

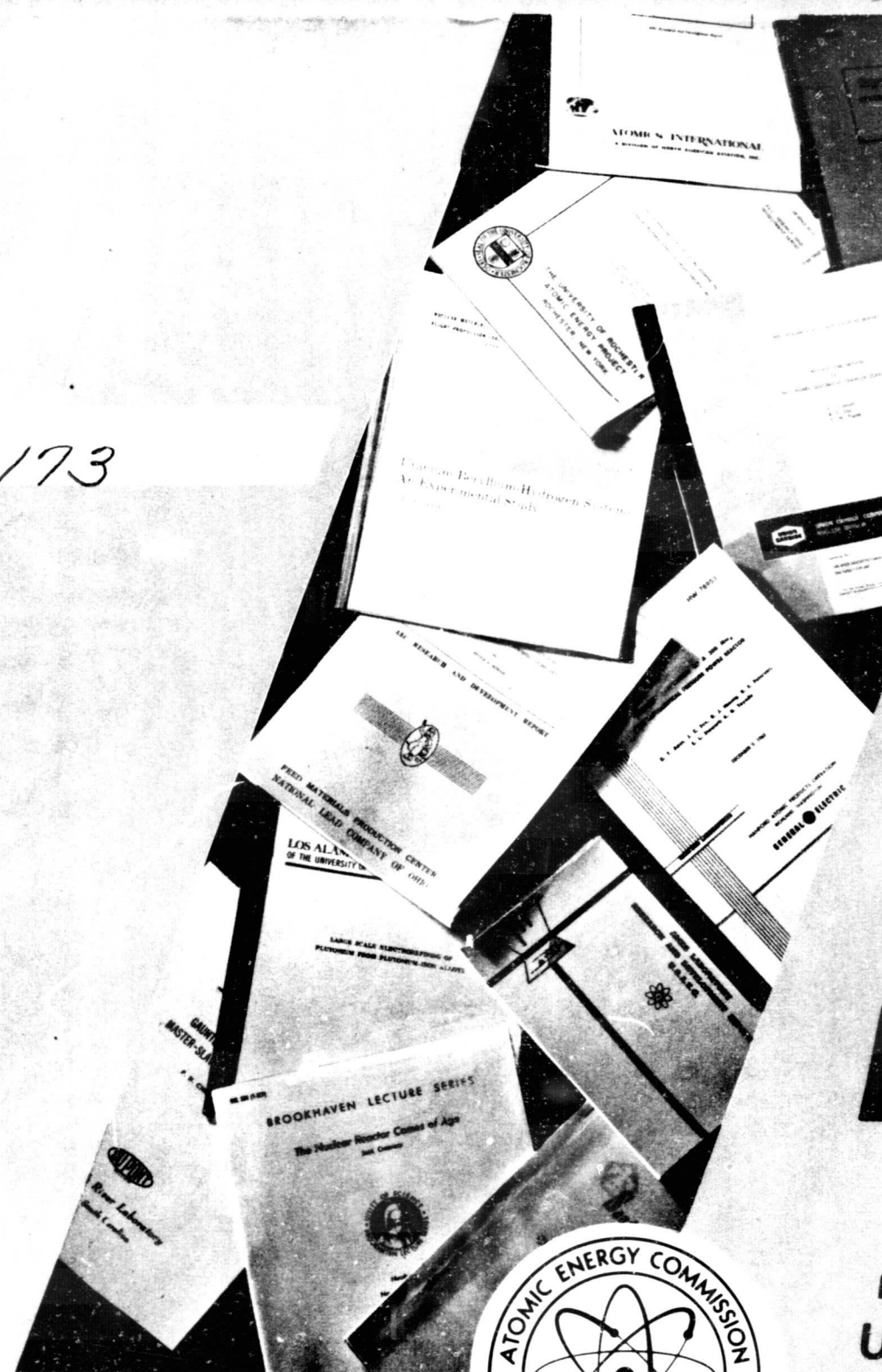
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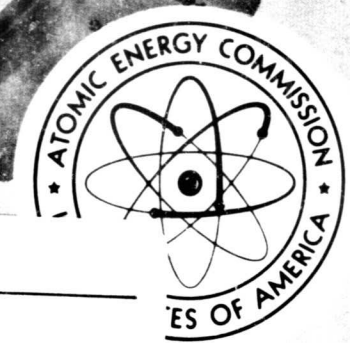
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RN-DR-0173

TREE ANALYSIS CODE (TRACE) PROGRAM E64106

NERVA Program



Contract SNP-1

NUCLEAR ROCKET OPERATIONS

October 1969

T. N. Throckmorton
H. R. Tayama

CLASSIFICATION CATEGORY

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I. INTRODUCTION

The TRACE Program is used to determine the probability, and the most likely sources, of a specific failure of a nonrepairable complex system prior to a specified time. The systems considered are binary-response structures that can be represented by a fault tree. A fault tree is a logic diagram, in which an output event (undesired system state or fault) is related by logic operations symbols to input events that may be lower-level system states, component states, command-function faults, or basic component failures. For this program, the component failures provide the basic input events, which are assumed to have independent time-to-failure probability distributions. The gates describe the logical relationships between events and the manner in which they may combine to produce other events, including the top event or system failure.

Because large systems with logically complex structures preclude analytic solution, computer simulation is used; but, when system failures are rare, direct simulation becomes impractical. In this situation, the Monte Carlo technique of importance sampling is used to reduce the required sample size and improve efficiency by large multiples.

II. STATEMENT OF PROBLEM

Although the probability of a possible failure mode occurring may be extremely small, the consequences for a particular system can be catastrophic, such as the explosion of a missile on its launching pad, the inadvertent firing of a warhead missile, or loss of power of a nuclear engine during certain critical states of launch. Therefore, in addition to estimating the probability of such rare events, the particular component or components must be identified whose malfunction would be the most probable cause of the events. Such an analysis of a large and logically complex system is a formidable analytic task.

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Solution of the above problem requires (1) a means of logically representing the structure of a system; i.e., how certain malfunctions or failures may combine to produce the undesired event, and (2) a mathematical technique to analyze the structure once it is defined. The concept of fault trees, originated at Bell Telephone Laboratories (Reference 1), provides a solution to the first requirement by giving an orderly description of the various combinations of possible occurrences within a system that can result in a particular undesirable event. Preparation of a fault tree is a detailed, time-consuming task and is not discussed here. Instead, a technique is discussed for analyzing a fault tree, estimating the probability of tree failure, and identifying the most probable causes. A more detailed discussion of fault trees may be found in Reference 2.

Simulation affords a good mathematical technique for solving such problems, but, when the events are rare, the sample sizes required for direct simulation make this technique impractical. Importance sampling affords a method for reducing sample size and expediting the simulation. The concept of using Monte Carlo importance sampling as a variance-reducing technique has been known for some time (References 3 and 4) but has not been applied to fault-tree simulation until fairly recently. The technique has been developed by the Aerospace Division of The Boeing Company (References 5 and 6). This use of importance sampling involves changing of the given component time-to-failure distributions so that failures occur before the prescribed end-of-mission time with a higher probability than for the given distributions, and occur after the prescribed end of mission time with a correspondingly lower probability. Weighting factors are computed from the relative distributions and are used to adjust for this distortion when the probability of fault-tree failure is estimated.

III. MATHEMATICAL FORMULATION

Most of this section makes free use of information from References 5 and 6, which discuss the more complex problem of simulating repairable systems. This section pertains only to nonrepairable systems, but the ideas are very similar.

A. BASIC FORMULATION

The system is assumed to be composed of independent binary-response (go, no-go) component faults and is itself a binary-response system. Each component fails randomly in time according to individual probability distributions, and all components are "go" (not failed) at time 0. Now let

t_i = time of failure of the i^{th} component

and

$\underline{t} = (t_1, t_2, t_3, \dots)$.

Then $\underline{t}$ is a random vector representing one possible history of all components in the system. If the time-to-failure distribution of the i^{th} component is $f_i(t)$, the distribution of $\underline{t}$, $f(\underline{t})$, is given by

$$f(\underline{t}) = \prod_i f_i(t_i) \quad (1)$$

since input failures are independent.

Let $s(\underline{t})$ be the time to failure of the system corresponding to a particular $\underline{t}$. Then the probability, p , of a system failure prior to the end of the mission at time T , with all components functioning at time zero, is given by

$$p = P[s(\underline{t}) < T].$$

which is given by

$$p = \int_A f(\underline{t}) d\underline{t}, \quad (2)$$

where A is the set of all vectors $\underline{t}$ such that $s(\underline{t}) < T$.

B. DIRECT SIMULATION

Define the random variable $\delta(\underline{t})$ by

$$\delta(\underline{t}) = \begin{cases} 1 & \text{if } \underline{t} \in A \\ 0 & \text{otherwise.} \end{cases} \quad (3)$$

Then, if S is the space of all vectors $\underline{t}$, Equation 2 may be rewritten as

$$p = \int_S \delta(\underline{t}) f(\underline{t}) d\underline{t}. \quad (4)$$

In general consider any integral

$$\theta = \int_S g(x) f(x) dx, \quad (5)$$

where $f(x)$ is a probability density function defined on S, i.e.,

$$\int_X f(x) dx = 1.$$

Then θ is known as the expected value or mean value of the function $g(x)$ over $f(x)$ and may be estimated unbiasedly by

$$\hat{\theta} = \frac{1}{n} \sum_{i=1}^n g(x_i)/n,$$

where $x_1, x_2, \dots, x_n$ is a random sample of size n from $f(x)$.

Hence, if $\underline{t}_1, \underline{t}_2, \dots, \underline{t}_n$ are sampled at random from $f(\underline{t})$, Equation 4 shows that an unbiased estimate of p is given by

$$\hat{p} = \frac{1}{n} \sum_{i=1}^n \delta(\underline{t}_i)/n.$$

This process is called direct simulation and is time-consuming and inefficient for rare events. A rough rule of thumb is that, if it is desired to estimate p within a standard error of 10% of $\hat{p}$, about 100 occurrences of the event are required. When p is 10^{-3} , this rule calls for a sample size of 10^5 .

C. IMPORTANCE SAMPLING

Importance sampling is a slight but powerful variation of direct sampling. Again consider the general integral of Equation 5 and suppose $h(x)$ is another probability density function defined on S. Then, θ may be rewritten as

$$\theta = \int_S g(x) f(x) dx = \int_S g(x) \frac{f(x)}{h(x)} h(x) dx. \quad (6)$$

Now, if n random variables $x'_1, x'_2, \dots, x'_n$ are sampled from $h(x)$, the parameter θ may be estimated by

$$\hat{\theta} = \frac{1}{n} \sum_{i=1}^n g(x'_i) w(x'_i)/n, \quad (7)$$

where

$$w(x) = \frac{f(x)}{h(x)} \quad (8)$$

and is called the weighting function. This weighting function compensates for the distortion caused by sampling from $h(x)$ instead of $f(x)$ and still provides an unbiased estimate. By choosing $h(x)$ so as to concentrate the sample points in the more "important" regions, the standard deviation of $\hat{p}$ can be appreciably reduced from that obtained by direct, or crude, simulation.

Suppose that a new probability density function $f^*(t)$ is defined on S , and consider Equation 4 rewritten as

$$p = \int_S \delta(t) \frac{f(t)}{f^*(t)} f^*(t) dt. \quad (9)$$

Whenever $f^*(t)$ is identical to $f(t)$ except for specific components, the ratio $f(t)/f^*(t)$ is easily computed. For example, suppose the failure distributions for input components 1 and 2 are changed from $f_1(t)$ and $f_2(t)$ to $f_1^*(t)$ and $f_2^*(t)$. Then

$$f^*(t) = f_1^*(t)f_2^*(t) \frac{f(t)}{f_1(t)f_2(t)},$$

and

$$w(t) = \frac{f(t)}{f^*(t)} = \frac{f_1(t)f_2(t)}{f_1^*(t)f_2^*(t)}. \quad (10)$$

Consequently, if $t_1^*, t_2^*, \dots, t_n^*$ are a random sample of vectors from $f^*(t)$, the probability of system failure is estimated by

$$\hat{p} = \frac{1}{n} \sum_{i=1}^n \delta(t_i^*) w(t_i^*)/n. \quad (11)$$

Thus, the problem becomes one of choosing importance functions for the component failures suitable to emphasize those input failure patterns that cause system failure prior to the end of the mission at time T .

D. THE POWER RULE

In performing a fault-tree simulation with importance sampling, it must be kept in mind that one of the prime purposes is to identify those sets of components most likely to cause system failure. Any set of components whose failure results in a state that induces system failure is called a cutset. A minimal cutset is one for which no proper subset is also a cutset. For direct Monte Carlo simulations, those cutsets that have the

highest probability are most likely to occur, because the probability that such a set will occur in a given trial is equal to its true probability. While importance sampling increases the number of occurrences of rare events compared with the number expected with direct simulation, care must be exercised not to sacrifice the balance of well-ordered probabilities. In other words, those cutsets having the highest true probabilities should still have the highest probabilities of occurring in the simulation.

More precisely, let P_i and P_j be true probabilities for two specific cutsets, and let P_i^* and P_j^* be the corresponding distorted probabilities under importance sampling. Then the following four conditions are necessary:

- (1) $P_i^* > P_i$
- (2) $P_i^* > P_j^*$ whenever $P_i > P_j$
- (3) $P_i^* = P_j^*$ whenever $P_i = P_j$
- (4) The sampling scheme is independent of the structure function.

For any series-parallel structure composed of independent non-repairable components, the probability that system failure will occur as a result of the i^{th} minimal cutset is given by

$$P_i = \prod_j P_{ij},$$

where P_{ij} is the failure probability for the j^{th} component of the cutset. Similarly, if independence between component pairs is maintained under the distorted sampling scheme,

$$P_i^* = \prod_j P_{ij}^*.$$

It follows from Condition 4 that, since the sampling scheme is to be valid for all cases, it must satisfy the requirements for the following special case.

Consider two sets such that

$$P_1 = P_2$$

and

$$P_1 = \prod_{j=1}^{n_1} P_{1j}, P_2 = \prod_{j=1}^{n_2} P_{2j}.$$

Furthermore, let

$$\begin{aligned} P_{1j} &= a \\ P_{2j} &= b \end{aligned} \quad \text{for all } j.$$

Then

$$P_1 = a^{n_1} = P_2 = b^{n_2}.$$

For a distorted sampling scheme that changes a to a^* and b to b^* ,

$$P_1^* = (a^*)^{n_1} = P_2^* = (b^*)^{n_2}$$

under Condition 3. Thus,

$$\frac{\log a^*}{\log a} = \frac{\log b^*}{\log b},$$

which is true only if

$$P_{ij}^* = P_{ij}^r.$$

This implies that

$$P_i^* = P_i^r.$$

Imposing Conditions 1 and 2 leads to the requirement $0 < r < 1$.

Hereafter, any importance density function with the property that

$$P^* = P^r \quad 0 < r < 1 \quad (12)$$

will be called the power rule. For any other sets i and j where $P_i > P_j$, the power rule implies $P_i^* > P_j^*$ and $P_i^* > P_i$. Direct simulation corresponds to the special case $r = 1$.

E. THE IMPORTANCE DISTRIBUTION

This program assumes exponential time-to-failure distributions for the components. Consider a particular component and let λ denote the mean failure rate (failures per unit of time). The probability density function is given by

$$f(t) = \lambda e^{-\lambda t} \quad t > 0, \quad (13)$$

and the probability of component failure prior to time T is

$$P = \int_0^T \lambda e^{-\lambda t} dt = 1 - e^{-\lambda T}. \quad (14)$$

Using the power rule, let $P^* = P^r$ (for $0 < r < 1$) and define the importance density function by

$$f^*(t) = \begin{cases} \frac{P^*}{P} f(t) & \text{if } 0 < t \leq T \\ \frac{1-P^*}{1-P} f(t) & \text{if } t > T. \end{cases} \quad (15)$$

The fact that this is a probability density function may be verified by

$$\begin{aligned} \int_0^\infty f^*(t) dt &= \int_0^T f^*(t) dt + \int_T^\infty f^*(t) dt \\ &= \frac{P^*}{P} \int_0^T f(t) dt + \frac{1-P^*}{1-P} \int_T^\infty f(t) dt \\ &= P^* + (1-P^*) = 1. \end{aligned}$$

Since the component failures are independent,

$$f^*(t) = \prod_i f_i^*(t). \quad (16)$$

The weighting function $w(t)$ is therefore given by

$$w(t) = \frac{f(t)}{f^*(t)} \prod_i w_i(t), \quad (17)$$

where

$$w_i(t) = \frac{f_i(t)}{f_i^*(t)} = \begin{cases} \frac{P_i}{P_i^*} & \text{if } 0 \leq t \leq T \\ \frac{1-P_i}{1-P_i^*} & \text{if } t > T. \end{cases} \quad (18)$$

F. ESTIMATION OF SYSTEM FAILURE PROBABILITY UNDER THE POWER RULE

If $t_1^*, t_2^*, \dots, t_n^*$ are a random sample of vectors from $f^*(t)$, Equations 11 and 17 show that the system failure probability may be estimated by

$$\hat{p} = \frac{1}{n} \sum_{i=1}^n \delta(t_i^*) w(t_i^*),$$

where

$$w(t_i^*) = \prod_j w_j(t_i^*).$$

The following paragraphs, however, show that weights for only those components in the minimal cutset need be used.

From Equation 4 we have the desired probability expressed as

$$p = \int_S \delta(t) f(t) dt, \quad (19)$$

where t is a vector of component failure times and S is the space of all such vectors. Now,

$$\int_S f^*(t^*) dt^* = 1; \quad (20)$$

so we may multiply Equation 19 by this integral without changing its value; i.e.,

$$\begin{aligned} p &= \int_S \delta(t) f(t) dt \int_S f^*(t^*) dt^* \\ &= \int_{S \times S} \delta(t) f(t) f^*(t^*) dt dt^*. \end{aligned} \quad (21)$$

Now, let $g(t|t^*)$ be an importance density for t that is conditional on the outcome t^* . Then Equation 21 may be written

$$p = \int \delta(t) \frac{f(t)}{g(t|t^*)} g(t|t^*) f^*(t^*) dt dt^*; \quad (22)$$

and the probability estimate is given by

$$\hat{p} = \frac{1}{n} \sum_j \delta(t_j) w(t_j, t_j^*), \quad (23)$$

where

$$w(t_j, t_j^*) = \frac{f(t_j)}{g(t_j|t_j^*)} \quad (24)$$

The conditional distribution $g(t|t^*)$ is defined as follows. Select random t_1^* 's from $f_1^*(t)$ and check the system for failure assuming the t_1^* 's are in fact the life lengths of the components. If the system has not failed, generate new random variables t_1 for all the inputs by using the original $f(t)$. If the system has failed, let C be the minimal cutset of components causing the failure. Then define t_1 so that $t_1 = t_1^*$ for those components in C , and generate new random variables t_1 from $f_1(t)$ for those not in C . The importance density for t_1 conditional on t_1^* under this definition is

$$g(t_1|t_1^*) = \begin{cases} f_1^*(t_1) & \text{if } i \in C \\ f_1(t_1) & \text{if } i \notin C, \end{cases} \quad (25)$$

and the weight function becomes

$$w(t, t^*) = \frac{f(t)}{g(t|t^*)} = \prod_i \frac{f_i(t_i)}{g_i(t_i|t_i^*)},$$

where

$$\frac{f_i(t_i)}{g_i(t_i|t_i^*)} = \begin{cases} \prod_i \frac{f_i(t_i^*)}{f_i^*(t_i^*)} & \text{for } i \in C \\ 1 & i \notin C. \end{cases} \quad (26)$$

The weight function thus equals one for all components not in the minimal cutset, and, for those in the cutset, the ratio is $f_i(t)/f_i^*(t)$. For the i^{th} component to be in the minimal cutset, t_i^* must be less than T ; so, from Equation 18, this ratio equals P_i/P_i^* . Thus

$$w(t, t^*) = \prod_{i \in C} \frac{P_i}{P_i^*}, \quad (27)$$

and, from Equation 23,

$$\begin{aligned} \hat{p} &= \sum_{j=1}^n \delta(t_j) \prod_{i \in C_j} \frac{P_i}{P_i^*} / n \\ &= \sum_i \prod_{i \in C_k} \frac{P_i}{P_i^*} / n, \end{aligned} \quad (28)$$

where k ranges over only those trials resulting in system failure. In other words, a trial weight consists of the product of component weights for only those components in the minimal cutset; and $\hat{p}$ is obtained as the sum, over all failed trials, of the trial weights divided by the total number of trials.

The variance of $\hat{p}$ is estimated by

$$V(\hat{p}) = \frac{\sum_{j=1}^n (\delta_j w_j - \hat{p})^2}{n(n-1)}. \quad (29)$$

G. CALCULATED PROBABILITY OF SYSTEM FAILURE

Once the minimal cutsets for a specific tree have been identified, another approximation of system failure probability is available. Let the k components of the system be denoted by 1, 2, ..., k ; and suppose the following minimal cutsets have been identified: (1,2), (3,4), and (1,3,5). If ϕ represents the tree status, we can define the Boolean statement

$$\phi = 12 + 34 + 135. \quad (30)$$

The probability of tree failure may be approximated by

$$P(\phi) = P(12) + P(34) + P(135), \quad (31)$$

since, when the probabilities are small, second- and higher-order terms such as $P(12 \text{ and } 34)$ are negligible in comparison with the first-order terms.

Since the component faults are assumed to be independent and have exponential failure distributions, $P(\phi)$ is easily calculated for a nonrepairable system by

$$P(\phi) = \sum_k \prod_{i \in C_k} (1 - e^{-\lambda_i T}), \quad (32)$$

where k ranges over all minimal cutsets C_k .

This calculation is provided by the program and should afford reasonable check on $\hat{p}$.

IV. METHOD OF SOLUTION

A. PROGRAM LOGIC

The program uses the following basic logic.

1. A forcing parameter, r , is read in.

The following calculations are performed for each component:

$$P_1 = 1 - e^{-\lambda_1 T}$$

$$P_1^* = P_1^r$$

$$w_1 = P_1 / P_1^*$$

2. A trial is initialized.

All components are set to "go;" i.e., not failed (FALSE in the program). All houses* are checked and the appropriate ones are failed. The tree status is checked, and, if failed status is indicated, the program terminates with an error message. If not, the time to failure is randomly generated from importance distributions for each component; and those times that are less than T are stored.

*A house identifies a system state normally expected to be in existence throughout the mission phase being analyzed. Houses always input to an AND gate and are assigned a probability of occurrence of 1.0 when the branch they are in is to be included in the simulated mission, and are assigned 0.0 when it is desired to delete the particular branch from the analysis.

3. Component failures are simulated.

The smallest t_1 for all components not already failed is found, and the corresponding component is set to fail. The tree status is checked; if failed, step 4 is performed; if not failed step 3 is repeated. If all checks for $t_1 < T$ are completed, a new trial is started at step 2.

4. Minimal cutset is identified.

The procedure used here does not necessarily yield the smallest minimal cutset, but it does provide a minimal cutset in that no proper subset of it is a cutset. By starting with the last component failed and working in the reverse order from that in which the failures occurred, a component is set to "go" and the tree is checked. If the tree is still failed, the last component checked is left at "go" and the next component is set to "go" and so on. If when checked, the tree is not failed, the last component set to "go" is reset to failed; and the next component in the cutset is set to "go." After all failed components have been reset and the tree status checked in this way, those remaining in a failed status form the minimal cutset; i.e., if any one of them is now set to "go," the tree is not failed. If this cutset has already been identified, the number of times it has occurred is increased by one; and a new trial is started at step 2. If this is a new cutset, step 5 is performed.

5. Minimal cutset calculations.

For each new minimal cutset, the following statistics are calculated.

$$\text{Trial Weight} = w_{tr_1} = \prod_{j \in C_1} w_1$$

$$\text{Cutset probability} = Ps_1 = \prod_{j \in C_1} P_j.$$

The status of all gates is checked, and a list of those in a failed status is printed. If the desired number of trials has been completed, step 6 is performed; if not, a new trial is started at step 2.

6. Final Calculations

Let k_j be the number of times the j^{th} minimal cutset occurred and $k = \sum_j k_j$ be the total number of failures out of n trials. The following calculations are then performed:

$$(1) \hat{p} = \sum_j k_j w_{tr_j} / n.$$

$$(2) V(\hat{p}) = \frac{(n-k)\hat{p}^2 + \sum_j k_j (w_{tr_j} - \hat{p})^2}{n(n-1)}.$$

$$(3) Psf = \sum_j Ps_j.$$

B. GENERATION OF RANDOM-FAILURE TIMES FROM IMPORTANCE DISTRIBUTION

For a given component, the importance density function $f^*(t)$ is defined by Equation 15. From $f^*(t)$, the cumulative distribution, $F^*(t)$, is obtained as

$$F^*(t) = \begin{cases} \frac{P^*}{P} (1 - e^{-\lambda t}) & t \leq T \\ P^* + \frac{1-P^*}{1-P} (e^{-\lambda T} - e^{-\lambda t}) & t > T, \end{cases} \quad (33)$$

which is shown graphically in Figure 1.

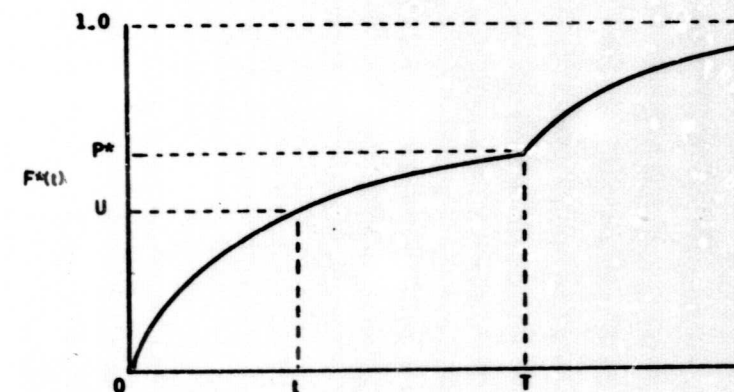


Figure 1 - $F^*(t)$ vs t

A uniform random number U is obtained from subroutine RANDU, which uses the power residue method, and is tested for being less than P^* . If U is $> P^*$, the failure time will be greater than T and is not calculated. If $U \leq P^*$, it is set equal to $F^*(t)$; and the equation is solved for t to give

$$t = -\log_e (1 - \frac{P}{P^*} U) / \lambda.$$

C. RANDOM INHIBIT GATES

Let q be the probability of failure associated with a random inhibit gate. To maintain the proper order of probabilities, importance sampling is also used on these. Let $q^* = q^F$; then, each time the tree is

checked, a uniform random number U is generated for each gate of this type. If $U \leq q^*$, the gate will fail if its input is failed. If $U > q^*$, the gate cannot fail. Weights q/q^* are also calculated. For each random inhibit gate that is failed for a minimal cutset, these weights are included in the trial weight calculations of step 5.

D. PRIORITY GATES

A priority gate fails only if the inputs to it occur in a particular order. However, when a cutset has been found and a minimal cutset is being identified in step 4, the priority is ignored because the inputs originally failed in the proper order whereas, in selecting a minimal cutset, components are checked in the reverse order. Unless priority is ignored, these gates could not be reset to fail; and erroneous cutsets and critical paths would be obtained. Because the inputs to the gate originally failed in the proper order and it acts like an AND gate, the reverse-order process yields proper results by ignoring priority during this tracing step.

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APPENDIX A
LISTING OF "PROGRAM TRACE"

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C LINE = LINE COUNTER FOR OUTPUT TRAC0052
C MINSET(500,10) = STORAGE AREA FOR MINIMAL CUTSETS TRAC0053
C MSFT(10) = INDICES OF MINIMAL CUTSET COMPONENTS TRAC0054
C NC = NUMBER OF COMPONENTS TRAC0055
C NCI = NO. COMPONENTS + 1 (INDEX OF FIRST HOUSE) TRAC0056
C NCPL = NUMBER OF COMPONENTS FAILED IN A TRIAL PRIOR TO T TRAC0057
C NCOMP = TOTAL NUMBER OF COMPONENTS AND HOUSES (NC+NM) TRAC0058
C NCUT = NUMBER OF COMPONENTS + HOUSES IN CUTSET TRAC0059
C NCUT1 = NCUT-1 TRAC0060
C NCUT2 = NCUT + 1 TRAC0061
C NEW = FLAG FOR STARTING NEW PAGE TRAC0062
C NEXT(1000) = INDICES OF FAILED COMPONENTS TRAC0063
C NG = NUMBER OF GATES TRAC0064
C NM = NUMBER OF HOUSES TRAC0065
C NMFL = NUMBER OF HOUSES FAILED TRAC0066
C NMFL1 = NMFL + 1 TRAC0067
C NMSFT(500) = NUMBER COMPONENTS IN ITH MINIMAL CUTSET TRAC0068
C NRI = NUMBER OF RANDOM INHIBIT GATES TRAC0069
C NSFTS = NUMBER OF DIFFERENT MINIMAL CUTSETS FOUND TRAC0070
C NSFL = NUMBER OF SYSTEM FAILURES TRAC0071
C NTR = NUMBER OF TRIALS PER CASE TRAC0072
C P(1000) = PROB OF FAILURE OF ITH COMPONENT PRIOR TO TIME T TRAC0073
C PI = TEMPORARY CALCULATION OF PSF(1) TRAC0074
C PERCENT = PERCENT SYSTEM FAILURES WITH 10 OR LESS COMP. IN MIN. SET TRAC0075
C PI(100) = PROBABILITY OF FAILURE OF INHIBIT GATES TRAC0076
C PROB = PROBABILITY OF SYSTEM FAILURE ESTIMATED FROM WEIGHTING FUNCTION TRAC0077
C PS = PROBABILITY OF SYSTEM FAILURE, DIRECT CAL. = SUM OF PSF(1) TRAC0078
C PSF(500) = PROB FAILURE OF MINIMAL CUTSET BY DIRECT COMPUTATION TRAC0079
C PSTAR(1000) = PROB OF FAILURE OF ITH COMP FOR IMPORTANCE DIST. TRAC0080
C R = FORCING PARAMETER FOR IMPORTANCE SAMPLING TRAC0081
C RICH = PROBABILITY OF FAILURE FLAGS FOR R.I. GATES. TRAC0082
C IF RANDOM VARIABLE IS THAN PROBABILITY, FLAG = .TRUE. TRAC0083
C OTHERWISE, FLAG = .FALSE. TRAC0084
C STDERM = STANDARD ERROR OF PROB TRAC0085
C T = MISSION LENGTH TRAC0086
C TEMPI = TEMPORARY STORAGE TRAC0087
C TEMPNM = TEMPORARY NAME STORAGE TRAC0088
C TITLE = TITLE IDENTIFICATION OF CASE TRAC0089
C TNEXT(1000) = TIME OF FAILURE OF COMPONENTS TRAC0090
C U = UNIFORM RANDOM NUMBER BETWEEN 0 AND 1 TRAC0091
C VAR = VARIANCE OF PROB TRAC0092
C WT(1000) = WEIGHTING FUNCTION FOR ITH COMPONENT TRAC0093
C WT1 = TEMPORARY CALCULATION OF WT(1) TRAC0094
C WT(100) = WEIGHTS FOR RANDOM INHIBIT GATES TRAC0095
C WTR(500) = WEIGHTING FUNCTION FOR TRIAL TRAC0096
C ***** TRAC0097
C ***** TRAC0098
C ***** TRAC0099
C ***** TRAC0100
COMMON /MYREF/ TITLE(9), COMPNM(1000), GATENM(2000), PI(100), TRAC0100
1 WT(10), R, INT(100), IX, K2, GTYPE(2000), COMPS(1000), TRAC0101
2 GATEST(2000), RICH(100) TRAC0102

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3 -

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REAL*8 TITLE, TEMPNM, COMPNM, GATENM, LAST//LAST//, ENDPBR//END // TRAC0103
REAL*8 CHANGE//CHANGE//, PRINT//PRINT// TRAC0104
REAL*4 LAMDA(1000) TRAC0105
INTEGER*4 FLGATE(500) TRAC0106
INTEGER*2 NMSFT(500), MFLAG, M//M// TRAC0107
INTEGER*2 GTYPE, IAST(500), PG//P// TRAC0108
LOGICAL*1 COMPS, GATEST, TOP, RICH TRAC0109
DIMENSION P(1000), PSTAR(1000), WT(1000), TNEXT(1000), NEXT(1000), TRAC0110
1 WTR(500), KOUNT(500), MINSET(500,10), PSF(500), MSFT(10) TRAC0111
DIMENSION RSAVE(20) TRAC0112
C ***** TRAC0113
C ***** TRAC0114
C ***** TRAC0115
C ***** TRAC0116
C ***** TRAC0117
C ***** TRAC0118
C ***** TRAC0119
C ***** TRAC0120
C ***** TRAC0121
C ***** TRAC0122
C ***** TRAC0123
C ***** TRAC0124
C ***** TRAC0125
9000 FORMAT('TRACE -- TREE ANALYSIS CODE, AERJET-GENERAL CORPORATION, TRAC0125
1 SACRAMENTO, CALIFORNIA'//) TRAC0126
9010 FORMAT( 9A8) TRAC0127
9020 FORMAT( 11, 29X, 9A8 ) TRAC0128
9025 FORMAT(16, 1X, 19, 1X, E13.4 ) TRAC0129
9030 FORMAT(A1, T1, A6, 1X, F10.4, 1X, E13.4 ) TRAC0130
9040 FORMAT( //25H NUMBER OF TRIALS = ,19/25H RANDOM NO. CONSTANT TRAC0131
1= ,19/21H MISSION LENGTH = , F13.1// ) TRAC0132
9045 FORMAT(25H NUMBER OF COMPONENTS = ,19/25H NUMBER OF HOUSES = TRAC0133
1 ,19/30H TOTAL NO. COMP. AND HOUSES = ,14// ) TRAC0134
9050 FORMAT(// 28X, 'COMPONENT NAMES AND PROBABILITIES TIMES 10 TO THE TRAC0135
16TH POWER' // ) TRAC0136
9060 FORMAT( 4(1X,14,2X,A6,2X, E13.4,5X)) TRAC0137
9070 FORMAT(//47X, 'HOUSE NAMES AND PROBABILITY ASSIGNED' // ) TRAC0138
9080 FORMAT( 5(1X,14,2X,A6,2X,F3.1,5X)) TRAC0139
9090 FORMAT(' INPUT RESTRICTION VIOLATED. TOTAL NUMBER OF COMPONENTS AT TRAC0140
1ND HOUSES MUST NOT EXCEED 1000.'// 1X,17, ' HAVE BEEN INPUT.'// TRAC0141
2' PROGRAM WILL LIST FIRST 1000 THEN CHECK FOR VIOLATION OF GATE RE TRAC0142
3STRICTIONS'// ) TRAC0143
9100 FORMAT(A6,F7.6) TRAC0144
9110 FORMAT(// ' CASE NUMBER ',15, ' FORCING PARAMETER IS ',F8.4) TRAC0145
9115 FORMAT(//35X, '***** FAILED GATES FOR ITH MINIMAL CUTSET *****'// TRAC0146
1 CUTSET NO. OF ' NO. GATES', 50X, 'GATE NAMES' // ) TRAC0147
9120 FORMAT (/16,2X,16,2X,14(2X,A6) / (16X,14(2X,A6) ) ) TRAC0148
9125 FORMAT (/16, ' ', 1X,16,2X,14(2X,A6) / (16X,14(2X,A6) ) ) TRAC0149
9130 FORMAT(//33X, '***** MINIMAL CUTSETS WITH 10 OR LESS COMPONENTS *****'// TRAC0150
1000// ) TRAC0151
2' CUTSET CUTSET PROBABILITY NO. OF// TRAC0152
3' RANK NO. OF FAILURE OCCURRENCES',35X, 'COMPONENTS'// ) TRAC0153

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9140 FORMAT ('0',14, 4X,14,2X,F16.6,5X,14,3X,10(2X,A6) ) TRAC0154
9150 FORMAT(/// ' ***** SUMMARY DATA FOR CASE NUMBER',16,' *****'/// TRAC0155
1' NUMBER OF TRIALS COMPLETED =',17// TRAC0156
2' NUMBER OF SYSTEM FAILURES =',17// TRAC0157
3' PERCENT OF SYSTEM FAILURE =',F7.2// TRAC0158
4' NO. ADDITIONAL SYSTEM FAILURES =',17,' (OVER 10 COMP. IN MINIMATRAC0159
5' OUTSET - NOT INCLUDED IN ABOVE FAILURE COUNT)'// TRAC0160
6' NO. OF DISTINCT MINIMAL CUTSETS =',17//) TRAC0161
9160 FORMAT(4X,' ESTIMATES BASED ON IMPORTANCE SAMPLING'// TRAC0162
1' PROBABILITY OF SYSTEM FAILURE =',F13.6// TRAC0163
2' VARIANCE OF ABOVE ESTIMATE =',F13.6// TRAC0164
3' STANDARD ERROR OF ESTIMATE =',F13.6//) TRAC0165
9170 FORMAT ('0',4X,' ESTIMATE BASED ON MINIMAL CUTSETS' // TRAC0166
1' PROBABILITY OF SYSTEM FAILURE =',F13.6 //) TRAC0167
9180 FORMAT ( /// ' THE OBSERVED PERCENT OF SYSTEM FAILURES,' F7.2, TRAC0168
1' IS WITHIN ACCEPTABLE LIMITS OF 7.5 TO 14.0' ) TRAC0169
9190 FORMAT ( /// ' THE OBSERVED PERCENT OF SYSTEM FAILURES,' F7.2, TRAC0170
1' IS OUTSIDE ACCEPTABLE LIMITS OF 7.5 TO 14.0'// TRAC0171
2' A NEW FORCING PARAMETER SHOULD BE TRIED'// TRAC0172
3' A LARGER FORCING PARAMETER WILL TEND TO REDUCE THE PERCENTAGE'//TRAC0173
4' A SMALLER ONE WILL TEND TO INCREASE IT' ) TRAC0174
9200 FORMAT(/// ' TREE FAILS WITH HOUSES ALONE'// ' PROGRAM WILL GO TO NEXTTRAC0175
1' IT PROBLEM'/// 49X,' TREE FAILED WITH FOLLOWING HOUSES'//) TRAC0176
9210 FORMAT(10(3X,A6) ) TRAC0177
9220 FORMAT(/// 60X,' FAILED GATES'// 15(2X,A6) ) TRAC0178
9230 FORMAT( /// ' THE MAXIMUM OF 500 DISTINCT MINIMAL CUTSETS HAS BEEN PTRAC0179
FOUND'// ' PROGRAM WILL GO TO NEXT CASE FOLLOWING SUMMARY' ) TRAC0180
9240 FORMAT(/// ' INPUT RESTRICTION VIOLATED -- PROGRAM WILL GO TO NEXT PTRAC0181
1' PROBLEM' ) TRAC0182
9300 FORMAT ('NOTE.....ASTERISKS AFTER CUTSETS NO. IN TABLE BELOW INDITRAC0183
ICATE ONE OR MORE PRIORITY GATES IS INCLUDED IN FAILURE PATH.'// ) TRAC0184
9310 FORMAT ('+',12X,'+') TRAC0185
C TRAC0186
C ***** TRAC0187
10 READ(5,9010, END= 550 ) TITLE TRAC0188
WRITE(6,9000) TRAC0189
NEW = 0 TRAC0190
WRITE(6,9020) NEW, TITLE TRAC0191
NEW = 1 TRAC0192
C ***** TRAC0193
C TRAC0194
C ***** INITIALIZE PROBLEM VARIABLES ***** TRAC0195
C TRAC0196
C ***** TRAC0197
KASF = 0 TRAC0198
NC = 0 TRAC0199
NM = 0 TRAC0200
NCOMP = 0 TRAC0201
NG = 0 TRAC0202
NMFL = 0 TRAC0203
IFLAG = 0 TRAC0204

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READ(5,9025) NTR, IX,T TRAC0205
IF(IX.EQ. 0) IX = 13579 TRAC0206
C ***** TRAC0207
C INSURE THAT IX IS ODD TRAC0208
C ***** TRAC0209
IXX = IX/2 TRAC0210
IF ( (IX - 2*IXX) .EQ. 0 ) IX = IX + 1 TRAC0211
C ***** TRAC0212
C TRAC0213
C ***** READ COMPONENT CARDS AND CALCULATE PROB OF FAILURE FOR EACH ***** TRAC0214
C TRAC0215
C ***** TRAC0216
30 READ(5,9030) MFLAG,TEMPNM,TEMP1,TEMP2 TRAC0217
IF ( TEMPNM .EQ. LAST) GO TO 50 TRAC0218
NCOMP = NCOMP + 1 TRAC0219
IF ( NCOMP .GT. 1000 ) GO TO 30 TRAC0220
IF ( MFLAG .EQ. M ) GO TO 40 TRAC0221
NC = NC+1 TRAC0222
COMPNM(NC) = TEMPNM TRAC0223
LAMDA(NC) = TEMP2 TRAC0224
P(NC) = 1.0 - EXP(-LAMDA(NC) * T /10.000A) TRAC0225
GO TO 30 TRAC0226
40 NM = NM+1 TRAC0227
COMPNM(1001-NM) = TEMPNM TRAC0228
LAMDA(1001-NM) = TEMP1 TRAC0229
GO TO 30 TRAC0230
C ***** TRAC0231
C TRAC0232
C PLACE HOUSES IN COMPONENT ARRAYS IMMEDIATELY TRAC0233
C FOLLOWING THE LAST COMPONENT TRAC0234
C TRAC0235
C ***** TRAC0236
50 IF(NM.EQ. 0) GO TO 65 TRAC0237
DO 60 I = 1,NM TRAC0238
TEMPNM = COMPNM(NC+1) TRAC0239
COMPNM(NC+1) = COMPNM(1001-I) TRAC0240
COMPNM(1001-I) = TEMPNM TRAC0241
TEMP2 = LAMDA(NC+1) TRAC0242
LAMDA(NC+1) = LAMDA(1001-I) TRAC0243
60 LAMDA(1001-I) = TEMP2 TRAC0244
C ***** TRAC0245
C TRAC0246
C ***** WRITE OUT THE COMPONENT INPUT DATA ***** TRAC0247
C TRAC0248
C ***** TRAC0249
65 WRITE(6,9040) NTR,IX,T TRAC0250
IF ( NCOMP .LE. 1000 ) GO TO 68 TRAC0251
WRITE(6,9090) NCOMP TRAC0252
GO TO 70 TRAC0253
68 WRITE(6,9045) NC, NM, NCOMP TRAC0254
70 WRITE (6,9020) NEW,TITLE TRAC0255

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WRITE(6,9050)
N2 = 0
71 N1 = N2 + 1
IF ( (NC-N2) .GT. 260 ) GO TO 74
72 N2 = NC
73 WRITE(6,9060) (1, COMPNM(I), LAMBDA(I), I = N1, N2)
IF (NC .EQ. N2) GO TO 75
WRITE(6,9020) NEW, TITLE
WRITE(6,9050)
GO TO 71
74 N2 = N2 + 260
GO TO 73
-----
C ----- WRITE OUT HOUSE INPUT DATA -----
C -----
75 IF ( (NH .EQ. 0) ) GO TO 80
N2 = 0
76 N1 = N2 + 1
WRITE(6,9020) NEW, TITLE
WRITE(6,9070)
IF ( (NH-N2) .GT. 370 ) GO TO 79
77 N2 = NH
78 WRITE(6,9080) (1, COMPNM(NC+I), LAMBDA(NC+I), I = N1, N2)
IF (NH .EQ. N2) GO TO 80
GO TO 76
79 N2 = N2 + 370
GO TO 78
C *****
C ***** CHECK FOR VIOLATION OF DIMENSION RESTRICTIONS *****
C ***** READ GATE INPUT DATA *****
C *****
80 CALL GATES (NCOMP, NG, NRI)
IF (NCOMP .GT. 1000 .OR. NG .GT. 2000 .OR. NRI .GT. 100) GO TO 500
IF (K2 .NE. 0) GO TO 500
C *****
C
C READ FORCING PARAMETER CARDS AND INITIALIZE
C VARIABLES TO START A NEW CASE. IF IT IS AN
C END CARD GO TO START A NEW PROBLEM
C
C *****
C -----
C THE FOLLOWING FORTRAN STATEMENTS UP TO STATEMENT 95 WERE ADDED OR
C MODIFIED BY F.YEE
C
C
C IPRINT = 0
C IP = 0
84 KFLAG = 0
C IPP = 0
90 CONTINUE
IF (KFLAG .GT. 0) GO TO 92

```

TRAC0256
 TRAC0257
 TRAC0258
 TRAC0259
 TRAC0260
 TRAC0261
 TRAC0262
 TRAC0263
 TRAC0264
 TRAC0265
 TRAC0266
 TRAC0267
 TRAC0268
 TRAC0269
 TRAC0270
 TRAC0271
 TRAC0272
 TRAC0273
 TRAC0274
 TRAC0275
 TRAC0276
 TRAC0277
 TRAC0278
 TRAC0279
 TRAC0280
 TRAC0281
 TRAC0282
 TRAC0283
 TRAC0284
 TRAC0285
 TRAC0286
 TRAC0287
 TRAC0288
 TRAC0289
 TRAC0290
 TRAC0291
 TRAC0292
 TRAC0293
 TRAC0294
 TRAC0295
 TRAC0296
 TRAC0297
 TRAC0298
 TRAC0299
 TRAC0300
 TRAC0301
 TRAC0302
 TRAC0303
 TRAC0304
 TRAC0305
 TRAC0306

```

READ (5,9100) TEMPNM, N
IF (TEMPNM .EQ. PRINT) IPRINT = 1
C -----
C TEST FOR CHANGE OF CONTROL CARD.
C
C IF (TEMPNM .NE. CHANGE) GO TO 94
C
C NEW CONTROL CARD OPTION FOLLOWS.
C
C KFLAG = 1
C WRITE (6,9020) NEW, TITLE
C WRITE (6,9000)
6000 FORMAT ('CHANGE OF CONTROL CARD.')
READ (5,9025) NTR, IX, I
IF (IX .EQ. 0) IX = 13579
IXX = IX/2
IF ((IX-2*IXX) .EQ. 0) IX = IX+1
WRITE (6,9040) NTR, IX, I
DO 91 I=1,NC
91 P(I) = 1.0-EXP(-LAMBDA(I)*T/10.0**6)
92 CONTINUE
IPP = IPP+1
IF (IPP .GT. IP) GO TO 89
93 R = RSAVE(IPP)
GO TO 95
94 CONTINUE
IF (TEMPNM .EQ. ENDPRT) GO TO 10
IP = IPP+1
C -----
C SAVE FORCING PARAMETERS FOR CHANGE OF CONTROL CARD OPTION.
C
C IF (IP .LE. 20) RSAVE(IP) = R
C IF (R .EQ. 0.) GO TO 90
95 KASE = KASE + 1
IF (IPRINT .EQ. 0) GO TO 96
WRITE(6,9020) NEW, TITLE
WRITE(6,9110) KASE, N
WRITE (6,9300)
WRITE(6,9115)
96 CONTINUE
LINE = 15
KTN = 0
KTN = 0
VAR = 0.0
PHUM = 0.0
NSFL = 0
NSFTS = 0
ON 100 I = 1,500
NMSFT(I) = 0
PSF(I) = 0.0
LAST(I) = 0

```

TRAC0307
 TRAC0308
 TRAC0309
 TRAC0310
 TRAC0311
 TRAC0312
 TRAC0313
 TRAC0314
 TRAC0315
 TRAC0316
 TRAC0317
 TRAC0318
 TRAC0319
 TRAC0320
 TRAC0321
 TRAC0322
 TRAC0323
 TRAC0324
 TRAC0325
 TRAC0326
 TRAC0327
 TRAC0328
 TRAC0329
 TRAC0330
 TRAC0331
 TRAC0332
 TRAC0333
 TRAC0334
 TRAC0335
 TRAC0336
 TRAC0337
 TRAC0338
 TRAC0339
 TRAC0340
 TRAC0341
 TRAC0342
 TRAC0343
 TRAC0344
 TRAC0345
 TRAC0346
 TRAC0347
 TRAC0348
 TRAC0349
 TRAC0350
 TRAC0351
 TRAC0352
 TRAC0353
 TRAC0354
 TRAC0355
 TRAC0356
 TRAC0357


```

100 KOUNT(1) = 0
DO 110 I = 1, NC
    PSTAR(1) = P(1) ** R
110 WT(1) = P(1) / PSTAR(1)
C *****
C ***** INITIALIZE TRIAL VARIABLES - START NEW TRIAL *****
C *****
120 IF (KTR .GE. NTR) GO TO 320
    KTR = KTR + 1
    NHFL = 0
    NCFL = 0
    PS = 1.0
    TOP = .FALSE.
    DO 125 I = 1, NRI
125 RICH(1) = .FALSE.
    DO 130 I = 1, NCOMP
130 COMPST(1) = .FALSE.
    DO 135 I = 1, NG
135 GATEST(1) = .FALSE.
    IF (INH .EQ. 0) GO TO 150
C -----
C ----- FAIL HOUSES AS REQUIRED -----
C -----
    NC1 = NC + 1
    DO 140 I = NC1, NCOMP
        IF (LAMDA(I) .EQ. 0) GO TO 140
        COMPST(I) = .TRUE.
        NHFL = NHFL + 1
        NEXT(NHFL) = I
        CALL TREE(TOP, I, INH)
        IF (.NOT. TOP) GO TO 140
        IF (INH .EQ. 0) GO TO 137
        COMPST(I) = .FALSE.
        NHFL = NHFL - 1
137 IFLAG = 1
    GO TO 297
140 CONTINUE
C *****
C ***** IMPORTANCE SAMPLING OF COMPONENT FAILURE TIMES *****
C *****
    NCFL = NHFL
150 DO 160 I = 1, NC
    CALL RANDU(IX, IY, U)
    IX = IY
    IF (U .GT. PSTAR(1)) GO TO 160
    NCFL = NCFL + 1
    NEXT(NCFL) = I
    TRAC0358
    TRAC0359
    TRAC0360
    TRAC0361
    TRAC0362
    TRAC0363
    TRAC0364
    TRAC0365
    TRAC0366
    TRAC0367
    TRAC0368
    TRAC0369
    TRAC0370
    TRAC0371
    TRAC0372
    TRAC0373
    TRAC0374
    TRAC0375
    TRAC0376
    TRAC0377
    TRAC0378
    TRAC0379
    TRAC0380
    TRAC0381
    TRAC0382
    TRAC0383
    TRAC0384
    TRAC0385
    TRAC0386
    TRAC0387
    TRAC0388
    TRAC0389
    TRAC0390
    TRAC0391
    TRAC0392
    TRAC0393
    TRAC0394
    TRAC0395
    TRAC0396
    TRAC0397
    TRAC0398
    TRAC0399
    TRAC0400
    TRAC0401
    TRAC0402
    TRAC0403
    TRAC0404
    TRAC0405
    TRAC0406
    TRAC0407
    TRAC0408
    TRAC0409
    TRAC0410
    TRAC0411
    TRAC0412
    TRAC0413
    TRAC0414
    TRAC0415
    TRAC0416
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    TRAC0434
    TRAC0435
    TRAC0436
    TRAC0437
    TRAC0438
    TRAC0439
    TRAC0440
    TRAC0441
    TRAC0442
    TRAC0443
    TRAC0444
    TRAC0445
    TRAC0446
    TRAC0447
    TRAC0448
    TRAC0449
    TRAC0450
    TRAC0451
    TRAC0452
    TRAC0453
    TRAC0454
    TRAC0455
    TRAC0456
    TRAC0457
    TRAC0458
    TRAC0459
    TNEXT(NCFL) = -ALOG(1.0 - WT(1) * U) / LAMDA(1) * 10.0 ** 6
160 CONTINUE
    IF (NCFL .EQ. NHFL) GO TO 120
C *****
C ***** FAIL COMPONENTS IN ORDER OF FAILURE TIMES *****
C *****
    NHFL1 = NHFL + 1
    DO 180 NCUT = NHFL1, NCFL
    DO 170 I = NCUT, NCFL
        IF (TNEXT(NCUT) .LE. TNEXT(I)) GO TO 170
        TEMP1 = TNEXT(I)
        TNEXT(I) = TNEXT(NCUT)
        TNEXT(NCUT) = TEMP1
        ITEMP = NEXT(I)
        NEXT(I) = NEXT(NCUT)
        NEXT(NCUT) = ITEMP
170 CONTINUE
    COMPST(NEXT(NCUT)) = .TRUE.
    NT = NEXT(NCUT)
    COMPST(NT) = .TRUE.
    CALL TREE(TOP, NEXT(NCUT), INH)
    IF (.NOT. TOP) GO TO 180
    IF (INH .EQ. 0) GO TO 200
    COMPST(NT) = .FALSE.
    NCUT = NCUT - 1
    GO TO 200
180 CONTINUE
    GO TO 120
C *****
C ***** TREE IS FAILED - LOCATE MINIMAL CUTSET *****
C *****
    200 K = 0
    IF (NCUT .NE. 1) GO TO 202
    K = 1
    NSET(K) = NEXT(NCUT)
    GO TO 205
    202 NCUT2 = NCUT + 1
    NCUT1 = NCUT - 1
    L = 0
    DO 220 I = 1, NCUT
        J = NCUT2 - 1
        COMPST(NEXT(J)) = .FALSE.
        NT = NEXT(J)
        COMPST(NT) = .FALSE.
        CALL TREE(TOP, NEXT(J), L)
        IF (TOP) GO TO 210
    210 COMPST(NEXT(J)) = .TRUE.

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      NT = NEXT(I)
      COMPOSITE = .TRUE.
      K = K + 1
      IF ( K .LE. 10 ) GO TO 205
      KTN = KTN + 1
      GO TO 120
205  MSET(K) = NEXT(I)
      L = NEXT(J)
      GO TO 220
210  L = 0
220  CONTINUE
      IF ( .NOT. TOP ) CALL TRACE( TOP, 0, 1 )
      IF ( K .EQ. 1 ) GO TO 205
      *****
      SET MINIMAL CUTSET INTO COMPO. SET, BEGIN
      *****
230  K1 = K - 1
      DO 250 I = 1, K1
        L = 1 + I
        DO 260 J = 1, K
          IF ( MSET(I) .EQ. MSET(J) ) GO TO 270
          ITEMP = MSET(I)
          MSET(I) = MSET(J)
          MSET(J) = ITEMP
250  CONTINUE
260  NSET = NSET + 1
      IF ( NSET .EQ. 0 ) GO TO 280
      *****
      CHECK IF THIS MINIMAL CUTSET HAS BEEN FOUND PREVIOUSLY
      *****
      DO 270 I = 1, NSETS
        IF ( NMSET(I) .NE. K ) GO TO 270
        DO 280 J = 1, K
          IF ( MSET(J) .NE. MINSET(I) ) GO TO 270
270  CONTINUE
        KOUNT(I) = KOUNT(I) + 1
        PROB = PROB + WT(I)
        GO TO 120
280  CONTINUE
      *****
      NEW MINIMAL CUTSET -- STORE IN MINSET
      PERFORM PROBABILITY CALCULATIONS
      *****
290  NSETS = NSETS + 1
      KOUNT(NSETS) = 1
      WT1 = 1.0
      P1 = 1.0
      NMSET(NSETS) = K
      DO 290 J = 1, K

```

```

TRAC0460
TRAC0461
TRAC0462
TRAC0463
TRAC0464
TRAC0465
TRAC0466
TRAC0467
TRAC0468
TRAC0469
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TRAC0471
TRAC0472
TRAC0473
TRAC0474
TRAC0475
TRAC0476
TRAC0477
TRAC0478
TRAC0479
TRAC0480
TRAC0481
TRAC0482
TRAC0483
TRAC0484
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TRAC0497
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TRAC0499
TRAC0500
TRAC0501
TRAC0502
TRAC0503
TRAC0504
TRAC0505
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TRAC0507
TRAC0508
TRAC0509
TRAC0510

```

APPENDIX A

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

```

      MINSET(NSETS,J) = MSET(J)
      IF ( MSET(J) .GT. NC ) GO TO 290
      P1 = P1 * P(MSET(J))
      WT1 = WT1 * WT(MSET(J))
290  CONTINUE
      IF ( NRI .EQ. 0 ) GO TO 296
      *****
      WEIGHTS FOR RANDOM INHERIT GATES THAT ARE SET TO TRUE
      *****
      DO 295 I = 1, NRI
        IF ( .NOT. GATEST( IRI(I) ) ) GO TO 295
        NT = IRI(I)
        IF ( .NOT. GATEST(NT) ) GO TO 295
        P1 = P1 * P(I)
        WT1 = WT1 * WT(I)
295  CONTINUE
296  PSF(NSETS) = P1
      PROB = PROB + WT1
      WT(NSETS) = WT1
      *****
      DETERMINE WHICH GATES ARE FAILED AND WRITE THEM OUT- NEW CUTSET
      *****
297  L = 0
      DO 300 I = 1, NG
        IF ( .NOT. GATEST(I) ) GO TO 300
        L = L + 1
        FLGATF(L) = 1
300  CONTINUE
      IF ( IFLAG .EQ. 1 ) GO TO 400
      LINE = LINE + 2 + L/15
      IF ( LINE .LE. 80 ) GO TO 305
      IF ( IPRINT .EQ. 0 ) GO TO 305
      WRITE(6,9020) NEW, TITLE
      WRITE(6,9110) KASE, R
      WRITE(6,9300)
      WRITE(6,9115)
      LINE = 17 + L/15
305  DO 306 J=1,L
        NJT = FLGATF(J)
        IF ( GTYPE(NJT) .NE. PG ) GO TO 306
        IAST(NSETS) = 1
        IF ( IPRINT .EQ. 0 ) GO TO 307
        WRITE(6,9125) NSETS, L, (GATENN(FLGATF(I)), I = 1, L)
        GO TO 307
306  CONTINUE
        IF ( IPRINT .EQ. 0 ) GO TO 307
        WRITE(6,9120) NSETS, L, (GATENN(FLGATF(I)), I = 1, L)
307  CONTINUE
      IF ( NSETS .LT. 500 ) GO TO 120
      WRITE(6,9230)
      *****

```

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TRAC0511
TRAC0512
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TRAC0560

```

APPENDIX A

```

C
C ***** SUMMARY CALCULATIONS FOR END OF CASE *****
C
C *****
C
170 PRIN = KTR
PS = 0.0
IF ( NSFL .NE. 0 ) GO TO 171
PROR = 0.0
VAR = 0.0
STERR = 0.0
PERCENT = 0.0
GO TO 175
171 ENSE = NSFL
PROR = PROR + ENSE
VAR = ( PRIN - ENSE ) * PROR
DO 172 I = 1, NSETS
  KS = PS + ENSE(I)
  TOUT = KOUNT(I)
172 VAR = VAR + TOUT * ( ENSE(I) - PROR ) ** 2
VAR = VAR / ( KTR - 1 )
STERR = SQRT(VAR)
PERCENT = 100.0 * ENSE / KTR
C *****
C ***** REMOVE HOUSES (IF ANY) FROM THE MINIMAL CSETS FOR PRINTING. *****
C *****
DO 173 J=1, NSETS
  K = NMSET(J)
DO 174 I=1, K
  IF ( MINSET(I, J) .LE. 0 ) GO TO 341
  NMSET(I) = J-1
GO TO 172
341 CONTINUE
342 CONTINUE
C *****
C *****
C ***** WRITE OUT MINIMAL CSETS AND CASE SUMMARY *****
C *****
LINE = 10
DO 343 I=1, NSETS
  LINE = LINE + 1
  IF ( LINE .GT. 18 ) AND ( LINE .LE. 90 ) GO TO 344
  WRITE(6,9020) NEW, TITLE
  WRITE(6,9110) KASE, K
  WRITE(6,9300)
  WRITE(6,9130)
  LINE = 18
343 CONTINUE
C *****
C ***** PRINT IN ORDER OF LARGEST PROBABILITIES. *****
C *****

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TRAC0562
 TRAC0563
 TRAC0564
 TRAC0565
 TRAC0566
 TRAC0567
 TRAC0568
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 TRAC0609
 TRAC0610
 TRAC0611
 TRAC0612

APPENDIX A

12

```

333 KK = 1
DO 334 JJ=1, NSETS
334 IF ( PSF(KK) .GT. 0 ) GO TO 335
  KK = KK + 1
  IF ( KK - NSETS ) 334, 334, 340
335 IF ( PSF(KK) - PSF(JJ) ) 336, 337, 338
336 KK = JJ
GO TO 334
337 IF ( KOUNT(KK) - KOUNT(JJ) ) 336, 338, 339
338 CONTINUE
  K = NMSET(KK)
  WRITE(6,9140) I, KK, PSF(KK), KOUNT(KK),
  1 (COMPNN( MINSET(KK, J) ), J=1, K)
  PSF(KK) = 0.
  IF ( IAST(KK) .NE. 0 ) WRITE(6,9310)
340 CONTINUE
345 WRITE(6,9020) NEW, TITLE
  WRITE(6,9110) KASE, K
  WRITE(6,9140) KASE, KTR, NSFL, PERCENT, KTRN, NSETS
  WRITE(6,9170) PS
  WRITE(6,9160) PROR, VAR, STERR
C IF ( PERCENT .GT. 10.0 .OR. PERCENT .LT. 7.5 ) GO TO 350
C WRITE(6,9180) PERCENT
C GO TO 90
C 350 WRITE(6,9190) PERCENT
C GO TO 90
C *****
C ***** TREE FAILS WITH HOUSES ALONE - WRITE DATA, GO TO NEXT PROBLEM *****
C *****
400 WRITE(6,9200)
  WRITE(6,9210) (COMPNN(NEXT(I)), I = 1, NMFL )
  WRITE(6,9220) (GATENN(PLGATE(I)), I = 1, L)
C *****
C ***** INPUT RESTRICTION VIOLATED, READ OUT 2 CARDS TO NEXT PROBLEM *****
C *****
500 WRITE(6,9240)
510 READ(5,9100) TEMNN
  IF ( TEMNN .EQ. ENDPRI ) GO TO 510
  GO TO 510
550 STOP
END
C
C *****
C ***** SUBROUTINE RANDU *****
C *****
C ***** PURPOSE *****
C ***** COMPUTES UNIFORMLY DISTRIBUTED RANDOM REAL NUMBERS BETWEEN *****
C ***** 0 AND 1.0 AND RANDOM INTEGERS BETWEEN 2PR3 AND *****

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TRAC0613
 TRAC0614
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 TRAC0616
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 TRAC0662
 TRAC0663

APPENDIX A

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C      28311. EACH ENTRY USES AN INPUT AN INTEGER RANDOM NUMBER AND PRODUCES A NEW INTEGER AND REAL RANDOM NUMBER. TRAC0666
C      TRAC0667
C      TRAC0668
C      TRAC0669
C      TRAC0670
C      TRAC0671
C      TRAC0672
C      TRAC0673
C      TRAC0674
C      TRAC0675
C      TRAC0676
C      TRAC0677
C      TRAC0678
C      TRAC0679
C      TRAC0680
C      TRAC0681
C      TRAC0682
C      TRAC0683
C      TRAC0684
C      TRAC0685
C      TRAC0686
C      TRAC0687
C      TRAC0688
C      TRAC0689
C      TRAC0690
C      TRAC0691
C      TRAC0692
C      TRAC0693
C      TRAC0694
C      TRAC0695
C      TRAC0696
C      TRAC0697
C      TRAC0698
C      TRAC0699
C      TRAC0700
C      TRAC0701
C      TRAC0702
C      TRAC0703
C      TRAC0704
C      TRAC0705
C      TRAC0706
C      TRAC0707
C      TRAC0708
C      TRAC0709
C      TRAC0710
C      TRAC0711
C      TRAC0712
C      TRAC0713
C      TRAC0714

```

28311. EACH ENTRY USES AN INPUT AN INTEGER RANDOM NUMBER AND PRODUCES A NEW INTEGER AND REAL RANDOM NUMBER.
 USAGE
 CALL RANDU(IY, YFL)
 DESCRIPTION OF PARAMETERS
 IY = FOR THE FIRST ENTRY THIS MUST CONTAIN ANY ODD INTEGER NUMBER WITH NINE OR LESS DIGITS. AFTER THE FIRST ENTRY, IY SHOULD BE THE PREVIOUS VALUE OF IY COMPUTED BY THIS SUBROUTINE.
 YFL = A RESULTANT INTEGER RANDOM NUMBER REQUIRED FOR THE NEXT ENTRY TO THIS SUBROUTINE. THE RANGE OF THIS NUMBER IS BETWEEN ZERO AND 28311.
 YFL = THE RESULTANT UNIFORMLY DISTRIBUTED, FLOATING POINT, RANDOM NUMBER IN THE RANGE 0.1 TO 1.0.
 REMARKS
 THIS SUBROUTINE IS SPECIFICALLY SYSTEMIZED
 THIS SUBROUTINE WILL PRODUCE A RANDOM NUMBER
 BEFORE REPEATING
 SUBROUTINES AND FUNCTION SUBROUAINS REQUIRED
 NONE
 METHOD
 POWER ANALYSIS METHOD DISCUSSED IN IBM MANUAL C20-2011.
 RANDOM NUMBER GENERATION AND TESTING

 SUBROUTINE RANDU(IY, YFL)
 IY = IY * 65539
 IF(IY) 5, 6, 6
 5 IY = IY + 2147483647 + 1
 6 YFL = IY
 YFL = YFL * .4656612E-9
 RETURN
 END

THIS MULTI-ENTRY SUBROUTINE WILL
 (GATES) 1. READ GATE CARDS (EACH GROUP FOLLOWED BY
 "LAST" CARD), SET UP DICTIONARIES
 (TREE) 2. CALC. PE AND WGT. FOR R.I. GATES WHEN THE
 CHANGES, CHECK R.I. GATES AND THEIR PROBABILITY,
 TRACE A FAILED COMPONENT THRU ALL POSSIBLE
 PATHS TO THE TOP
 (TRACE) 3. CHANGE STATUS OF 1 OR 2 COMPONENTS AND TRACE
 SAME THRU ALL POSSIBLE PATHS TO THE TOP

APPENDIX A

```

C      TRAC0715
C      TRAC0716
C      TRAC0717
C      TRAC0718
C      TRAC0719
C      TRAC0720
C      TRAC0721
C      TRAC0722
C      TRAC0723
C      TRAC0724
C      TRAC0725
C      TRAC0726
C      TRAC0727
C      TRAC0728
C      TRAC0729
C      TRAC0730
C      TRAC0731
C      TRAC0732
C      TRAC0733
C      TRAC0734
C      TRAC0735
C      TRAC0736
C      TRAC0737
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C      TRAC0740
C      TRAC0741
C      TRAC0742
C      TRAC0743
C      TRAC0744
C      TRAC0745
C      TRAC0746
C      TRAC0747
C      TRAC0748
C      TRAC0749
C      TRAC0750
C      TRAC0751
C      TRAC0752
C      TRAC0753
C      TRAC0754
C      TRAC0755
C      TRAC0756
C      TRAC0757
C      TRAC0758
C      TRAC0759
C      TRAC0760
C      TRAC0761
C      TRAC0762
C      TRAC0763
C      TRAC0764
C      TRAC0765

```

 COMPNM = COMPONENT NAMES
 COMST = COMPONENT STATUS
 COMT = SUBSCRIPTS OF GATES FED BY A COMPONENT
 DATA = WORKING AREA
 FALSP = '0' - SUCCESS FLAG
 GATNM = GATE NAMES
 GATEST = GATE STATUS
 GINI(,1) = SUBSCRIPTS OF GATES FED TO A GATE
 (,2) = SUBSCRIPTS OF COMPONENTS FED TO A GATE
 GOUT = SUBSCRIPTS OF GATES FED BY A GATE
 GTYPE = GATE TYPE - OR, AND, R.I.
 ICOMP = SUBSCRIPT OF COMPONENT THAT DID NOT FAIL
 ICOMPY = SUBSCRIPT OF COMPONENT THAT FAILED
 INM = FLAG, ON MEANS TREE WAS TOPPED BECAUSE OF RI GATES
 IPRINT = PRINT FLAG, ONPRINT GATE CARD TABLE
 IRI = SUBSCRIPTS OF R.I. GATES (POSITION IN GATNM ARRAY)
 IRIF = FLAG, ON MEANS THERE IS BEING TRACED BECAUSE OF
 CHANGE OF STATUS OF RI GATE
 ITRACE = 0, ENTRY TREE...NOT 0, ENTRY TRACE
 IX = ODD INTEGER, 9 OR LESS DIGITS, INPUT TO OBTAIN YFL
 IY = ODD INTEGER RETURNED FROM RANDU
 K = FLAG, NO. OF GATE NAMES READ IN SO FAR
 K1 = FLAG, NO. OF R.I. GATES READ IN SO FAR
 K2 = FLAG, NO. OF COMP. NAME INPUT IN ERROR
 K3 = FLAG, NO. OF GATES WITH INCORRECT TYPE CODE
 K4 = COUNTER OF RI GATES BEING CHECKED
 M = MAXIMUM NUMBER OF COMPONENTS
 N = MAXIMUM NUMBER OF GATES
 NCOMP = NUMBER OF COMPONENTS INPUT
 NG = NUMBER OF GATES INPUT
 NJ(ODD) = SUBSCRIPT OF GATE OR COMP.
 (EVEN) = RELATIVE LATERAL POSITION OF GATE/COMP.
 (NJ IS USED TO KEEP TRACK OF TRACING)
 NRI = NUMBER OF R.I. GATES INPUT
 N1 = MAXIMUM NUMBER OF GATES FED BY A GATE OR COMP.
 N2 = MAXIMUM NUMBER OF GATES OR COMP. FED TO A GATE
 N3 = MAXIMUM NUMBER OF R.I. GATES
 PI = INPUT PROBABILITIES ASSOC. WITH R.I. GATES
 PIN = PROBABILITY OF R.I. GATE INPUT
 PSTAN = PROBABILITY USED TO SET FAIL CHANCE OF R.I. GATE
 R = EXPONENT 'R'
 RICH = PROBABILITY OF FAILURE FLAGS FOR R.I. GATES.
 IF RANDOM VARIABLE IS THAN PROBABILITY.FLAG = .TRUE.
 OTHERWISE.FLAG = .FALSE.
 RK = PREVIOUS 'R' VALUE
 TOP = STATUS OF TREE
 TRUE = '1' - FAIL FLAG
 TYPE = GATE TYPE OF GATE JUST READ IN
 WTI = WEIGHTS
 YFL = UNIFORM RANDOM NUMBER

APPENDIX A


```

C-----TRAC0868
C                                     TRAC0869
C      TREE GATE                                     TRAC0870
C                                     TRAC0871
C-----TRAC0872
C      55 DO 60 I=1,N2                                     TRAC0873
C          IF (NJ(J1) .EQ. 0) GO TO 65                     TRAC0874
C      60 CONTINUE                                         TRAC0875
C      65 GATEST(NJ(J1)) = RICH(1)                         TRAC0876
C      65 NJT = NJ(J1)                                     TRAC0877
C          GATEST(NJT) = RICH(1)                           TRAC0878
C      IF (RICH(1)) 1 GO TO 120                             TRAC0879
C      IF (RICH(1)) 1 GO TO 110                             TRAC0880
C      GO TO 130                                           TRAC0881
C-----TRAC0882
C                                     TRAC0883
C      PRIORITY GATE                                     TRAC0884
C                                     TRAC0885
C-----TRAC0886
C      66 IF (RICH(1) .NE. 0) GO TO 70                     TRAC0887
C          IF (GIN(NJ(J1),1,1) .EQ. 0) GO TO 67           TRAC0888
C-----TRAC0889
C                                     TRAC0890
C      PRIORITY ORDER = GATE, GATE OR GATE, COMPONENT 1   TRAC0891
C-----TRAC0892
C                                     TRAC0893
C      NJT = GIN(NJ(J1),1,1)                             TRAC0894
C      IF (NJT .EQ. 1) GO TO 67                            TRAC0895
C      IF (NJT .EQ. 0) GO TO 130                          TRAC0896
C      GO TO 68                                             TRAC0897
C      67 IF (NJT .EQ. 1) GO TO 130                       TRAC0898
C      68 IF (NJT .EQ. 1) GO TO 130                       TRAC0899
C      NJT = NJ(J1)                                       TRAC0900
C      GATEST(NJT) = .TRUE.                               TRAC0901
C      GO TO 110                                           TRAC0902
C-----TRAC0903
C                                     TRAC0904
C      PRIORITY ORDER = COMPONENT, GATE OR COMPONENT, COMPONENT TRAC0905
C-----TRAC0906
C                                     TRAC0907
C      69 NJT = GIN(NJ(J1),1,2)                         TRAC0908
C      IF (NJT .EQ. 1) GO TO 130                          TRAC0909
C      IF (NJT .EQ. 0) GO TO 130                          TRAC0910
C      NJT = NJ(J1)                                       TRAC0911
C      GATEST(NJT) = .TRUE.                               TRAC0912
C      GO TO 110                                           TRAC0913
C-----TRAC0914
C                                     TRAC0915
C      PRIORITY GATE....CHECK ALL GATES AND COMPONENTS FED TO GATE TRAC0916
C-----TRAC0917
C                                     TRAC0918

```

APPENDIX A

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C-----TRAC0919
C                                     TRAC0920
C      70 J = NJ(J1)                                     TRAC0921
C-----TRAC0922
C      .....CHECK GATES.....                             TRAC0923
C-----TRAC0924
C      80 DO 90 I=1,N2                                     TRAC0925
C          IF (GIN(J,1,1) .EQ. 0) GO TO 90                 TRAC0926
C          IF (GATEST(GIN(J,1,1))) GO TO 130               TRAC0927
C      90 CONTINUE                                         TRAC0928
C      NJT = GIN(J,1,1)                                   TRAC0929
C      IF (NJT .EQ. 1) GO TO 130                          TRAC0930
C      80 CONTINUE                                         TRAC0931
C-----TRAC0932
C      .....CHECK COMPONENTS.....                         TRAC0933
C-----TRAC0934
C      90 DO 100 I=1,N2                                    TRAC0935
C          IF (GIN(J,1,2) .EQ. 0) GO TO 100                TRAC0936
C          IF (NOT. COMPST(GIN(J,1,2))) GO TO 130          TRAC0937
C      100 CONTINUE                                        TRAC0938
C      NJT = GIN(J,1,2)                                   TRAC0939
C      IF (NJT .EQ. 1) GO TO 130                          TRAC0940
C      100 CONTINUE                                        TRAC0941
C      105 GATEST(J) = .TRUE.                             TRAC0942
C-----TRAC0943
C      GATE FED TO, FAILED                                TRAC0944
C-----TRAC0945
C      110 NJ(J1+1) = J2                                  TRAC0946
C      IF (GOUT(NJ(J1),1) .NE. 0) GO TO 120               TRAC0947
C-----TRAC0948
C      TREE TOPPED.....SET 'TOP' TO TRUE (FAILED)         TRAC0949
C-----TRAC0950
C      TOP = .TRUE.                                       TRAC0951
C      GO TO 130                                           TRAC0952
C-----TRAC0953
C      120 J1 = J1 + 2                                    TRAC0954
C      NJ(J1) = GOUT(NJ(J1-2),1)                         TRAC0955
C      J2 = 1                                              TRAC0956
C      GO TO 50                                            TRAC0957
C-----TRAC0958
C      GATE FED DID NOT FAIL.....AT LEAST 1 GATE OR COMPONENT TRAC0959
C      DID NOT FAIL                                       TRAC0960
C-----TRAC0961
C      130 J2 = J2 + 1                                    TRAC0962
C      IF (J1 .EQ. 1) GO TO 145                          TRAC0963
C-----TRAC0964
C      145

```

APPENDIX A


```

135 IF(J2,GT,N1) GO TO 140
IF (J1,EQ,1) GO TO 145
IF(GOUT(NJ(J1-2),J2),EQ,0) GO TO 140
NJ(J1) = GOUT(NJ(J1-2),J2)
GO TO 50
140 J2 = NJ(J1-1) + 1
J1 = J1 - 2
IF(J1,GT,1) GO TO 135
J1 = 1
145 IF(J2,GT,N1) GO TO 150
IF (J1,EQ,0) GO TO 146
NJ(J1) = GOUT(NJ(J1),J2)
GO TO 147 OR
146 NJ(J1) = CODE(ICOMPT,J1)
147 IF(NJ(J1),EQ,0) GO TO 150
GO TO 50
C
150 IF(TRACE,NF,0) GO TO 300
IF(TRACE,NF,0) GO TO 35
RTN
C
C*****
C*****
C ENTRY TRACE (TOP, ICOMP, ICOMP)
C
C*****
C*****
C ITRACE = 1
C ITRF = 0
C IF(ICOMPT,NF,0) GO TO 40
300 IF(ICOMPT,EQ,0) GO TO 450
C-----
C COMPONENT SET TO FALSE, THAT IS SUCCESS
C TRACE TREE DECREASES. GATES MAY BE CHANGED TO SUCCESS.
C IF TOPPED, SET TOP TO FALSE.
C-----
C NJ(J1) = CODE(ICOMPT,J1)
C J1 = 1
C J2 = 1
C10 IF( GTYPE(NJ(J1)),EQ,OR) GO TO 310
C-----
C 'AND' OR 'XOR' OR 'PRIORITY' GATE.....NOT FAILED
C-----
C GATEST(NJ(J1)) = FALSE.
C NJT = NJ(J1)
C GATEST(NJT) = FALSE.

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 TRAC1019
 TRAC1020

APPENDIX A

```

GO TO 370
C-----
C 'OR' GATE.....CHECK ALL GATES AND COMPONENTS FED TO GATE
C-----
C 320 J = NJ(J1)
C-----
C .....CHECK GATES.....
C-----
C DO 330 I=1,N2
IF(GIN(J,I),EQ,0) GO TO 340
IF(GATEST(GIN(J,I))) GO TO 400
C NJT = GIN(J,I)
IF( GATEST(NJT) ) GO TO 400
330 CONTINUE
C-----
C .....CHECK COMPONENTS.....
C-----
C 340 DO 350 I=1,N2
IF(GIN(J,I),EQ,0) GO TO 360
IF(COMPST(GIN(J,I))) GO TO 400
C NJT = GIN(J,I)
IF( COMPST(NJT) ) GO TO 400
350 CONTINUE
360 GATEST(J) = FALSE.
C-----
C GATE FED TO, NOT FAILED
C-----
C 370 NJ(J1+1) = J2
IF(GOUT(NJ(J1),1),NF,0) GO TO 380
C-----
C TREE TOPPED.....SET TOP TO FALSE (NOT FAILED)
C-----
C TOP = FALSE.
GO TO 400
C
380 J1 = J1 + 2
NJ(J1) = GOUT(NJ(J1-2),1)
J2 = 1
GO TO 310
C-----
C-----

```

TRAC1021
 TRAC1022
 TRAC1023
 TRAC1024
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 TRAC1033
 TRAC1034
 TRAC1035
 TRAC1036
 TRAC1037
 TRAC1038
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APPENDIX A

APPENDIX A

APPENDIX A


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      K1 = K1 + 1
      IF (K1 .LE. N1) GO TO 672
C-----
C.....ERROR - MAXIMUM N.O. GATE INPUT EXCEEDED.....
      WRITE(6,905) GATENM(1)
      905 FORMAT(' MAXIMUM N.O. GATE INPUT EXCEEDED, GATE ' A6, ' CANNOT
      1 BE ADDED TO TABLE.....')
      N1 = K1
      NG = K
      GO TO 667
C-----
C
      672 IRI(K1) = 1
      PI(K1) = PIN
C
      675 IF( TYPE .EQ. AND .OR. TYPE .EQ. OR .OR. TYPE .EQ. RI .OR.
      1 TYPE .EQ. PG ) GO TO 678
      K3 = K3 + 1
C-----
C.....ERROR - INCONNECT GATE TYPE CODE.....
      WRITE(6,918) GATENM(1)
      918 FORMAT(' GATE ' A6, ' CONTAINS INCORRECT TYPE CODE.....')
C-----
C
      678 IF( NG .EQ. 0 ) GO TO 710
      J2 = 0
C-----
C.....STORE FEEDER GATE NAME IF NOT PREVIOUSLY REGISTERED.....
C-----
      NG1 = K
      DO 700 J1=1,NG
      DO 680 J2=1,NG1
      IF (DATA(J1) .EQ. GATENM(J2)) GO TO 685
      680 CONTINUE
      K = K + 1
      IF (K .GT. N ) GO TO 666
      682 GATENM(K) = DATA(J1)
      J = K
C-----
C.....STORE SUBSCRIPT OF FEEDER GATE.....
C-----
      685 J2 = J2 + 1
      IF( TYPE .NE. PG .OR. ID .LE. 1 ) GO TO 687
      IF( J2 .GT. 1 ) GO TO 686
      GIN(1,1,1) = J

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TRAC1174
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APPENDIX A

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      GO TO 689
      686 GIN(1,2,1) = J
      GO TO 689
      687 GIN(1,J2,1) = J
C-----
C.....STORE SUBSCRIPT OF GATE.....
C-----
      689 DO 690 J3=1,N1
      IF (GOUT(J,J3) .NE. 0) GO TO 690
      GOUT(J,J3) = 1
      GO TO 700
      690 CONTINUE
      700 CONTINUE
C-----
C.....PICK UP ALL 'FEEDER' GATES AND COMPONENTS AND
      STORE SUBSCRIPTS FOR GATE JUST READ IN. 'FEEDER'
      REFERS TO GATES/COMPONENTS FED INTO A GATE.
      STORE SUBSCRIPT OF GATE FOR EACH FEEDER GATE AND
      COMPONENT AS A GATE BEING 'FED TO'.
C-----
C
      710 IF( NC .EQ. 0 ) GO TO 650
      NCO = NCOMP
      IF( NCOMP .GT. N ) NCO = N
      J2 = 0
      J4 = NG+1
      J5 = NG + NC
      DO 740 J1=J4,J5
      DO 715 J=1,NCO
      IF (DATA(J1) .EQ. COMPNM(J)) GO TO 720
      715 CONTINUE
      K2 = K2 + 1
C-----
C.....ERROR - COMPONENT NAME REQUESTED NOT FOUND.....
      WRITE(6,905) DATA(J1), GATE
      905 FORMAT(' COMPONENT NAME -' A6, '- DESIGNATED FOR GATE ' A6,
      1 ' NOT FOUND IN TABLE.....')
      GO TO 740
C-----
C.....STORE SUBSCRIPT OF FEEDER COMPONENT.....
C-----
      720 J2 = J2 + 1
      IF( TYPE .NE. PG ) GO TO 720

```

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APPENDIX A


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      WRITE(6,912) (COMPNM(GIN(I,J,2)), J=1,J1)
912 FORMAT( ' + ' 75X A(1X A6))
      GO TO 780
779 IF( J2 .EQ. 0 ) WRITE( 6,921 ) STAR
921 FORMAT( ' + ' 13X A2)
780 CONTINUE
C-----
C          PRINT TABLE OF GATES AND COMPONENTS AND THE GATES
C          THEY FEED
C-----
      LINE = 80
      IF( LINE .LT. 85 ) GO TO 785
      WRITE( 6,6000)  TITLE
      LINE = 0
785 WRITE( 6, 913 )
913 FORMAT(////)
      LINE = LINE + 5
790 WRITE( 6,914 )
914 FORMAT( T24, 'FEEDS THESE GATES', T43, 'FEEDS THESE GATES' /
1      ' NO. GATE      1      2      3      4', T59,
2      ' NO. COMPONENT      1      2      3      4' / )
      LINE = LINE + 3
      K = NG
      IF( NCOMP .GT. NG ) K = NCOMP
      DO 840 I = 1,K
      IF( I .GT. NG ) GO TO 810
      DO 795 J = 1,N1
      IF( GOUT(I,J) .NE. 0 ) GO TO 795
      J1 = J - 1
      GO TO 800
795 CONTINUE
      J1 = N1
800 IF( LINE .LT. 79 ) GO TO 805
      WRITE( 6, 902 )
      WRITE( 6,914 )
      LINE = 3
805 IF( J1 .EQ. 0 ) GO TO 806
      WRITE( 6,915 ) I, GATENM(I), (GATENM(GOUT(I,J)),J=1,J1)
915 FORMAT(/15, 3X A6, 3X 4(1X A6))
      GO TO 807
806 WRITE( 6,915) I, GATENM(I)
      WRITE( 6,921 ) STAR
807 IFF = 0
      IF( I .GT. NCOMP ) GO TO 835
      GO TO 815
C
      810 IFF = 1
      815 DO 820 J = 1,N1
      IF( COUT(I,J) .NE. 0 ) GO TO 820

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APPENDIX A

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      J1 = J-1
      GO TO 825
820 CONTINUE
      J1 = N1
825 IF( IFF .NE. 0 ) GO TO 830
      IF( J1 .EQ. 0 ) GO TO 828
      WRITE( 6,916 ) I, COMPNM(I), (GATENM(COUT(I,J)),J=1,J1)
916 FORMAT( ' + ' 55X 15, 4X A6, 5X 4(1X A6))
      GO TO 835
828 WRITE( 6,916 ) I, COMPNM(I)
      WRITE( 6,921 ) STAR
      GO TO 835
830 IF( LINE .LT. 79 ) GO TO 832
      WRITE( 6,902 )
      WRITE( 6,914 )
      LINE = 3
832 IF( J1 .EQ. 0 ) GO TO 834
      WRITE( 6,917 ) I, COMPNM(I), (GATENM(COUT(I,J)),J=1,J1)
917 FORMAT(/56X 15, 4X A6, 5X 4(1X A6))
      GO TO 835
834 WRITE( 6,917 ) I, COMPNM(I)
      WRITE( 6,921 ) STAR
835 LINE = LINE + 2
840 CONTINUE
890 RETURN
C=====
C.....ERROR - PREMATURE EOF, NO 'LAST' CARD OR OTHER DATA.....
895 WRITE(6, 909)
909 FORMAT( / ' NO 'LAST' CARD OR OTHER DATA INPUT.....')
      STOP
C=====
C
      END

```

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APPENDIX A

APPENDIX B

USER'S MANUAL FOR
PROGRAM E64106,
TREE ANALYSIS CODE

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APPENDIX B

PURPOSE OF PROGRAM

This program performs a Monte Carlo simulation to identify the minimal cutsets and critical paths of a fault tree and to estimate the probabilities of fault-tree failure. A fault tree is a diagram that provides an orderly description of those relationships between possible events within a system that can result in a specific failure of the system. The basic input events to a tree are primary and secondary component failures. Such failures are usually time-dependent and independent of each other. In this program, the time to failure for a component is assumed to be a random variable with an exponential distribution. The relationships between events and the manner in which they may combine to produce other events are described by logic gates. Various types of gates are allowed and described in the input section.

A cutset is a set of basic inputs (components) whose combined failure will result in occurrence of the top undesired event in the tree (the specific system failure represented by the fault tree). A minimal cutset is a cutset for which the top event in the tree will not occur if any one of the components has not failed. A fault path is a set of gates through which component failures cause the top of the tree to fail. Critical paths are those fault paths that contribute significant to the probability of tree failure.

The program applies the technique of importance sampling to reduce computer time requirements. This technique consists of modifying the component time-to-failure distributions so failures occur prior to the prescribed end-of-mission time, with a higher probability than for the original distribution, and, after that time, with a correspondingly lower probability. Because this procedure increases the percentage of system failures obtained, minimal cutsets are detected with fewer trials. The procedure also acts as a variance reducing technique and, through the use of weighting functions, provides an unbiased estimate of the probability of fault-tree failure. The power rule is used for the importance sampling.

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II. RESTRICTIONS

Any number of problems (trees) may be stacked, and any number of cases per tree (different forcing parameters) may be run. Number of trials, random number constant, and mission time may be changed. For each problem, the following restrictions hold:

1. The total number of components must not exceed 1000.
2. The total number of gates must not exceed 2000.
3. No more than 100 random inhibit gates may be used.
4. No gate may have more than eight input components and eight input gates.
5. Priority gates must have two inputs. These inputs may be two gates, two components, or one of each.
6. Random inhibit gates may have only one input other than the associated probability.
7. Any gate or component may provide input to a maximum of four gates.
8. The number of gates along the path from any component to the top of the tree must not exceed 100.

The program will summarize results and terminate prior to completing the requested number of trials if the tree fails because of houses alone or if the number of distinct minimal cutsets identified exceeds 500. If a

APPENDIX B

minimal cutset contains over ten components and houses, it will be ignored; and the trial will be considered successful. The number of such events, however, will be counted and printed out.

III. OPERATING INSTRUCTIONS

The program is written in FORTRAN IV for the IBM 360/65. No disks or special tapes are used. Approximately 310,000 bytes of core are required.

IV. INPUT

A. COMPONENT TYPES

Two types of basic inputs or components are handled by the program.

1. Standard Component

A standard component fails during a trial (a simulated mission length) according to a failure time randomly selected from an exponential distribution. The user furnishes the failure rate (mean number of failures per million time units, normally hours) for each standard component.

2. House

A house is either always on (i.e., the system state described by the house exists for the duration of the mission) or always off for the entire set of trials. Houses are useful in determining subsystem effects on tree failure by permitting simulation of the remainder of the system with that subsystem in a prescribed on or off status. The user furnishes the status for each house. A house input goes only to an AND gate.

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B. GATE TYPES

The logic of a gate determines when it fails on the basis of the failure status of its input. An input to a gate may be either a component or another gate. Four types of gates are handled by the program:

<u>Gate Type</u>	<u>Logic</u>
OR	An OR gate is failed if any one or more of its inputs is failed.
AND	An AND gate is failed if all its inputs are failed; otherwise, it is not failed.
PRIORITY	A PRIORITY gate is limited to two inputs. It is failed only if both inputs are failed and the failures occurred in a prescribed order.
RANDOM INHIBIT	A RANDOM INHIBIT gate has only one input in addition to an assigned probability for the inhibit conditions. At any particular time, it is failed with that probability only if its input is also failed.

C. INPUT CARDS

The following input cards are required for each problem (unless noted as optional) in the order indicated. Time units are noted as hours, but any time unit is acceptable if used consistently.

1. Title Card

Col. 1-72 Any alphanumeric identification desired to identify the problem.

APPENDIX B

2. Control Card

All values on this card must be right-adjusted.

Col. 1-6	Number of trials to be run per case.
Col. 7	Blank
Col. 8-16	Random Number Constant - any odd integer. If blank, program assumes 13579. Different constants will produce different sequences of random numbers.
Col. 17	Blank
Col. 18-30	Mission length in hours (E format).

3. Component Cards

Col. 1-6	Component Name - left-adjusted. First character must be H if a house.
Col. 7	Blank
Col. 8	House status. (Blank if not a house) 0 - house off 1 - house on
Col. 9	Blank
Col. 10-22	Failure rate - number of failures per million hours (E format, right-adjusted)

4. LAST Card

Col. 1-4 LAST - Indicates end of component cards.

APPENDIX B

5. Gate Cards

Col. 1-6 Gate Name - left-adjusted.
First character of name determines gate type.
R - OR gate
A - AND gate
P - PRIORITY gate
I - RANDOM INHIBIT gate

Col. 7 Blank if not priority gate.
1 - first input given must occur first.
2 - second input given must occur first.

Col. 8 Number of input gates to this gate.

Col. 9 Number of input components to this gate.

Col. 10-16 Probability of failure if RANDOM INHIBIT gate; otherwise blank.

Col. 17 Blank

Col. 18-72 Names of input gates and components. Gates listed first, components second. Names left-adjusted with one blank column after each six-column field. If more than eight inputs, continue on second card in columns 18-72.

6. PRINT Card (Optional)

Col. 1-5 PRINT - If included program will print out all gates and their inputs along with gates to which each component and gate provides input.

7. LAST Card

Col. 1-4 LAST - Indicates end of gate cards.

8. PRINT Card (Optional)

Col. 1-5 PRINT - If included program will print all the failed gates for the minimal cutsets for each of the following forcing parameter cards in 9.

APPENDIX B

9. Forcing Parameter Cards (As many as desired; one required. The program will save a maximum of 20 forcing parameters for a possible change of Control Card.)

Col. 1-9 Blank
10-16 Forcing parameter R ($0 < R \leq 1$)

10. CHANGE Card (Optional card; can be used any number of times.)

Col. 1-6 CHANGE - Indicate that the next card is a new control card. (See Input Cards, Section b.)

11. Control Card (Optional) (Additional to initial Control Card) Format for additional ---- CHANGE Card.

12. END Card

Col. 1-3 END - Indicates end of problem.

V. OUTPUT

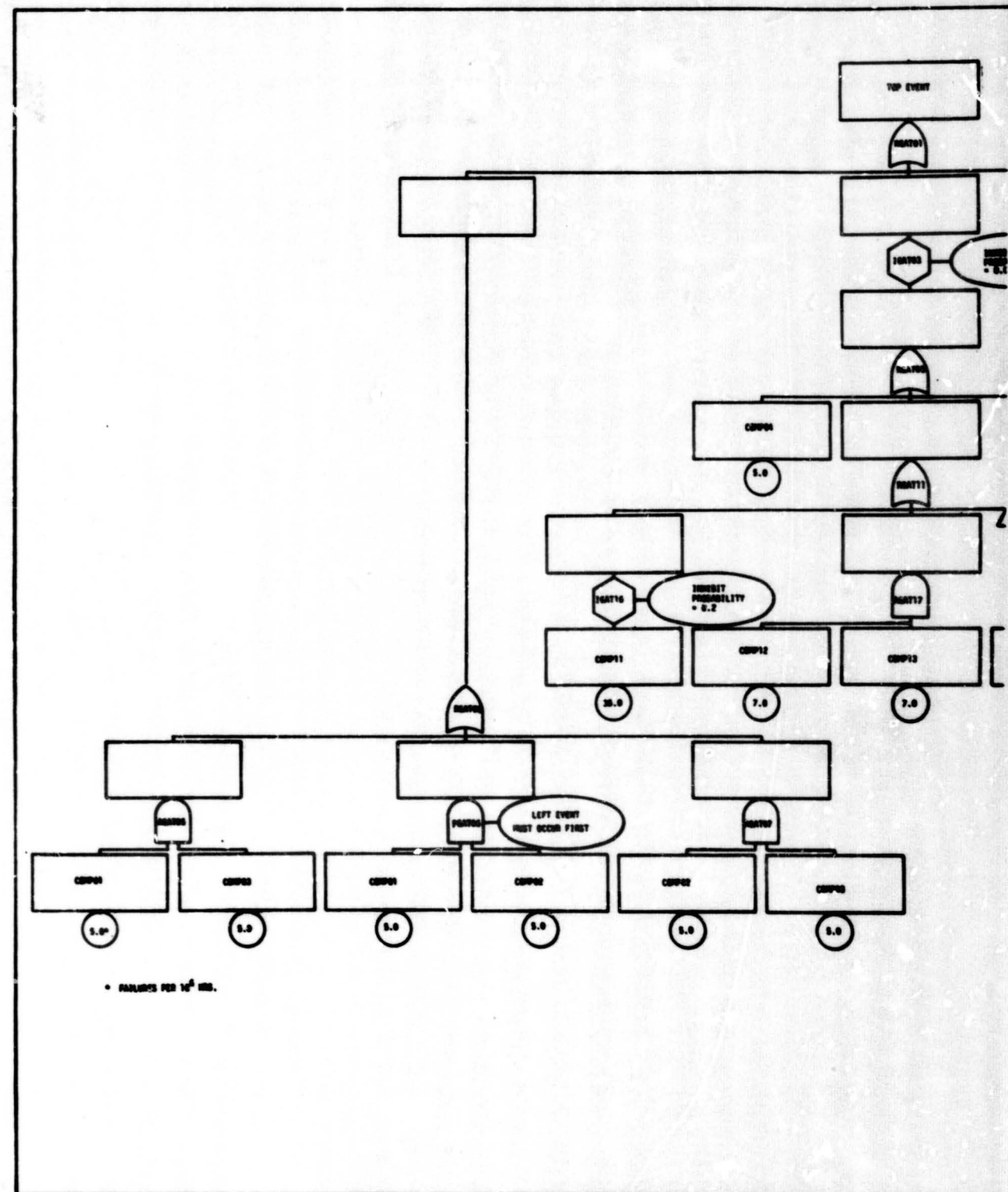
A. Each Problem or Tree

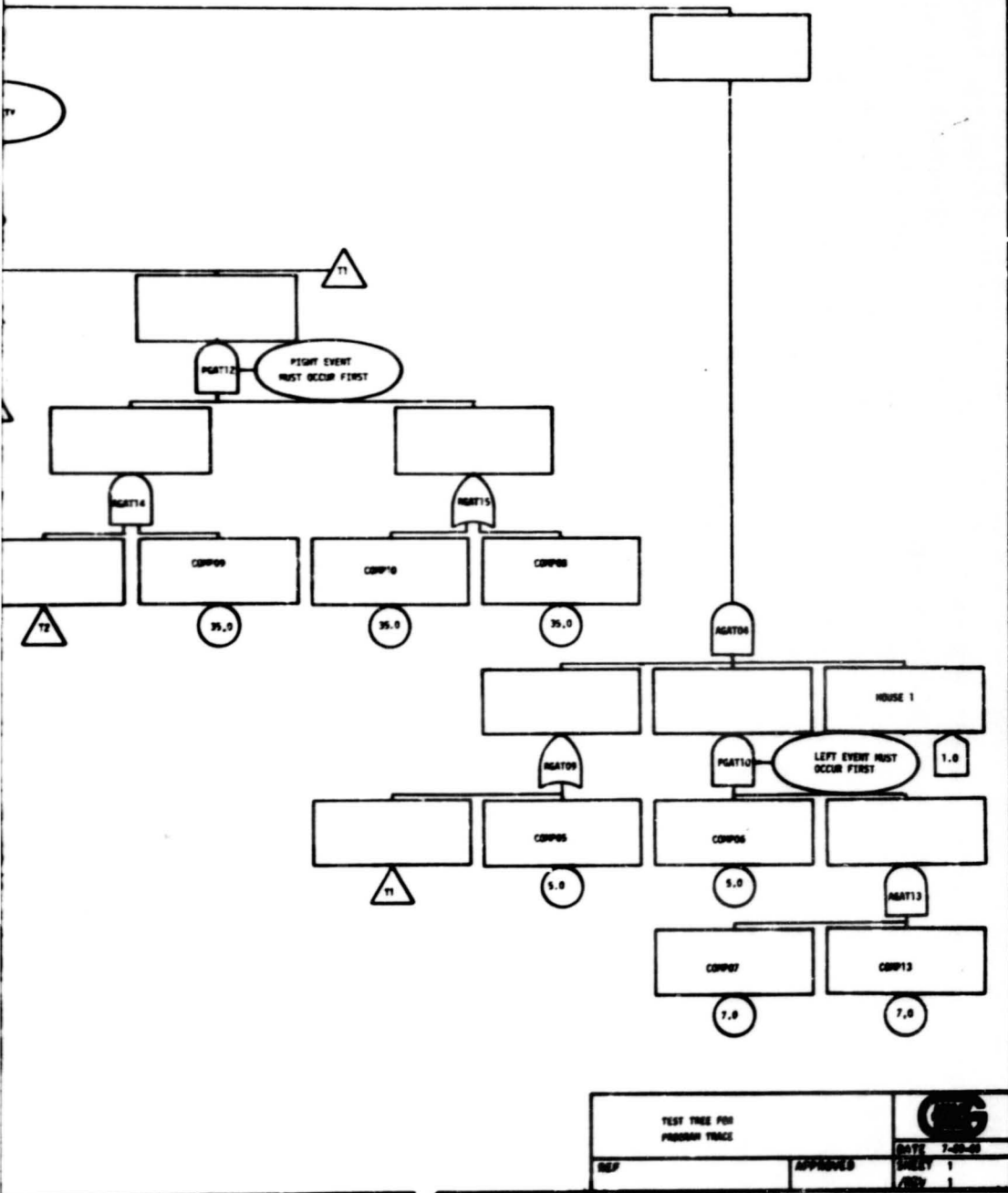
1. Title at top of each page.
2. Number of trials, random number constant, mission length.
3. Number of components and number of houses input.
4. Component names and corresponding failure probabilities.
5. House names and probability (1.0 or 0.0) assigned.
6. Inhibit gates and the assigned probabilities.
7. Number of gates input.
8. (Optional) Gate names and their corresponding inputs along with gates to which each component and gate provides input.

APPENDIX B

B. For Each Case

1. Case number.
2. Forcing parameter for this case.
3. (Optional) Failed gates for each minimal cutset.
4. Cutset rank, cutset number, calculated probability of failure, number of occurrences and components contained in each minimal cutset.
5. Number of trials completed, number of system failures, percent of system failures, number of minimal cutsets found, and number of system failures caused by minimal cutsets of over ten components.
6. A calculated probability of system failure based on the identified minimal cutsets and their original time to failure distributions.
7. Based on importance sampling; estimated probability of system failure, its variance and its standard error.





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CUSTOMER INSTRUCTIONS		KEYPUNCH INSTRUCTIONS		CUSTOMER	
1. ENTER DATA LEGIBLY WITHIN SPACES PROVIDED		☒ PUNCH 1 CARD PER HAND POSTED LINE ITEM		DATE 7-29-69	
2. ENTER DATA BETWEEN 1=1, 0=0, 9=9, 8=8, 7=7, 6=6, 5=5, 4=4, 3=3, 2=2, 1=1		PUNCH ALL * LINES WHETHER POSTED OR NOT. IF NECESSARY PROVIDE BLANK CARDS		JOB NO. B64106	
3. Component Names must be left adjusted.		PUNCH ALL * LINES THAT ARE HAND POSTED		PROGRAMMER	
		PUNCH INCLUDING SPACES		TITLE	
		ALL SPACES MAY BE IGNORED		FORM APPROVED (KEY PUNCH)	
		ALL SPACES MAY BE IGNORED EXCEPT ON 1 CARD		DATE	
		ALL SPACES MAY BE IGNORED EXCEPT (Specify only)			
		ALL SIGNS AND SP LINES MUST BE PUNCHED			
		DO NOT PUNCH PRE-PRINTED SIGNS SHOWN AFTER LAST HANDWRITTEN VALUE ENTRY			
		☒ USE 240 SYMBOLS			

COMPONENT INPUT SHEET	
TEST TREE FOR PROGRAM TRACE	
COMP 01	0.5E+01
COMP 02	0.5E+01
COMP 03	0.5E+01
COMP 04	0.5E+01
COMP 05	0.5E+01
COMP 06	0.5E+01
COMP 07	0.7E+01
COMP 08	3.5E+01
COMP 09	3.5E+01
COMP 10	3.5E+01
COMP 11	3.5E+01
COMP 12	0.7E+01
COMP 13	0.7E+01
LAST	

PLEASE PRINT CLEARLY - USE BLACK PENCIL

CUSTOMER INSTRUCTIONS		KEYPUNCH INSTRUCTIONS		CUSTOMER	
1. ENTER DATA LEGIBLY WITHIN SPACES PROVIDED		☒ PUNCH 1 CARD PER HAND POSTED LINE ITEM		DATE 7-29-69	
2. ENTER DATA BETWEEN 1=1, 0=0, 9=9, 8=8, 7=7, 6=6, 5=5, 4=4, 3=3, 2=2, 1=1		PUNCH ALL * LINES WHETHER POSTED OR NOT. IF NECESSARY PROVIDE BLANK CARDS		JOB NO. B64106	
3. All Data Names must be left adjusted		PUNCH ALL * LINES THAT ARE HAND POSTED		PROGRAMMER	
		PUNCH INCLUDING SPACES		TITLE	
		ALL SPACES MAY BE IGNORED		FORM APPROVED (KEY PUNCH)	
		ALL SPACES MAY BE IGNORED EXCEPT ON 1 CARD		DATE	
		ALL SPACES MAY BE IGNORED EXCEPT (Specify only)			
		ALL SIGNS AND SP LINES MUST BE PUNCHED			
		DO NOT PUNCH PRE-PRINTED SIGNS SHOWN AFTER LAST HANDWRITTEN VALUE ENTRY			
		☒ USE 240 SYMBOLS			

EXAMPLE OF THE CORRESPONDING INPUT REQUIRED.		DATE INPUT SHEET	
AGAT 01	30	AGAT 02	AGAT 03
AGAT 02	30	AGAT 04	AGAT 05
AGAT 03	10.08	AGAT 06	AGAT 07
AGAT 04	21	AGAT 08	AGAT 09
AGAT 05	02	AGAT 10	HAUSE 1
AGAT 06	102	COMP 01	COMP 02
AGAT 07	02	COMP 03	COMP 04
AGAT 08	21	COMP 05	COMP 06
AGAT 09	11	COMP 07	COMP 08
AGAT 10	21	COMP 09	COMP 10
AGAT 11	21	COMP 11	COMP 12
AGAT 12	220	COMP 13	COMP 14
AGAT 13	02	COMP 15	COMP 16
AGAT 14	11	COMP 17	COMP 18
AGAT 15	02	COMP 19	COMP 20
AGAT 16	01.2	COMP 21	COMP 22
AGAT 17	02	COMP 23	COMP 24
PRINT			
LAST			
	0.50		
	0.35		
	0.20		
	0.45		

PLEASE PRINT CLEARLY - USE BLACK PENCIL

TEST TREE FOR PROGRAM TRACE

COMPONENT NAMES AND DEGRADILITIES TIMES 10 TO THE 6TH POWER

1	COMP01	0.500000E 01	2	COMP02	0.500000E 01	3	COMP03	0.500000E 01	4	COMP04	0.500000E 01
5	COMP05	0.500000E 01	6	COMP06	0.500000E 01	7	COMP07	0.700000E 01	8	COMP08	0.350000E 02
9	COMP09	0.350000E 02	10	COMP10	0.350000E 02	11	COMP11	0.350000E 02	12	COMP12	0.700000E 01
13	COMP13	0.700000E 01									

APPENDIX B

TEST TREE FOR PROGRAM TRACE

HOUSE NAME AND DEGRADABILITY ASSIGNED

1 HOUSE1 1.0

IMMEDIATE GATES AND DEGRADABILITY ASSIGNED

1 IGATE01 0.00

2 IGATE02 0.20

TOTAL NUMBER OF GATES IS 17
NUMBER OF GATES WITH DEGRADABILITY IS 2

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NO.	GATE	FED BY THESE GATES								FED BY THESE COMPONENTS							
		1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
1	RGAT01	RGAT02	IGAT03	AGAT04													
2	RGAT02	AGAT05	RGAT06	AGAT07													
3	IGAT03	RGAT08															
4	AGAT04	RGAT09	RGAT10							HOUSE1							
5	AGAT05									COMP01	COMP03						
6	RGAT06									COMP01	COMP02						
7	AGAT07									COMP02	COMP03						
8	RGAT08	RGAT12	RGAT11							COMP04							
9	RGAT09	RGAT13								COMP05							
10	RGAT10		AGAT17							COMP06							
11	RGAT12	RGAT15	AGAT14														
12	RGAT11	AGAT17	IGAT16														
13	AGAT13									COMP07	COMP13						
14	AGAT17									COMP12	COMP17						
15	IGAT16									COMP11							
16	AGAT14	AGAT17								COMP09							
17	RGAT15									COMP10	COMP08						

[illegible]

TEST TREE FOR PROGRAM TRACE

CASE NUMBER 1
FORCING PARAMETER IS C.400000

NOTE.....ASTERISKS AFTER CUTSET NO. IN TABLE BELOW INDICATE CASE OR MORE PRIORITY GATES IS INCLUDED IN FAILURE PATH.

***** FAILED GATES FOR ITH MINIMAL CUTSET *****

CUTSET NO.	NO. OF GATES	GATE NAMES				
1	1	RGAT01	IGAT02	RGAT08		
2	5	RGAT01	IGAT03	RGAT08	RGAT11	IGAT16
3	1	RGAT01	RGAT02	AGAT05		
4*	3	RGAT01	RGAT02	RGAT06		
5	5	RGAT01	IGAT03	RGAT08	RGAT11	AGAT17

TEST TREE FOR PROGRAM TRACE

CASE NUMBER 1
FORCING PARAMETER IS C.400000

NOTE.....ASTERISKS AFTER CUTSET NO. IN TABLE BELOW INDICATE CASE OR MORE PRIORITY GATES IS INCLUDED IN FAILURE PATH.

***** MINIMAL CUTSETS WITH 10 OR LESS COMMENTS *****

CUTSET NO.	CUTSET NO.	PROBABILITY OF FAILURE	NO. OF OCCURRENCES	COMMENTS	
1	2	0.298162E-03	10	CC0011	
2	1	0.297480E-03	9	CC0006	
3	2	0.124133E-04	2	CC0001	CC0033
4	4*	0.120133E-04	1	CC0001	CC0002
5	5	0.202100E-04	1	CC0012	CC0013

TEST TYPE FOR PROGRAM TRACE

CASE NUMBER 1
FORCING PARAMETER IS 0.400000

***** SUMMARY DATA FOR CASE NUMBER 1 *****

NUMBER OF TRIALS COMPLETED = 200
NUMBER OF SYSTEM FAILURES = 27
PERCENT OF SYSTEM FAILURES = 13.5%
NO. ADDITIONAL SYSTEM FAILURES = 0 (COVER 10 COME. IN MINIMAL CUTSET - NOT INCLUDED IN ABOVE FAILURE COUNT)
NO. OF DISTINCT MINIMAL CUTSETS = 4

ESTIMATE BASED ON MINIMAL CUTSETS
PROBABILITY OF SYSTEM FAILURE = 0.713400E-03

ESTIMATES BASED ON IMPORTANCE SAMPLING
PROBABILITY OF SYSTEM FAILURE = 0.655440E-03
VARIANCE OF ABOVE ESTIMATE = 0.171153E-07
STANDARD ERROR OF ESTIMATE = 0.130853E-03

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APPENDIX B

TEST TYPE FOR PROGRAM TRACE

CASE NUMBER 2
FORCING PARAMETER IS 0.300000

NOTE.....ASTERISKS AFTER CUTSETS NO. IN TABLE BELOW INDICATE ONE OR MORE PRIORITY GATES IS INCLUDED IN FAILURE PATH.

***** FAILED GATES FOR 1TH MINIMAL CUTSET *****

CUTSET NO.	NO. OF GATES	GATE NAMES
1	5	RGAT01 IGAT02 RGAT03 RGAT04 IGAT05
2	3	RGAT01 IGAT03 RGAT04
3	3	RGAT01 RGAT02 AGAT07
4*	3	RGAT01 RGAT02 RGAT03
5	3	RGAT01 RGAT02 AGAT05

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TEST TREE FOR PROGRAM TRACE

CASE NUMBER 3
 SENSING PARAMETER IS C.300000

NOTE.....ASTERISK AFTER CUTSET NO. IN TABLE BELOW INDICATE ONE OR MORE PRIORITY GATES IS INCLUDED IN FAILURE PATH.

***** FAILURE GATES FOR 1TH MINIMAL CUTSET 00000 *****

CUTSET NO.	NO. OF GATES	GATE NAMES
1	3	RGATCH1 RGATCH2 RGATCH3
2	5	RGATCH1 RGATCH2 RGATCH3 RGATCH4 RGATCH5
3	3	RGATCH1 RGATCH2 AGATCH
4	3	RGATCH1 RGATCH2 AGATCH
5	3	RGATCH1 RGATCH2 RGATCH3
6	5	RGATCH1 RGATCH2 RGATCH3 RGATCH4 AGATCH

TEST TREE FOR PROGRAM TRACE

CASE NUMBER 3
 SENSING PARAMETER IS C.300000

NOTE.....ASTERISK AFTER CUTSET NO. IN TABLE BELOW INDICATE ONE OR MORE PRIORITY GATES IS INCLUDED IN FAILURE PATH.

***** MINIMAL CUTSETS WITH 10 OR LESS COMPONENTS *****

CUTSET NO.	CUTSET NO.	PROBABILITY OF FAILURE	NO. OF OCCURRENCES	COMPONENTS
1	2	0.358167E-03	29	CC0011
2	1	0.287402E-03	17	CC0000
3	3	0.125127E-04	8	CC0001 CC0003
4	4	0.125127E-04	3	CC0002 CC0003
5	5	0.125127E-04	1	CC0001 CC0002
6	6	0.202100E-03	1	CC0012 CC0013

TEST TAP FOR PROGRAM TRACE

CASE NUMBER 1
FORCING PARAMETER IS 0.000000

00000 SUMMARY DATA FOR CASE NUMBER 1 00000

NUMBER OF TRIALS COMPLETED = 200
NUMBER OF SYSTEM FAILURES = 40
PERCENT OF SYSTEM FAILURES = 20.00
NO. OF DISTINCT MINIMAL CUTSETS = 6
COVER 10 COMB. IN MINIMAL CUTSET - NOT INCLUDED IN ABOVE FAILURE COUNT

ESTIMATE BASED ON MINIMAL CUTSET
PROBABILITY OF SYSTEM FAILURE = 0.72640E-03

ESTIMATES BASED ON IMPORTANCE SAMPLING
PROBABILITY OF SYSTEM FAILURE = 0.60000E-03
VARIANCE OF ABOVE ESTIMATE = 0.17251E-07
STANDARD ERROR OF ESTIMATE = 0.11512E-03

APPENDIX B

TEST TAP FOR PROGRAM TRACE

CASE NUMBER 2
FORCING PARAMETER IS 0.000000

NOTE.....ASTERISKS AFTER CUTSET NO. IN TABLE BELOW INDICATE ONE OR MORE PRIORITY GATES IS INCLUDED IN FAILURE PATH.

00000 FAILED GATES FOR 1TH MINIMAL CUTSET 00000

CUTSET NO.	NO. OF GATES	GATE NAMES
1	3	RGATC1 IGATC2 RGATC6
2	5	RGATC1 IGATC2 RGATC6 RGAT11 AGAT17
3	5	RGATC1 IGATC2 RGATC6 RGAT11 IGAT16
4	3	RGATC1 RGATC2 RGATC6
5	4	RGATC1 RGATC2 AGATC7

APPENDIX B

TEST TREE FOR PROGRAM TRACE

CASE NUMBER 4
FORCING PARAMETER IS C.450000

NOTE: LASTED ISMS AFTER CUTSET NO. IN TABLE BELOW INDICATE ONE OR MORE PRIORITY GATES IS INCLUDED IN FAILURE PATH.

***** MINIMAL CUTSETS WITH 10 OR LESS COMPONENTS *****

CUTSET RANK	CUTSET NO.	PROBABILITY OF FAILURE	NO. OF OCCURRENCES	COMPONENTS
1	1	0.130147E-03	5	COMP11
2	2	0.130147E-03	4	COMP04
3	3	0.130147E-03	1	COMP01 COMP02
4	4	0.130147E-03	1	COMP02 COMP03
5	5	0.130147E-03	1	COMP12 COMP13

TEST TREE FOR PROGRAM TRACE

CASE NUMBER 4
FORCING PARAMETER IS C.450000

***** SUMMARY DATA FOR CASE NUMBER 4 *****

NUMBER OF TOTALS COMPLETED = 200
NUMBER OF SYSTEM FAILURES = 15
PERCENT OF SYSTEM FAILURES = 7.5
NO. ADDITIONAL SYSTEM FAILURES = 0 (OVER 10 COMP. IN MINIMAL CUTSET - NOT INCLUDED IN ABOVE FAILURE COUNT)
NO. OF DISTINCT MINIMAL CUTSETS = 5

ESTIMATE BASED ON MINIMAL CUTSETS
PROBABILITY OF SYSTEM FAILURE = 0.713460E-03

ESTIMATES BASED ON IMPORTANCE SAMPLING
PROBABILITY OF SYSTEM FAILURE = 0.056707E-03
VARIANCE OF ABOVE ESTIMATE = 0.004736E-07
STANDARD ERROR OF ESTIMATE = 0.002176E-03

CHANGE OF CONTROL CATE.

NUMBER OF TRIALS = 300
RANDOM NO. CONSTANT = 12485
MISSION LENGTH = 720.0

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APPENDIX B

TEST TREE FOR PROGRAM TRACE

CASE NUMBER 2
FORCING PARAMETER IS C.400000

NOTE.....ASTERISKS AFTER CATEGORIES NO. IN TABLE BELOW INDICATE CASE OR CASE PRIORITY CATES IS INCLUDED IN FAILURE PATH.

***** FAILED STATES FOR 1TH MEDICAL CUTSET *****

CUTSET NO. NO. OF CATES

CATE NAMES

1	3	RGATC1	IGATC2	RGATC8		
2	5	RGATC1	IGATC2	RGATC8	RSAT11	IGAT16
3	3	RGATC1	RGATC2	AGATC5		
4	3	RGATC1	RGATC2	RGATC6		
5	5	RGATC1	IGATC2	RGATC8	RSAT11	AGAT17
6	3	RGATC1	RGATC2	AGATC7		

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APPENDIX B

TEST TREE FOR PROGRAM TRACE

CASE NUMBER 5
FORCING PARAMETER IS 0.400000

NOTE.....ASTERISKS AFTER CUTSET NO. IN TABLE BELOW INDICATE ONE OR MORE PRIORITY GATES IS INCLUDED IN FAILURE PATH.

***** MINIMAL CUTSETS WITH 10 OR LESS COMPONENTS *****

CUTSET RANK	CUTSET NO.	PROBABILITY OF FAILURE	NO. OF OCCURRENCES	COMPONENTS
1	2	0.358168E-03	28	CCMP11
2	1	0.387480E-03	16	CCMP04
3	7	0.129137E-04	3	CCMP01 CCMP03
4	40	0.129137E-04	2	CCMP01 CCMP02
5	6	0.129137E-04	1	CCMP02 CCMP03
6	5	0.902190E-04	1	CCMP12 CCMP13

TEST TREE FOR PROGRAM TRACE

CASE NUMBER 5
FORCING PARAMETER IS 0.400000

***** SUMMARY DATA FOR CASE NUMBER 5 *****

NUMBER OF TRIALS COMPLETED = 300
NUMBER OF SYSTEM FAILURES = 48
PERCENT OF SYSTEM FAILURE = 16.00
NO. ADDITIONAL SYSTEM FAILURES = 0 (OVER 10 COMPS. IN MINIMAL CUTSET - NOT INCLUDED IN ABOVE FAILURE COUNT)
NO. OF DISTINCT MINIMAL CUTSETS = 6

ESTIMATE BASED ON MINIMAL CUTSETS
PROBABILITY OF SYSTEM FAILURE = 0.726403E-03

ESTIMATES BASED ON IMPORTANCE SAMPLING
PROBABILITY OF SYSTEM FAILURE = 0.116470E-02
VARIANCE OF ABOVE ESTIMATE = 0.286219E-07
STANDARD ERROR OF ESTIMATE = 0.169180E-03

TEST TREE FOR PROGRAM TRACE

CASE NUMBER 1
PRIORITY PARAMETER IS C.1234567
NOTE.....ASTERISKS AFTER CUTSET NO. IN TABLE BELOW INDICATE ONE OR MORE PRIORITY GATES IS INCLUDED IN FAILURE PATH.

***** FAILED GATES FOR 1TH MINIMAL CUTSET *****

CUTSET NO.	NO. OF GATES	GATE NAMES					
1	1	RGATE1	IGATE1	RGATE1			
2	4	RGATE1	IGATE1	RGATE1	RGATE1	IGATE1	
3	1	RGATE1	IGATE1	RGATE1			
4	3	RGATE1	RGATE1	RGATE1			
5	1	RGATE1	IGATE1	RGATE1			

TEST TREE FOR PROGRAM TRACE

CASE NUMBER 1
PRIORITY PARAMETER IS C.1234567
NOTE.....ASTERISKS AFTER CUTSETS NO. IN TABLE BELOW INDICATE ONE OR MORE PRIORITY GATES IS INCLUDED IN FAILURE PATH.

***** MINIMAL CUTSETS WITH 10 OR LESS COMPONENTS *****

CUTSET NO.	NO. OF GATES	PROBABILITY OF FAILURE	NO. OF OCCURRENCES	COMPONENTS	
1	2	0.158142E-03	25	CCMP11	
2	1	0.287480E-03	27	CCMP04	
3	2	0.129123E-04	4	CCMP01	CCMP03
4	4	0.129123E-04	4	CCMP02	CCMP03
5	3	0.129123E-04	2	CCMP01	CCMP02

TEST TREE FOR PROGRAM TRACE

CASE NUMBER
PENDING PARAMETER IS C.120000

00000 SUMMARY DATA FOR CASE NUMBER 0 00000

NUMBER OF TOTALS COMPLETED 300
NUMBER OF SYSTEM FAILURES 54
PERCENT OF SYSTEM FAILURE 18.0%
NO. OF DISTINCT MINIMAL CUTSETS 5
COVER TO COMP. IN MINIMAL CUTSET - NOT INCLUDED IN ABOVE FAILURE COUNT

ESTIMATE BASED ON MINIMAL CUTSETS
PROBABILITY OF SYSTEM FAILURE 0.124300E-01

ESTIMATES BASED ON IMPORTANCE SAMPLING
PROBABILITY OF SYSTEM FAILURE 0.000350E-03
VARIANCE OF ABOVE ESTIMATE 0.140160E-07
STANDARD ERROR OF ESTIMATE 0.116701E-03

APPENDIX B

TEST TREE FOR PROGRAM TRACE

CASE NUMBER
PENDING PARAMETER IS C.120000

NOTE.....SYSTEMS AFTER CUTSET NO. IN TABLE BELOW INDICATE ONE OR MORE PRIORITY GATES IS INCLUDED IN FAILURE PATH.

00000 FAILED GATES FOR 1TH MINIMAL CUTSET 00000

CUTSET NO.	NO. OF GATES	GATE NAMES					
1	4	RGATC1	IGATC2	RGATC8	RGAT11	IGAT16	
2	3	RGATC1	RGATC2	AGATC7			
30	3	RGATC1	RGATC2	PGATC6			
4	3	RGATC1	IGATC3	RGATC8			
5	3	RGATC1	RGATC2	AGATC6			
60	5	RGATC1	AGATC4	RGATC6	RGAT19	AGAT13	
7	5	RGATC1	IGATC3	RGATC8	RGAT11	AGAT17	

APPENDIX B

TEST TREE FOR PROGRAM TRACE

CASE NUMBER 7
FORCING PARAMETER IS C.3C9CC0

NOTE.....ADDITIONAL CUTSET NO. IN TABLE BELOW INDICATE CUT OR MORE PRIORITY GATES IS INCLUDED IN FAILURE PATH.

***** MINIMAL CUTSETS WITH 10 OR LESS COMPONENTS *****					
CUTSET NAME	CUTSET NO.	PROBABILITY OF FAILURE	NO. OF OCCURRENCES	COMPONENTS	
1	1	0.390122E-03	53	CCMP11	
2	4	0.387400E-03	40	CCMP04	
3	30	0.129133E-04	5	CCMP01	CCMP02
4	8	0.129133E-04	3	CCMP01	CCMP07
5	2	0.129133E-04	4	CCMP02	CCMP03
6	7	0.302109E-02	4	CCMP12	CCMP13
7	00	0.390122E-03	2	CCMP05	CCMP06 CCMP07 CCMP13

APPENDIX B

TEST TREE FOR PROGRAM TRACE

CASE NUMBER 7
FORCING PARAMETER IS C.3C0CC0

***** SUMMARY DATA FOR CASE NUMBER 7 *****

NUMBER OF TRIALS COMPLETED = 700
NUMBER OF SYSTEM FAILURES = 113
PERCENT OF SYSTEM FAILURE = 37.67
NO. ADDITIONAL SYSTEM FAILURES = 3 (100% TO COMP. IN MINIMAL CUTSET - NOT INCLUDED IN ABOVE FAILURE COUNT)
NO. OF DISTINCT MINIMAL CUTSETS = 7

ESTIMATE BASED ON MINIMAL CUTSETS
PROBABILITY OF SYSTEM FAILURE = 0.724403E-03

ESTIMATES BASED ON IMPORTANCE SAMPLING
PROBABILITY OF SYSTEM FAILURE = 0.111010E-02
VARIANCE OF ABOVE ESTIMATE = 0.100000E-07
STANDARD ERROR OF ESTIMATE = 0.100000E-03

APPENDIX B

TEST TREE FOR PROGRAM TRACE

CASE NUMBER 8
FORCING PARAMETER IS C.45CC0C

NOTE.....ASTERISKS AFTER CUTSET NO. IN TABLE BELOW INDICATE ONE OR MORE PRIORITY GATES IS INCLUDED IN FAILURE PATH.

***** FAILED GATES FOR 1TH MINIMAL CUTSET *****

CUTSET NO.	NO. OF GATES	GATE NAMES				
1	5	RGAT01	IGAT03	RGAT08	RGAT11	IGAT16
2	3	RGAT01	IGAT03	RGAT08		
3	5	RGAT01	IGAT03	RGAT08	RGAT11	AGAT17
40	3	RGAT01	RGAT02	RGAT08		

APPENDIX B

TEST TREE FOR PROGRAM TRACE

CASE NUMBER 8
FORCING PARAMETER IS C.45CC0C

NOTE.....ASTERISKS AFTER CUTSET NO. IN TABLE BELOW INDICATE ONE OR MORE PRIORITY GATES IS INCLUDED IN FAILURE PATH.

***** MINIMAL CUTSETS WITH 10 OR LESS COMPONENTS *****

CUTSET NAME	CUTSET NO.	PROBABILITY OF FAILURE	NO. OF OCCURRENCES	COMPONENTS	
1	1	0.398168E-01	6	CC0011	
2	2	0.287405E-03	12	CC0004	
3	4*	0.189123E-04	1	CC0001	CC0002
4	3	0.208109E-08	1	CC0012	CC0013

APPENDIX B

CASE NUMBER =
FORCING PARAMETER IS 0.497000

***** SUMMARY DATA FOR CASE NUMBER 2 *****

NUMBER OF TRIALS COMPLETED = 300
NUMBER OF SYSTEM FAILURES = 20
PERCENT OF SYSTEM FAILURES = 6.67
NO. ADDITIONAL SYSTEM FAILURES = 0 (COVER 10 COME. IN MINIMAL CUTSET - NOT INCLUDED IN ABOVE FAILURE COUNT)
NO. OF DISTINCT MINIMAL CUTSETS = 4

ESTIMATE BASED ON MINIMAL CUTSETS
PROBABILITY OF SYSTEM FAILURE = 0.700577E-03

ESTIMATES BASED ON IMPORTANCE SAMPLING
PROBABILITY OF SYSTEM FAILURE = 0.730217E-03
VARIANCE OF ABOVE ESTIMATE = 0.274551E-07
STANDARD ERROR OF ESTIMATE = 0.165702E-03

TEST TYPE FOR PROGRAM TRACE

CHANGE OF CONTROL CASE

NUMBER OF TRIALS = 300
RANDOM NO. CONSTANT = 74463
MISSION LENGTH = 1000.0

TEST TREE FOR PROGRAM TRACE

CASE NUMBER 0
FORCING PARAMETER IS C.400000

NOTE.....ASTERISKS AFTER CUTSET NO. IN TABLE BELOW INDICATE ONE OR MORE PRIORITY GATES IS INCLUDED IN FAILURE PATH.

***** FAILED GATES FOR ITM MINIMAL CUTSET *****

CUTSET NO.	NO. OF GATES	GATE NAMES				
1	3	RGAT01	RGAT02	AGAT07		
2	5	RGAT01	IGAT03	RGAT02	RGAT11	IGAT10
3	3	RGAT01	IGAT03	RGAT02		
4	3	RGAT01	RGAT02	AGAT02		
5	5	RGAT01	IGAT03	RGAT02	RGAT11	AGAT17

TEST TREE FOR PROGRAM TRACE

CASE NUMBER 0
FORCING PARAMETER IS C.400000

NOTE.....ASTERISKS AFTER CUTSET NO. IN TABLE BELOW INDICATE ONE OR MORE PRIORITY GATES IS INCLUDED IN FAILURE PATH.

***** MINIMAL CUTSETS WITH 10 OR LESS COMPONENTS *****

CUTSET NO.	CUTSET NO.	PRIORITY OF FAILURE	NO. OF OCCURRENCES	COMPONENTS	
1	2	0.9503122-03	29	CCMP11	
2	3	0.3990032-03	15	CCMP04	
3	1	0.2497222-04	3	CCMP02	CCMP03
4	4	0.7487222-04	2	CCMP01	CCMP03
5	5	0.3872222-05	1	CCMP12	CCMP13

TEST TREE FOR PROGRAM TRACE

CASE NUMBER 10
FORCING PARAMETER IS C.100000

***** SUMMARY DATA FOR CASE NUMBER 10 *****

NUMBER OF TOTALS COMPLETED 1 100
NUMBER OF SYSTEM FAILURES 1 10
NUMBER OF SYSTEM FAILURES 1 10
NO. ADDITIONAL SYSTEM FAILURES 1 10
NO. OF DISTINCT MINIMAL CUTSETS 1 10
C (OVER 10 COMP. IN MINIMAL CUTSET - NOT INCLUDED IN ABOVE FAILURE COUNT)

ESTIMATE BASED ON MINIMAL CUTSETS
COMPARISON OF SYSTEM FAILURE = C.100000-00

ESTIMATE BASED ON IMPORTANCE SAMPLING
COMPARISON OF SYSTEM FAILURE = C.155750F-00
VARIANCE OF ABOVE ESTIMATE = C.455750F-00
STANDARD ERROR OF ESTIMATE = C.213750F-00

APPENDIX B

TEST TREE FOR PROGRAM TRACE

CASE NUMBER 10
FORCING PARAMETER IS C.100000

NOTE.....ASTERISKS AFTER CUTSET NO. IN TABLE BELOW INDICATE ONE OR MORE PRIORITY GATES IS INCLUDED IN FAILURE PATH.

***** FAILED GATES FOR EACH MINIMAL CUTSET *****

CUTSET NO.	NO. OF GATES	GATE NAMES
1	1	PGATC1 PGATC2 AGATC7
2	5	PGATC1 IGATC3 PGATC2 PGATC11 AGATC7
3	3	PGATC1 PGATC2 AGATC8
4	3	PGATC1 IGATC3 PGATC2
5	5	PGATC1 IGATC3 PGATC2 PGATC11 IGATC6
6	1	PGATC1 PGATC2 PGATC3

APPENDIX B

TEST CASE FOR PROGRAM TRACE

CASE NUMBER 10
FORCING PARAMETER IS C.300000

NOTE.....CUTSETS WITH PRIORITY NO. 15 TABLE BELOW INDICATE ONE OR MORE PRIORITY CATE IS INCLUDED IN FAILURE PATH.

***** MINIMAL CUTSET WITH 15 OR LESS COMPONENTS *****					
CUTSET NO.	CUTSET NO.	PROBABILITY OF FAILURE	NO. OF COMPONENTS	COMPONENTS	
1	9	0.000000E-03	10	CC0011	
2	6	0.000000E-07	24	CC0004	
3	1	0.000000E-04	8	CC0002 CC0003	
4	3	0.000000E-04	8	CC0001 CC0003	
5	00	0.000000E-04	4	CC0001 CC0002	
6	2	0.000000E-04	4	CC0012 CC0013	

APPENDIX B

TEST CASE FOR PROGRAM TRACE

CASE NUMBER 10
FORCING PARAMETER IS C.300000

***** SUMMARY DATA FOR CASE NUMBER 10 *****

NUMBER OF TRIALS COMPLETED = 300
NUMBER OF SYSTEM FAILURES = 83
PERCENT OF SYSTEM FAILURE = 27.67
NO. OF DISTINCT SYSTEM FAILURE PATHS = 9 (OVER 10 COMP. IN MINIMAL CUTSET - NOT INCLUDED IN ABOVE FAILURE COUNT)
NO. OF DISTINCT MINIMAL CUTSETS = 6

ESTIMATE BASED ON MINIMAL CUTSETS
PROBABILITY OF SYSTEM FAILURE = 0.102703E-02

ESTIMATES BASED ON IMPORTANCE SAMPLING
COEFFICIENT OF VARIATION = 0.147330E-02
VARIANCE OF ABOVE ESTIMATE = 0.203600E-07
STANDARD ERROR OF ESTIMATE = 0.102703E-03

APPENDIX B

TEST TREE FOR PROGRAM TRACE

CASE NUMBER 11

FORCING PARAMETER IS C.300000

NOTE.....ANTHROPS AFTER CUTSET NO. IN TABLE BELOW INDICATE ONE OR MORE PRIORITY GATES IS INCLUDED IN FAILURE PATH.

***** FAILED GATES FOR 1TH DUTY SET *****

CUTSET NO. NO. OF GATES

GATE NAMES

1	3	RGAT01	RGAT02	AGAT07
2	1	RGAT01	IGAT02	RGAT02
3	5	RGAT01	IGAT02	RGAT03
40	3	RGAT01	RGAT02	RGAT06
5	5	RGAT01	IGAT02	RGAT03
6	1	RGAT01	RGAT02	AGAT09

APPENDIX B

TEST TREE FOR PROGRAM TRACE

CASE NUMBER 11

FORCING PARAMETER IS C.300000

NOTE.....ANTHROPS AFTER CUTSET NO. IN TABLE BELOW INDICATE ONE OR MORE PRIORITY GATES IS INCLUDED IN FAILURE PATH.

***** DUTY SET CUTSETS WITH 10 OR LESS COMPONENTS *****

CUTSET NO.	CUTSET NO.	PROBABILITY OF FAILURE	NO. OF OCCURRENCES	COMPONENTS
1	3	0.999999-03	46	CC0011
2	2	0.999999-03	36	CC0004
3	1	0.999999-04	12	CC0002 CC0003
4	6	0.999999-04	6	CC0001 CC0003
5	40	0.999999-04	3	CC0001 CC0002
6	5	0.999999-05	7	CC0012 CC0013

APPENDIX B

TEST TAP FOR PROGRAM TRACE

CASE NUMBER 11
FORCING PARAMETER IS C.100000

***** SUMMARY DATA FOR CASE NUMBER 11 *****

NUMBER OF TRIALS COMPLETED = 300
NUMBER OF SYSTEM FAILURES = 110
PERCENT OF SYSTEM FAILURES = 36.67
NO. OF DISTINCT SYSTEM FAILURE CLUSTERS = 2 (OVER 10 COMP. IN MINIMAL CUTSET - NOT INCLUDED IN ABOVE FAILURE COUNT)
NO. OF DISTINCT MINIMAL CUTSETS = 6

ESTIMATE BASED ON MINIMAL CUTSETS
PROBABILITY OF SYSTEM FAILURE = 0.10783E-02

ESTIMATES BASED ON IMPORTANCE SAMPLING
PROBABILITY OF SYSTEM FAILURE = 0.13488E-02
VARIANCE OF ABOVE ESTIMATE = 0.15028E-07
STANDARD ERROR OF ESTIMATE = 0.12266E-03

APPENDIX B

TEST TAP FOR PROGRAM TRACE

CASE NUMBER 12
FORCING PARAMETER IS C.000000

NOTE.....ASTERISK IN CUTSET NO. IN TABLE BELOW INDICATE ONE OR MORE PRIORITY GATES IS INCLUDED IN FAILURE PATH.

***** FAILED GATES FOR THE MINIMAL CUTSET *****

CUTSET NO.	NO. OF GATES	GATE NAMES				
1	4	PGATC1	IGATC2	RGATC2	QGAT11	IGAT16
2	3	PGATC1	IGATC2	RGATC2		
3	3	PGATC1	RGATC2	AGATC7		
4	3	PGATC1	QGAT08	RGATC2		
5	5	PGATC1	IGATC2	RGATC2	QGAT11	AGAT17

APPENDIX B

CASE NUMBER 12
FORCING PARAMETER IS C.490000

NOTE.....AFTER THIS AFTER CUTSET NO. IN TABLE BELOW INDICATE ONE OR MORE PRIORITY GATES IS INCLUDED IN FAILURE PATH.

***** MINIMAL CUTSETS WITH 10 OR LESS COMPONENTS *****

CUTSET RANK	CUTSET NO.	PROBABILITY OF FAILURE	NO. OF INCURRENCES	COMPONENTS
1	1	0.220713E-03	22	COMP11
2	2	0.259003E-03	8	COMP04
3	3	0.248722E-04	4	COMP02 COMP03
4	4	0.248722E-04	2	COMP01 COMP02
5	5	0.248722E-04	2	COMP12 COMP13

APPENDIX B

TEST TEST FOR PROGRAM TRACE

CASE NUMBER 12
FORCING PARAMETER IS C.490000

***** SUMMARY DATA FOR CASE NUMBER 12 *****

NUMBER OF TRIALS COMPLETED = 300
NUMBER OF SYSTEM FAILURES = 12
PERCENT OF SYSTEM FAILURES = 12.00
NO. ADDITIONAL SYSTEM FAILURES = 0 (OVER 10 COMPS. IN MINIMAL CUTSET - NOT INCLUDED IN ABOVE FAILURE COUNT)
NO. OF DISTINCT MINIMAL CUTSETS = 5

ESTIMATE BASED ON MINIMAL CUTSETS
PROBABILITY OF SYSTEM FAILURE = C.100294E-02

ESTIMATES BASED ON IMPORTANCE SAMPLING
PROBABILITY OF SYSTEM FAILURE = C.16079E-02
VARIANCE OF ABOVE ESTIMATE = C.71946E-07
STANDARD ERROR OF ESTIMATE = C.26822E-03

APPENDIX B