01006          GO TO 93
01007    583   IF(NTC-1)104,103,104
01012    103   ERR=PFAT-.1
01013          IF(ABS(ERR)-.001)58,58,57
01016    57    TI=TI*(1.-(ERR/.8))
01017          GO TO 53
01020    104   IF(TI-5000.)105,58,58
```

```
01023     105  TI=TI+100.
01024          GO TO 53
01025     58   T1=TI
01026          WRITE(6,413)FAVGF
01031          IF(NTC-1) 93,203,93
01034     203  WRITE(6,441)T1
01037          GO TO 93
01040     400  FORMAT(I4)
01041     401  FORMAT(5E12.6)
01042     402  FORMAT(7H      N=,I4)
01043     403  FORMAT(7H      N=,I4)
01044     404  FORMAT(7H LAMDA=,E12.6)
01045     405  FORMAT(7H     NR=,I4,20H    (NUMBER OF RUNS))
01046     406  FORMAT(7H     IR=,I4,23H    (RANDOM NUMBER SET))
01047     407  FORMAT(7H     MM=,I4,28H    (COMMON SPARE LIST FLAG))
01050     408  FORMAT(7H    NRL=,I4,30H    (NON REPETITIVE LIST FLAG))
01051     409  FORMAT(6F12.0)
01051    C     409 FORMAT IS A SPARE LIST READ IN FORMAT
01052     413  FORMAT(28H        AVG. NO. OF FAILURES=,F7.2)
01053     414  FORMAT(21H1SEQUENCE OF FAILURES//)
01054     415  FORMAT(106H RUN NO.     FAILURE I.D.     FAILURE RAN. NO.     TIME
01054         CRAN. NO.     HOURS BETWEEN FAILURES     FAILURE NO.)
01055     416  FORMAT (I5)
01056     417  FORMAT(I15,I4,F6.0,F16.6,F19.6,F21.1,I21)
01057     418  FORMAT(11H AVG. TIME=,F8.1,55H                                          TO
01057         CTAL OPERATING TIME=,F7.1,18H   TOTAL FAILURES=,I3)
01060     419  FORMAT(7H KTEMP=,I4)
01061      420 FORMAT(7H    MIN=,I4,39H    (OPR. BLOCKS REQ. TO RESOLVE ERROR))
01062     421  FORMAT (7H   MBLL=,I4,31H    (MISSING BLOCK LIST LENGTH))
01063     422  FORMAT(7H    NSF=,I4,27H    (NO SAMPLE FORMAT FLAG))
01064     423  FORMAT (7H    NOS=,I4)
01065     424  FORMAT (7H   ISW1=,I4)
01066     425  FORMAT (7H   ISW2=,I4)
01067     427  FORMAT (7H   NOP1=,I4)
01070     428  FORMAT (7H ISBAC=,I4)
01071     429  FORMAT(39H1FAILURE RESPONSIVE SYSTEM ORGANIZATION/)
01072     430  FORMAT(21H STRATEGY DESCRIPTION //)
01073     431  FORMAT(18H CONTROL CONSTANTS/)
01074     432  FORMAT(7H   NOP2=,I4)
01075     433  FORMAT(1H1)
01076     434  FORMAT(15H1MISSING BLOCKS//)
01077     435  FORMAT(5H LVL(,I2,3H )=,F6.0)
01100     441  FORMAT(21H 10 PERCENT FAILED AT,F8.1)
```

```
01101      444  FORMAT(10H]       -X-,11X,27H FREQUENCY OF FAILURES WITH/44H
01101         C                    X FAILED SUBSYSTEMS//(I9,F28.0))
01102      445  FORMAT(44H1COMPUTATION    TIME         PROB. OF FAILURE/)
01103      446  FORMAT( I7,F15.1,D20.6)
01104      450  FORMAT(11H SPARE LIST)
01105      452  FORMAT(D30.6)
01106      454  FORMAT(7H   NTC=,I4)
01107      456  FORMAT(11H ERROR EXIT)
01110           STOP
01111           END

         END OF LISTING.      0 *DIAGNOSTIC* MESSAGE(S).
PHASE 1 TIME =   3 SEC.
PHASE 2 TIME =   1 SEC.
PHASE 3 TIME =   3 SEC.
PHASE 4 TIME =   1 SEC.
PHASE 5 TIME =   2 SEC.
PHASE 6 TIME =   4 SEC.

TOTAL COMPILATION TIME =  14  SEC
```

```
WTIP   FOR  ALOCAT
COMPILATION BY UNIVAC 1107 FORTRAN-IV DATED     FEB. 10,1965 F4003
THIS COMPILATION WAS DONE ON 19 OCT 65 AT 17:06:37

   SUBROUTINE ALOCAT    ENTRY POINT 000170

   STORAGE USED (BLOCK, NAME, LENGTH)

         0001   *CODE   000221
         0000   *DATA   000055
         0002   *BLANK  002741

   EXTERNAL REFERENCES (BLOCK, NAME)

         0003   NWDU$
         0004   NI02$
         0005   NI01$

   STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0000    000010 103F        0000   000017 104F        0001    000031 107G       0001    000042 115G        0001
    0001    000066 132G        0001   000067 135G        0001    000071 140G       0001    000103 147G        0001
    0001    000122 165G        0001   000125 170G        0001    000130 173G       0001    000155 8L          0002 R
    0002 R  002734 FLAMD       0000 I 000005 I           0000 I  000007 J          0000 I  000006 K           0000 R

00100      1.    C
00101      2.          SUBROUTINE ALOCAT(M,N,KTEMP,FN,SUM,NSF)
00103      3.          DIMENSION RANGE(5)
00104      4.          DIMENSION B(5,20,15),FLAMD(5)
00105      5.          COMMON B, FLAMD
00106      6.          DO 1 I=1,M
00111      7.     1    SUM=SUM + FLAND(I)
00113      8.          FN=N
00114      9.          DO 2 I=1,M
00117     10.     2    RANGE(I)=FLAMD(I)/(FN*SUM)
```

```
00121          B(1,1,1)=0.
00122          B(1,1,2)=RANGE(1)
00123          DO 3 I=2,N
00126          B(I,1,1)=(FD*RANGE(I-1))+B(I-1,1,1)
00127      3   B(I,1,2)=RANGE(I)+B(I,1,1)
00131          DO 4 K=1,2
00134          DO 4 J=2,N
00137          DO 4 I=1,N
00142      4   B(I,J,K)=B(I,J-1,K)+RANGE(I)
00146          DO 5 I=1,N
00151          DO 5 J=1,N
00154      5   B(I,J,4)=0.
00157          IF(NSE-1)6,8,6
00162      6   WRITE(6,104)
00164          DO 7 I=1,N
00167          DO 7 J=1,N
00172          DO 7 K=1,2
00175      7   WRITE(6,103)I,J,K,B(I,J,K)
00206      8   RETURN
00207    103   FORMAT(3H B(,I2,2H ,,I2,2H ,,I2,3H )=,F12.6)
00210    104   FORMAT(12H1ALLOCATIONS)
00211          END

        END OF LISTING.      0 *DIAGNOSTIC* MESSAGE(S).
PHASE 1 TIME =    0 SEC.
PHASE 2 TIME =    0 SEC.
PHASE 3 TIME =    1 SEC.
PHASE 4 TIME =    1 SEC.
PHASE 5 TIME =    1 SEC.
PHASE 6 TIME =    0 SEC.

TOTAL COMPILATION TIME =   3  SEC
```

```
@TIP   FOR  COMFAC
COMPILATION BY UNIVAC 1107 FORTRAN-IV DATED     FEB. 10,1965 F4003
THIS COMPILATION WAS DONE ON 19 OCT 65 AT 17:06:41

   SUBROUTINE COMFAC     ENTRY POINT 000067

   STORAGE USED (BLOCK, NAME, LENGTH)

         0001   *CODE    000107
         0000   *DATA    000017
         0002   *BLANK   000000

   EXTERNAL REFERENCES (BLOCK, NAME)

         0003   NCDPS

   STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001   000046 123G       0001   000025 2L        0001   000032 3L        0001   000010 6L        0000 F
    0000 R 000001 DUM        0000 I 000003 JI        0000 I 000000 NDUM      0000 I 000002 NDUM1

00100      1.   C
00101      2.         SUBROUTINE COMFAC(TOP,BOT,FACTL)
00103      3.         DOUBLE PRECISION FACTL
00104      4.         IF(BOT)5,5,6
00107      5.    5    FACTL=1.
00110      6.         RETURN
00111      7.    6    IF(TOP-2.*BOT)1,1,2
00114      8.    1    NDUM=TOP-BOT
00115      9.         GO TO 3
00116     10.    2    NDUM=BOT
00117     11.    3    DUM=NDUM
00120     12.         FACTL=1.
00121     13.         NDUM1=NDUM-1
00122     14.         DO 4 JI=0,NDUM1
```

```
00125      15.            AJI=JI
00126      16.      +     FACTL=(FACTL*(TOP-AJI))/(FNM-AJI)
00130      17.            RETURN
00131      18.            END

         END OF LISTING.        0 *DIAGNOSTIC* MESSAGE(S).
PHASE 1 TIME =    0 SEC.
PHASE 2 TIME =    1 SEC.
PHASE 3 TIME =    0 SEC.
PHASE 4 TIME =    0 SEC.
PHASE 5 TIME =    1 SEC.
PHASE 6 TIME =    0 SEC.

TOTAL COMPILATION TIME =    2  SEC
```

```
MTIP    FOR  DET
COMPILATION BY UNIVAC 1107 FORTRAN-IV DATED      FEB. 10,1965 F4003
THIS COMPILATION WAS DONE ON 19 OCT 65 AT 17:05:44

   SUBROUTINE DET        ENTRY POINT 000071

   STORAGE USED (BLOCK, NAME, LENGTH)

         0001    *CODE    000106
         0000    *DATA    000031
         0002    *BLANK   002741


   EXTERNAL REFERENCES (BLOCK, NAME)

         0003    NWDU$
         0004    NI02$
         0005    NI01$


   STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001    000054 100L         0001    000024 113G        0001    000027 116G         0000    000002 890F         0001
    0000    000005 893F         0002 R  000000 B           0002    002734 FLAMD        0000 I  000000 I            0000 I



00100      1.    C
00101      2.          SUBROUTINE DET    (M,N,KTEMP,NSF)
00101      3.    C     NUMBERS STEP ACROSS ROWS FIRST
00103      4.          DIMENSION B(5,20,15),FLAMD(5)
00104      5.          COMMON B, FLAMD
00105      6.          IF(NSF-1) 892,891,392
00110      7.     892  WRITE(6,890)
00112      8.     891  DO 100 I=1,M
00115      9.          DO 100 J=1,N
00120     10.          B(I,J,3)=(I-1)*L+J
00121     11.          IF(NSF-1)101,100,101
00124     12.     101  WRITE(6,893) I,J,B(I,J,3)
```

```
00131      13.     190  CONTINUE
00134      14.          RETURN
00135      15.     690  FORMAT(1H1ID NUMBERS)
00136      16.     693  FORMAT(3H B(,I2,2H ,,I2,5H ,3)=,F5.0)
00137      17.          END

        END OF LISTING.       0 *DIAGNOSTIC* MESSAGE(S).
PHASE 1 TIME =    0 SEC.
PHASE 2 TIME =    0 SEC.
PHASE 3 TIME =    1 SEC.
PHASE 4 TIME =    0 SEC.
PHASE 5 TIME =    1 SEC.
PHASE 6 TIME =    0 SEC.

TOTAL COMPILATION TIME =   2  SEC
```

```
WTIP    FOR  FAIL
COMPILATION BY UNIVAC 1107 FORTRAN-IV DATED      FEB. 10,1965 F4003
THIS COMPILATION WAS DONE ON 19 OCT 65 AT 17:06:47


   SUBROUTINE FAIL        ENTRY POINT 000154

   STORAGE USED (BLOCK, NAME, LENGTH)

         0001    *CODE     000225
         0000    *DATA     000027
         0002    *BLANK    002741


   EXTERNAL REFERENCES (BLOCK, NAME)

         0003    UDRNRT


   STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001    000025 113G       0001    000030 116G       0001    000075 12L       0001    000106 14L       0001
    0001    000116 162G       0001    000046 5L         0001    000107 51L       0001    000015 6L        0001
    0001    000135 8L         0001    000137 9L         0002 R  000000 B         0000 R  000004 FFAL      0002
    0000 I  000000 I          0000 I  000003 I1         0000 I  000001 J         0000 I  000005 L         0000 I
    0003 R  000000 UDRNRT


00100       1.     C
00101       2.            SUBROUTINE FAIL(M,N,KTEMP,IR,MBLL,NJ,NI,FAL,FAILB,MIN,X,S,SYSFA)
00103       3.            DIMENSION B(5,20,15),FLAMD(5)
00104       4.            COMMON B, FLAMD
00105       5.            IF(MBLL)6,6,7
00110       6.      6     X=UDRNRT(IR)
00111       7.            FAILB=0.
00112       8.            DO 5 I=1,N
00115       9.            DO 5 J=1,N
00120      10.            IF(X-B(I,J,1))5,2,2
00122      11.      2     IF(X-B(I,J,2))5,3,3
```

```
00126    12.    3    FAILB=B(I,J,3)
00127    13.         NI=I
00130    14.         NJ=J
00131    15.         GO TO 7
00132    16.    6    CONTINUE
00135    17.         GO TO 6
00136    18.    7    B(NI,NJ,1)=0.
00137    19.         B(NI,NJ,2)=0.
00137    20.    C    TEST TO SEE IF REPAIR IS NECESSARY
00140    21.    50   MZ=0
00141    22.         DO 12 II=1,M
00144    23.         IF(B(II,NJ,2))11,12,11
00144    24.    C    MZ=NO. OF OPERATING SUBSYSTEMS
00147    25.    11   MZ=MZ + 1
00150    26.    12   CONTINUE
00152    27.         IF(MZ-MIN)13,14,14
00155    28.    13   S=1.
00156    29.         GO TO 51
00157    30.    14   S=0.
00160    31.     51  FFAL=0.
00161    32.         DO 4 L=1,M
00164    33.     4   FFAL=AMAX1(FFAL,B(L,NJ,4))
00166    34.         FAL=FFAL
00167    35.         IF(MZ-1)8,15,9
00172    36.    15   IF(MIN-3)9,8,9
00175    37.    8    SYSFA=1.
00176    38.    9    B(NI,NJ,4)=FAL+1.
00177    39.         RETURN
00200    40.         END

       END OF LISTING.      0 *DIAGNOSTIC* MESSAGE(S).
PHASE 1 TIME =   0 SEC.
PHASE 2 TIME =   1 SEC.
PHASE 3 TIME =   0 SEC.
PHASE 4 TIME =   1 SEC.
PHASE 5 TIME =   0 SEC.
PHASE 6 TIME =   1 SEC.

TOTAL COMPILATION TIME =   3  SEC
```

```
WTIP   FOR  LIST
COMPILATION BY UNIVAC 1107 FORTRAN-IV DATED      FEB. 10,1965 F4003
THIS COMPILATION WAS DONE ON 19 OCT 65 AT 17:06:51

   SURROUTINE LIST       ENTRY POINT 000352

   STORAGE USED (BLOCK, NAME, LENGTH)

         0001    *CODE    000402
         0000    *DATA    000110
         0002    *BLANK   002741


   EXTERNAL REFERENCES (BLOCK, NAME)

         0003    NRDU$
         0004    NIO1$
         0005    NIO2$
         0006    NWDU$


   STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0000   000012 102F      0000   000014 103F      0000   000023 104F      0000   000027 105F      0000
    0001   000247 11L       0001   000057 112G      0001   000075 122G      0001   000105 127G      0001
    0001   000106 132G      0001   000300 14L       0001   000126 143G      0001   000132 147G      0001
    0001   000155 163G      0001   000160 166G      0001   000115 2L        0001   000202 202G      0001
    0001   000210 31L       0001   000242 5L        0001   000320 6L        0001   000200 9L        0002 R
    0000 R 000007 BTEMP     0002   002734 FLAMD     0000 R 000003 FN        0000 I 000001 I         0000 I
    0000 I 000011 IBTEMP    0000 I 000004 INOW      0000 I 000006 ISPARE    0000 I 000010 ITEMP     0000 I
    0000 I 000000 K


00100       1.   C
00101       2.          SUBROUTINE LIST(MM,M,N,ITEMP,NSF)
00103       3.          DIMENSION B(5,20,15),FLAMD(5)
00104       4.          COMMON B, FLAMD
00105       5.          IF(MM-1)2,1,2
```

C-20

```
00111      1    READ(5,102)((I,J,K),K=5,KTEMP)
00116           WRITE(6,103)
00120           WRITE(6,102)((I,J,K),K=5,KTEMP)
00124           DO 7 K=5,KTEMP
00131           DO 7 I=2,N
00134      7    B(I,J,K)=B(1,J,K)
00137           GO TO 3
00140      2    WRITE(6,103)
00142           DO 20 I=1,N
00145           READ(5,102)(B(I,J,K),K=5,KTEMP)
00153     20    WRITE(6,102)(B(I,J,K),K=5,KTEMP)
00162      3    DO 6 I=1,N
00165           DO 6 J=1,N
00170           IF(ISF-1)8,9,8
00173      8    WRITE(6,105)
00175           WRITE(6,103)I,J
00201      9    DO 6 K=5,KTEMP
00204           IF(B(I,J,K))30,30,31
00207     30    B(I,J,K)=0.
00210           GO TO 14
00211     31    F=[illegible]
00212           IROW=(B(I,J,K)/F)+.9999
00213           IB=B(I,J,4)
00214           ISPARE=IB+J-1
00215           IF(ISPARE-1)5,4,4
00220      4    BTEMP=ISPARE
00221           GO TO 11
00222      5    BTEMP=ISPARE+[illegible]
00223     11    ITEMP=(BTEMP/F)+.9999
00224           IF(IROW-ITEMP) 12,13,12
00227     12    IBTEMP=BTEMP
00230           B(I,J,K)=((IROW-ITEMP)*[illegible])+BTEMP
00231           GO TO 1[illegible]
00232     13    B(I,J,K)=BTEMP
00233     14    IB=B(I,J,K)
00234           IF(ISF-1)10,6,10
00237     10    WRITE(6,104)IB,K
00243      6    CONTINUE
00247           RETURN
00250    102    FORMAT(6F12.0)
00251    103    FORMAT(1H ,30X,3[illegible](,I2,2[illegible],I2,2[illegible]),10X,2[illegible])
00252    104    FORMAT(1H ,32X,I4,15X,I4)
00253    105    FORMAT(1H ,25X,[illegible] ---------------------------------)
```

```
00254     49.      100 FORMAT(11H SPARE LIST)
00255     50.          END

        END OF LISTING.       0 *DIAGNOSTIC* MESSAGE(S).
PHASE 1 TIME =    1 SEC.
PHASE 2 TIME =    0 SEC.
PHASE 3 TIME =    1 SEC.
PHASE 4 TIME =    0 SEC.
PHASE 5 TIME =    1 SEC.
PHASE 6 TIME =    1 SEC.

TOTAL COMPILATION TIME =    4  SEC
```

```
WTIP   FOR  RANLIS
COMPILATION BY UNIVAC 1107 FORTRAN-IV DATED      FEB. 10,1965 F4003
THIS COMPILATION WAS DONE ON 19 OCT 65 AT 17:06:56

   SUBROUTINE RANLIS     ENTRY POINT 000224

   STORAGE USED (BLOCK, NAME, LENGTH)

         0001    *CODE    000255
         0000    *DATA    000071
         0002    *BLANK   002741


   EXTERNAL REFERENCES (BLOCK, NAME)

         0003    UDRNRT
         0004    NWDU$
         0005    NI02$
         0006    NI01$


   STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0000    000010 103F        0000    000017 104F        0000    000023 105F        0001    000026 106G        0001
    0001    000076 122G        0001    000122 137G        0001    000124 142G        0001    000125 145G        0001
    0001    000146 162G        0001    000165 173G        0001    000052 701L        0001    000207 705L        0001
    0001    000111 711L        0002 R 000000 B            0002    002734 FLAMD       0000 R 000003 FM         0000 R
    0000 I 000007 I            0000 I 000005 I1           0000 I 000004 IX           0000 I 000000 J          0000 I
    0000 I 000006 LB           0003 R 000000 UDRNRT


00100      1.   C
00101      2.            SUBROUTINE RANLIS(M,N,KTEMP,NOS,IRL,SYSFA,NSF)
00103      3.            DIMENSION B(5,20,15),FLAMD(5)
00104      4.            COMMON B,FLAMD
00104      5.   C        ROUTINE FOR GENERATING RANDOM SPARE LIST
00105      6.            DO 704 J=1,N
00110      7.            DO 704 K=5,KTEMP
```

```
00113      8.            FN=N
00114      9.            FM=M
00115     10.     701    IX=FN*FM*UDRNRT(IRL)  +1.
00116     11.            IF(NOS-1)711,712,705
00121     12.     712    DO 707 II=1,M
00124     13.            LB=B(II,J,3)
00125     14.            IF(IX-LB)707,701,707
00130     15.     707    CONTINUE
00132     16.     711    B(1,J,K)=IY
00133     17.     704    CONTINUE
00136     18.            DO 713 I=2,M
00141     19.            DO 713 J=1,N
00144     20.            DO 713 K=5,KTEMP
00147     21.     713    B(I,J,K)=B(1,J,K)
00153     22.            IF(NSF-1)709,706,709
00156     23.     709    DO 710 I=1,M
00161     24.            DO 710 J=1,N
00164     25.            WRITE (6,105)
00166     26.            WRITE (6,103)I,J
00172     27.            DO 710 K=5,KTEMP
00175     28.     710    WRITE(6,104)B(I,J,K),K
00204     29.            GO TO 706
00205     30.     705    SYSFA=1.
00206     31.     706    RETURN
00207     32.     103    FORMAT(1H ,30X,3H B(,I2,2H ,,I2,2H ),10X,2H K)
00210     33.     104    FORMAT(1H ,32X,F4.0,15X,I2)
00211     34.     105    FORMAT(1H ,25X,30H ------------------------------)
00212     35.            END

        END OF LISTING.      0 *DIAGNOSTIC* MESSAGE(S).
PHASE 1 TIME =   1 SEC.
PHASE 2 TIME =   0 SEC.
PHASE 3 TIME =   1 SEC.
PHASE 4 TIME =   0 SEC.
PHASE 5 TIME =   1 SEC.
PHASE 6 TIME =   0 SEC.

TOTAL COMPILATION TIME =   3  SEC
```

```
@TIP   FOR   SPACK
COMPILATION BY UNIVAC 1107 FORTRAN-IV DATED      FEB. 10,1965 F4P03
THIS COMPILATION WAS DONE ON 19 OCT 65 AT 17:07:09

   SUBROUTINE SPACK        ENTRY POINT 000170

   STORAGE USED (BLOCK, NAME, LENGTH)

        0001    *CODE    000230
        0000    *DATA    000055
        0002    *BLANK   002741


   EXTERNAL REFERENCES (BLOCK, NAME)

        0003    NWDU$
        0004    NIO2$


   STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001     000020 106G        0001     000041 117G        0001     000051 126G        0001     000060 131G        0001
    0001     000036 902L        0001     000125 903L        0001     000111 940L        0001     000120 950L        0001
    0001     000140 952L        0000     000010 953F        0001     000135 956L        0001     000034 982L        0001
    0002 R 000000 B             0000 R 000003 FIO           0002     002734 FLAMD       0000 I 000000 I             0000 I
    0000 I 000004 I1            0000 I 000007 I2            0000 I 000005 J1            0000 I 000002 K             0000 I


00100      1.    C
00101      2.              SUBROUTINE SBACK(M,N,KTEMP,NJ,FAL,SYSFA,NOP1,NOP2)
00103      3.              DIMENSION B(5,20,15),FLAMD(5)
00104      4.              COMMON B,FLAMD
00104      5.    C         PROGRAM TO SPRING BACK SPARE
00105      6.      901     DO 956 I=1,M
00105      7.    C         LOOK FOR PREVIOUS FAILURE
00110      8.              IF(B(I,NJ,4)-FAL)956,981,956
00110      9.    C         BEGIN SCANNING THE SPARE LIST TO BE USED
00113     10.      981     INHIB=NOP1
```

```
00114          GO TO 902
00115     982  INHIB=NOP2
00116     902  DO 903 K=5,KTEMP
00121          IF(B(I,NJ,K))952,903,905
00124     905  FID=B(I,NJ,K)
00124     C    SEARCH FOR THE SPARE WITH ID NUMBER=FID
00125          DO 950 I1=1,M
00130          DO 950 J1=1,N
00133          IF(B(I1,J1,3)-FID)950,908,950
00133     C    IF THE SPARE IS UNAVAILABLE,OR HAS FAILED,KEEP LOOKING
00136     908  IF(B(I1,J1,4))952,930,903
00141     930  KK=0
00142          DO 940 I2=1,M
00145          IF(B(I2,J1,4)-1.)931,940,940
00150     931  KK=KK+1
00151     940  CONTINUE
00153          IF(KK-INHIB)903,903,999
00156     950  CONTINUE
00161     903  CONTINUE
00163     932  IF(INHIB-NOP2)951,951,982
00166     956  CONTINUE
00170     952  WRITE(6,953)
00172          GO TO 999
00173     951  SYSFA=1.
00174          GO TO 999
00175     999  RETURN
00176     953  FORMAT(14H ERROR IN FAIL)
00177          END

       END OF LISTING.      0 *DIAGNOSTIC* MESSAGE(S).
PHASE 1 TIME =   1 SEC.
PHASE 2 TIME =   0 SEC.
PHASE 3 TIME =   1 SEC.
PHASE 4 TIME =   0 SEC.
PHASE 5 TIME =   1 SEC.
PHASE 6 TIME =   0 SEC.

TOTAL COMPILATION TIME =   3  SEC
```

```
@TIP   FOR  SEARCH
COMPILATION BY UNIVAC 1107 FORTRAN-IV DATED      FEB. 10,1965 F4003
THIS COMPILATION WAS DONE ON 19 OCT 65 AT 17:07:04

   SUBROUTINE SEARCH      ENTRY POINT 000053

   STORAGE USED (BLOCK, NAME, LENGTH)

         0001    *CODE    000074
         0000    *DATA    000024
         0002    *BLANK   002741

   STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001    000022 106G        0001    000023 111G       0001    000024 114G       0001    000037 3L        0001
    0002 R  000000 B           0002    002734 FLAMD      0000 I  000000 I          0000 I  000001 J         0000 I

00100      1.    C
00101      2.          SUBROUTINE SEARCH(FAILR,SPARE,NREP,M,N,KTEMP)
00103      3.          DIMENSION B(5,20,15),FLAMD(5)
00104      4.          COMMON B,FLAMD
00105      5.          DO 4 I=1,M
00110      6.          DO 4 J=1,N
00113      7.          DO 4 K=5,KTEMP
00116      8.          IF(B(I,J,K)-FAILR)4,1,4
00121      9.     1    IF(NREP-1)3,3,2
00124     10.     2    B(I,J,K)=SPARE
00125     11.          GO TO 4
00126     12.     3    B(I,J,K)=0.
00127     13.     4    CONTINUE
00133     14.          RETURN
00134     15.          END
       END OF LISTING.      0 *DIAGNOSTIC* MESSAGE(S).
PHASE 1 TIME =   1 SEC.
PHASE 2 TIME =   0 SEC.
PHASE 3 TIME =   0 SEC.
PHASE 4 TIME =   1 SEC.
PHASE 5 TIME =   0 SEC.
PHASE 6 TIME =   1 SEC.

TOTAL COMPILATION TIME =    3  SEC
```

```
ATIR   FOR  SWITCH
COMPILATION BY UNIVAC 1107 FORTRAN-IV DATED      FEB. 10,1965 F4003
THIS COMPILATION WAS DONE ON 19 OCT 65 AT 17:07:07


   SUBROUTINE SWITCH     ENTRY POINT 000470

   STORAGE USED (BLOCK, NAME, LENGTH)

         0001    *CODE    000565
         0000    *DATA    000100
         0002    *BLANK   002741


   EXTERNAL REFERENCES (BLOCK, NAME)

         0003    SEARCH
         0004    NWDU$
         0005    NI02$
         0006    NI01$


   STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001     000020 106G        0001     000044 126G        0001     000054 130G        0001     000063 133G        0001
    0001     000257 222G        0001     000302 230G        0001     000331 236G        0001     000340 243G        0001
    0001     000371 256G        0001     000431 276G        0001     000435 302G        0001     000134 503L        0001
    0001     000207 513L        0001     000236 514L        0001     000263 516L        0001     000306 518L        0001
    0001     000343 521L        0000     000026 533F        0001     000114 540L        0001     000127 550L        0001
    0001     000444 552L        0000     000020 553F        0000     000024 554F        0001     000144 556L        0000
    0001     000041 580L        0001     000037 582L        0002 R 000000 B          0000 R 000015 FAILR       0000 R
    0000 R 000005 FID         0002     002734 FLAMR       0000 I 000000 I          0000 I 000003 INHIB       0000 I
    0000 I 000012 ISPAR       0000 I 000006 I1          0000 I 000011 I2         0000 I 000017 J           0000 I
    0000 I 000013 JSPAR       0000 I 000007 J1          0000 I 000004 K          0000 I 000010 KK          0000 R


00100      1.    C
00101      2.          SUBROUTINE SWITCH(M,N,KTEMP,NJ,ISW1,ISW2,FAL,SYSFA,NOP1,NOP2,
00101      3.         CNSF,MIN)
```

```
00103        DIMENSION B(5,20,15),FLAMD(5)
00104        COMMON B, FLAMD
00104   C    LOOK FOR PREVIOUS FAILURE
00105   591  DO 556 I=1,M
00110        IF(B(I,NJ,4)-FAL) 556,502,556
00113   502  IRPL=I
00114        JRPL=NJ
00114   C    BEGIN SCANNING THE SPARE LIST TO BE USED
00115   581  INHIB=NOP1
00116        GO TO 580
00117   582  INHIB=NOP2
00120   580  DO 503 K=5,KTEMP
00123   504  IF(B(I,NJ,K))552,503,505
00126   505  FID=B(I,NJ,K)
00126   C    SEARCH FOR THE SPARE WITH ID NUMBER=FID
00127        DO 550 I1=1,M
00132        DO 550 J1=1,N
00135        IF(B(I1,J1,3)-FID)550,508,550
00140   508  IF(B(I1,J1,4))552,530,503
00140   C    IF THE SPARE HAS FAILED OR IS UNAVAILABLE, KEEP LOOKING
00143   530  KK=0
00144        DO 540 I2=1,M
00147        IF(B(I2,J1,4)-1.)531,540,540
00152   531  KK=KK+1
00153   540  CONTINUE
00155        IF(KK-INHIB)503,503,509
00160   509  ISPAR=I1
00161        JSPAR=J1
00162        SPARE=B(I1,J1,3)
00163        GO TO 510
00164   550  CONTINUE
00167   503  CONTINUE
00171        IF(INHIB-NOP2)551,551,582
00174   556  CONTINUE
00176        GO TO 551
00177   510  IF(ISW2-1)511,511,513
00202   511  FAILB=B(IRPL,JRPL,3)
00203        CALL SEARCH(FAILB,SPARE,ISW2,M,N,KTEMP)
00204        IF(ISW2)552,514,512
00207   512  FAILB=SPARE
00210        CALL SEARCH(FAILB,SPARE,ISW2,M,N,KTEMP)
00211        GO TO 514
00212   513  FAILB=SPARE
```

```
00213          CALL SEARCH(FAILR,SPARE,[illegible],N,KTEMP)
00214          FAILR=B(IRPL,JRPL,3)
00215          CALL SEARCH(FAILR,SPARE,ISW2,M,N,KTEMP)
00216     514  IF(ISW1-1)515,516,518
00221     515  DO 570 K=1,4
00224     570  B(IRPL,JRPL,K)=B(ISPAR,JSPAR,K)
00226          GO TO 521
00227     516  DO 517 K=1,KTEMP
00232     517  B(IRPL,JRPL,K)=B(ISPAR,JSPAR,K)
00234          GO TO 521
00235     518  DO 519 K=5,KTEMP
00240     519  B(IRPL,JRPL,K)=0.
00242          DO 560 K=1,4
00245     560  B(IRPL,JRPL,K)=B(ISPAR,JSPAR,K)
00247     521  DO 522 K=1,2
00252     522  B(ISPAR,JSPAR,K)=0.
00254     590  FFNUM=0.
00255          DO 523 I=1,M
00260      523 FFNUM=AMAX1(FFNUM,B(I,JSPAR,4))
00262          B(ISPAR,JSPAR,4)=FFNUM+1.
00263          GO TO 520
00264     551  IF(MIN-3)600,520,600
00267     600  SYSFA=1.
00270          IF(NSF-1)534,520,534
00273      534 WRITE(6,533)
00275          DO 585 J=1,N
00300      585 WRITE(6,554) (B(I,J,3),I=1,M)
00307          GO TO 520
00310     552  WRITE(6,553)
00312     553  FORMAT(14H ERROR IN FAIL)
00313      554 FORMAT(5F10.0)
00314      533 FORMAT(1H1)
00315      561 FORMAT(5H FAL=,F6.2)
00316     520  RETURN
00317          END

       END OF LISTING.     0 *DIAGNOSTIC* MESSAGE(S).
PHASE 1 TIME =   1 SEC.
PHASE 2 TIME =   1 SEC.
PHASE 3 TIME =   1 SEC.
PHASE 4 TIME =   1 SEC.
PHASE 5 TIME =   1 SEC.
PHASE 6 TIME =   1 SEC.

TOTAL COMPILATION TIME =   6 SEC
```

```
@TIM  FOR  TIME
COMPILATION BY UNIVAC 1107 FORTRAN-IV MATEL      FEB. 19,1965 F1003
THIS COMPILATION WAS DONE ON 19 OCT 65 AT 17:07:14

   SUBROUTINE TIME       ENTRY POINT 000031

   STORAGE USED (BLOCK, NAME, LENGTH)

         0001    *CODE    000054
         0000    *DATA    000007
         0002    *BLANK   002741

   EXTERNAL REFERENCES (BLOCK, NAME)

         0003    UDRNRT
         0004    ALOG

   STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001   000014 806L        0001   000017 807L       0004 R 000000 ALOG       0002   000000 B       0002 R
    0003 R 000000 UDRNRT      0000 R 000000 Y

00100      1.    C
00101      2.          SUBROUTINE TIME (IR,FN,SUM,IW,RNT,T,SUMT,NI)
00103      3.          DIMENSION R(5,20,15),FLAMD(5)
00104      4.          COMMON B,FLAMD
00105      5.          RNT=UDRNRT(IR)
00106      6.          IF(IW-1) 805,805,806
00111      7.     805  Y=SUM
00112      8.          GO TO 807
00113      9.      806 Y=Y-FLAMD(NI)
00114     10.     807  T=ALOG(RNT)/(-Y)
00115     11.          SUMT=SUMT+T
00116     12.          RETURN
00117     13.          END
```

```
END OF LISTING.      0 *DIAGNOSTIC* MESSAGE(S).
PHASE 1 TIME =   0 SEC.
PHASE 2 TIME =   0 SEC.
PHASE 3 TIME =   1 SEC.
PHASE 4 TIME =   0 SEC.
PHASE 5 TIME =   1 SEC.
PHASE 6 TIME =   0 SEC.

TOTAL COMPILATION TIME =   2  SEC
```