MASTER

**HUMAN FACTORS ANALYSIS
AND DESIGN METHODS
FOR NUCLEAR WASTE
RETRIEVAL SYSTEMS**

VOLUME III

**USER'S GUIDE FOR THE COMPUTERIZED
EVENT-TREE ANALYSIS TECHNIQUE**

AUGUST 1980

Submitted to:

**Lawrence Livermore National Laboratory
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DESIGN METHODS FOR
NUCLEAR WASTE RETRIEVAL SYSTEMS
VOLUME III
USER'S GUIDE FOR THE COMPUTERIZED
EVENT-TREE ANALYSIS TECHNIQUE

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SECTION I

INTRODUCTION

This document provides detailed instructions for using the Computerized Event-Tree Analysis Technique (CETAT), a program designed to assist a human factors analyst in predicting event probabilities in complex man-machine configurations found in waste retrieval systems. The instructions contained herein describe how to (a) identify the scope of a CETAT analysis, (b) develop operator performance data, (c) enter an event-tree structure, (d) modify a data base, and (e) analyze event paths and man-machine system configurations.

Designed to serve as a tool for developing, organizing, and analyzing operator-initiated event probabilities, CETAT simplifies the tasks of the experienced systems analyst by organizing large amounts of data and performing cumbersome and time consuming arithmetic calculations. The principal uses of CETAT in the waste retrieval development project will be to develop models of system reliability and evaluate alternative equipment designs and operator tasks. As with any automated technique, however, the value of the output will be a function of the knowledge and skill of the analyst using the program.

This document is one of four volumes of a series which, together, outline the role of human factors in the design of a waste retrieval system. **Volume I, Human Factors Design Methodology and Integration Plan**, describes the role of human factors engineering during the development of the waste retrieval system. **Volume II, A Compendium of Human Factors Design Data**, contains data on the design of system hardware which may be used in the waste depository and the waste retrieval equipment. **Volume III, Users Guide for the Computerized Event-Tree Analysis Technique** (this document), outlines the procedures for performing an event-tree analysis using CETAT. A detailed description of CETAT is provided in **Volume IV, Computerized Event-Tree Analysis Technique**. Together, these four documents provide an overview of a human factors design methodology which should be followed during the development of the waste retrieval system, and supply guidelines and data for the design of equipment which will be operated and/or used by human operators.

BACKGROUND

CETAT is a computer-based technique which allows a systems analyst, in particular, a human factors engineer experienced in evaluating operator reliability in man-machine systems, to calculate the probability of selected event sequences involving the predicted actions of a human operator. When in operation on an IBM 5120 or similar minicomputer, CETAT interacts with the analyst by assisting in the construction of an event-tree data base. The program then directs the analyst while he or she examines the probability and time parameters associated with selected event paths. By requiring the analyst to select the path to be analyzed at each branch in the event tree, any paths in the tree can be studied. The output of an event-path analysis is (a) the probability that the event path will be taken, given the originating state of the system, and (b) the total amount of time required to reach this ending system state if the described path has been taken.

The program, principally a tool to simplify and accelerate the process of identifying and analyzing event paths, has been designed to assist in analyzing particularly lengthy event trees. Therefore, its value is derived from its basis as an organizational tool and a method by which an analyst can manipulate, examine, and analyze large bodies of event-tree data.

Three central requirements of the waste retrieval development effort necessitated the creation of an automated event-tree analysis technique. First, the reliability analyses developed by Hudson and McCleery (1979) in the initial waste retrieval system development documents call for data on human error rate probabilities in a number of man-machine settings. Hence, a technique for generating the event probabilities associated with specific operator tasks was necessary. Secondly, a plan for performing in-depth analyses of human operator tasks and actions in waste retrieval subsystems was also needed. A methodology for analyzing event sequences, event probabilities, and task durations was seen as one means of evaluating operator tasks and work requirements. Thirdly, a technique which would simplify the design evaluation process and assist in identifying improperly designed man-machine interfaces was also required. An event-tree technique which would help the analyst evaluate man-machine configurations and predict the effects of changes to the system was seen as being of

significant value. In summary, it was determined that a computerized event-tree analysis technique providing both time and probability estimates of event sequences would best serve the needs of the project.

The central purpose of the event-tree methodology—providing probability values for selected event sequences—requires that data on the probability of assorted operator actions be available for inclusion in the event-tree program. CETAT is unique in that it relies on the human factors analyst to generate these human action probabilities. Although computerized event-tree analysis programs containing a data base of operator reliability values have been developed (Swain, 1964; Swain & Gutmann, 1980; WASH-1400, 1975), these data and the resulting event path probabilities may not accurately predict real-world events. Much of the data on which earlier techniques are based are derived from highly controlled laboratory studies of human error in which tasks are overly simplistic and operators have received very little training. The limitless number of possible operator actions, the complex interactions between actions, and the influence of workplace and job design on task performance are just three reasons why the generalizability of operator reliability data might be questioned. CETAT was developed under the premise that human reliability data is so system specific that the highest level of accuracy in predicting system performance can be obtained if the analyst, who is thoroughly familiar with the system, develops the actual time and event probability values based on his experience and a refined set of guidelines for developing probability values.

PROGRAM OVERVIEW

The purpose of performing an analysis with CETAT is to identify the probability and time values associated with a series of operator actions and the consequential state of the system. This involves developing an event tree of all of the meaningful operator actions within a selected system function, inputting this event-tree information in the system, and analyzing selected system-state/operator action/system-state paths. Figure 1 illustrates, in conceptual form, the structure of a CETAT event tree.

Figure 1. Conceptual diagram of a small CETAT event tree illustrating OPERATOR ACTIONS, SYSTEM STATES, LINKS, and TASKS.

SYSTEM STATES are defined as states of system hardware. Within the traditional decision-tree concept, **SYSTEM STATES** can be thought of as the decision nodes. Each node therefore defines a unique state of the system in which machine and other system components are in different places and positions.

ACTIONS are the actions of the human operator which will result in a change in the state of the system. Within the traditional decision-tree concept operator **ACTIONS** can be thought of as the paths between the decision nodes. Thus, **ACTIONS** are the elements (operator behaviors) which connect, in time, one **SYSTEM STATE** to another **SYSTEM STATE**.

LINKS are units of information consisting of a beginning **SYSTEM STATE**, an operator **ACTION**, and an ending **SYSTEM STATE**. To both input and analyze the data, the event tree is treated as a series of independent but connected **LINKS**.

TASKS are mini-event trees within the larger event tree consisting of a network of **LINKS** in which the operator is attempting to attain a desired system output. A CETAT event tree consists of as many as 99 **TASKS** which serve to organize the analytical effort and help modularize and constrict the branching of the event tree.

PROBABILITY is the likelihood that, given a specific **SYSTEM STATE**, the operator will perform a given operator **ACTION**. It is **not** the probability that a given **ACTION** will result in a given **SYSTEM STATE**. The purpose of CETAT being to model the actions of the human operator, **PROBABILITY** has been selected to represent the likelihood that a given **ACTION** will be taken. Thus, **PROBABILITY** is a function of the skill level of the operator, his or her training, the availability of job aids, the design and placement of controls and displays, other characteristics of the task, and not the reliability of the equipment. One **PROBABILITY** value is selected for each **LINK** within CETAT.

TIME is the estimated time which transpires between the beginning **SYSTEM STATE** and the ending **SYSTEM STATE**. In other terms, it is the approximate time required to get from one node to another. This value is also a function of the design of system hardware, the skill level of the operator, his or her training, the availability of job aids, and the design and placement of controls and displays. A single time value is selected for each **LINK**.

Figure 2 illustrates the four principal steps involved in performing an event-tree analysis using the program. These four processes are described below to provide an overview of the entire technique, and are described in detail in each of the associated sections of this document. The detailed descriptions, in addition to outlining the function of each process, describe how each is to be accomplished and the specific activities required when using the interactive computer system.

EVENT-TREE DEVELOPMENT

The analyst planning to implement CETAT during the analysis of a lengthy series of operator tasks must first develop an event tree which describes, within the limits of a particular analysis, the operator actions of interest or actions with great enough probabilities to merit inclusion in the analysis. Within any event-tree analysis there are, potentially, an infinite number of branches. For the technique to yield valuable information, rational limits must be placed on the number of branches to be included in the tree. In CETAT, the analyst determines which event paths are of great enough importance or high enough probability to be included in the analyses.

Figure 2. Four steps in performing CETAT analysis.

Developing the event tree involves five major steps:

1. Identifying the system function to be studied.
2. Identifying the operator workstation(s).
3. Identifying the operator tasks.
4. Developing the event tree.
5. Developing the probability and time-based data.

A large portion of this information will be available after the analyst has performed the procedures listed under Function Analysis, Task Description, and Task Analysis in **Volume I, Human Factors Design Methodology and Integration Plan** (Casey, 1980b). It is during this time that the analyst must specify the limits of the analysis (usually restricted to a single system function), and define the controls and displays with which operators can interact with the system during execution of this function. Having organized this information, the analyst must develop the actual event tree. This tree may be comprised of as many as 1,000 branches and an equal number of nodes. As with any branching event tree, one objective is to keep the tree within a manageable size. This is accomplished by having branches converge periodically into a limited number of SYSTEM STATES. The analyst must select and define the possible states of the system at the completion of each TASK (or attempted completion of each TASK).

Having defined the event tree, the analyst must now attach time and probability values to each of the possible operator actions. Again, much of this information will be available as part of the products of Task Description and Task Analysis discussed in Volume I. Each SYSTEM STATE (a description of the physical state of the system) has branching from it as many as seven possible operator activities, which, when performed, result in a new state of the system. The time estimates available from the Task Analyses should be integrated with the associated operator actions on the event tree, and the analyst should follow the recommended procedures for arriving at probability values for each operator action. To be as realistic as possible, the training associated with the task, the design of the controls and displays, and the fail-safe systems built into the equipment must all be weighed when developing a numerical value which represents the probability that a given action will be taken by an operator and result in a given state of the system.

DATA INPUT

The procedures to code and input data for CETAT can be performed with a minimal amount of training. The data input program has been designed to interact with the analyst by providing templates for the entry of event-tree data and alternate programs for minimizing the input effort and adding special comments. It is not necessary for the analyst to code event-tree data on coding sheets; the analyst inputs the event-tree characteristics directly into the system while CETAT, in turn, directs the analyst through the data input procedure.

DATA EDITING

The input procedure is capable of being resumed at a later date, and the analyst has the ability to edit and modify the event probability and time data as desired.

The editing procedures are also interactive; CETAT provides the analyst a number of alternatives for restructuring the event tree or modifying time or probability data. The program also provides printouts of the tree and associated data.

EVENT-TREE ANALYSIS

To provide the maximum utility, the analysis program of CETAT is designed to interact with the analyst while an event tree is being examined. Once all data have been entered and edited, the analyst, seated at the terminal, identifies the beginning state of the system. CETAT then identifies the operator actions which branch from this system state. The analyst selects the ACTION path of interest, and the program prints the resulting SYSTEM STATE. The probability of arriving at this SYSTEM STATE within the context of the event tree, and the total time required to reach this particular state of the system, given the preceding events, are displayed. CETAT then displays the possible operator actions emanating from this SYSTEM STATE and the analyst selects the action to be examined. The analyst continues to step through the tree until he has reached the ending SYSTEM STATE of interest. A printout is provided of the path which has been examined and the associated probability and time values.

SECTION II

EVENT-TREE DEVELOPMENT

The actual process of developing the event tree can be performed in one of two ways: (a) while the analyst is entering data into the computer, or (b) prior to entering any data into the computer. It is advisable, however, to graphically portray the event tree prior to starting the data entry procedures, particularly if the analyst is not experienced with the program or the event tree is particularly large (i.e., greater than a few hundred links). Regardless of which of the two methods the analyst chooses to follow, he or she should adhere to the following general procedure when developing the event tree.

STEP 1. IDENTIFY THE SYSTEM FUNCTION TO BE ANALYZED

The initial step in developing an event tree for later analysis with CETAT is to define the scope of the activity to be described. There are a number of variables which place logical constraints on the size of the analysis including the physical limits of the computer and the logical breakdown of system operations into discrete functions. CETAT has been designed to enable the thorough analysis of one system function, a function being a series of operator activities and operator tasks performed for the purpose of fulfilling a system requirement.

Although system functions can be defined at the molar or molecular level, CETAT is capable of handling a detailed analysis of a molar system function. With reference to the waste retrieval system, a system function to be analyzed by the program should be limited to the actions of a single operator located at a single work station, attempting to fulfill a simple system requirement. Within this context, example system functions might be (a) "Install floor flange," (b) "Align CET with floor flange," (c) "Remove canister," (d) "Transport canister," and (e) "Transfer canister to CWSRS".

It is recognized that some functions to be studied will require more than one operator and may take place in more than one work station. Whenever possible, however, the analysis should be defined by the constraints described above. An in-depth discussion of the specification of system functions within the waste retrieval system is discussed in pages 23-60 of Volume I.

STEP 2. IDENTIFY THE OPERATOR WORK STATION

After having identified the system function to be analyzed, part of this process being the specification of the work station from which the function will be enacted, a thorough description of the operator's workspace must be developed. This should include descriptions of the physical dimensions of the workspace and all controls and displays which are in any way related to the execution of the system function.

All relevant engineering drawings, models, and mockups should be acquired and forms drawn up to assist in the evaluation (if they have not been developed at an earlier date). The task information forms developed during Task Analysis (Volume I) should be of particular value, particularly the forms for Task Statements (Figure 3), Task Descriptions (Figure 4), and Operational Sequence Diagrams (Figures 5 and 6).

The analyst should also find it helpful to devise forms with relevant information about each control and display within the workspace. Such a form should contain narrative information on the physical description of a single control, the feedback provided by operation of the control, its functional location, relationships to other workspace elements, and its role in the execution of a task (Figure 7). It is important that this data be critically annotated because part of the purpose of developing the event tree is to determine the effects of improperly positioned and/or designed controls and displays.

STEP 3: IDENTIFY CORRECT TASK SEQUENCE

As a starting point, it is advisable for the analyst to develop task descriptions of the correct sequence of events within the proposed event tree. Again, this information should have been developed during the Task Statement Derivation phase of Preliminary Development (Volume I). If forms similar in content to Figure 3 have been developed and completed, it will be necessary to organize these tasks (forms) in the order in which they are performed.

STEP 4. DEVELOP THE EVENT TREE

The development of the CETAT event tree is a process in which the skills of the analyst are called upon to identify operator actions of consequence and

FUNCTION DESCRIPTION		CHECK ONE	OPERATION	X	TASK NO:
TRANSFER CANISTER TO THE CWSRS			MAINTENANCE SUPPORT		
TASK INFORMATION					
OPERATOR ACTION	OBJECT OF ACTION	PURPOSE OF ACTION			
Moves	CET canister vertical movement control	Lower canister into Canister Transfer Basket			
TASK STATEMENT					
Moves control into position to lower the canister into the Canister Transfer Basket					
PRECEDING TASK					
Observe green indicator light verifying that the Canister Extraction Transporter gate is fully opened.					
FOLLOWING TASK					
Observe (a) status of control to verify operator action, and (b) indicator light indicating that canister has been lowered into the Canister Transfer Basket.					
LOCATION OF TASK PERFORMANCE					
Cab of CET. Operator in voice communication with CWSRS operator.					
SEGMENT OF WORK CYCLE IN WHICH TASK IS PERFORMED					
After port alignment and before exit to remove next canister.					
DISCRETE OR CONTINUOUS TASK					
Operator's function is discrete. Lowering of canister halts automatically when at bottom.					
FREQUENCY OF PERFORMANCE					
After removal of each canister—four times in eight-hour shift.					
LIKELIHOOD THAT TASK PERFORMANCE IS REQUIRED					
Probability is 1.0 that task is performed with removal of a canister.					

Figure 3. Sample form for developing task statements.

FUNCTION DESCRIPTION	TRANSFER CANISTER TO THE CWSRS	TASK NO. 13
TASK DESCRIPTION	Moves toggle switch into down position to lower the canister into the Canister Transfer Basket.	
PERMISSIBLE EQUIPMENT COMPONENTS		
(A control having two alternatives: up and down) toggle switch, bat-handle switch, push button, foot switch, push-pull control, trigger, pointer knob.		
SELECTED CONTROL/DISPLAY COMPONENTS		
Two-way toggle switch. When vertically oriented, provides best control/object movement relationship.		
CONSIDERATIONS		
COMMUNICATION REQUIREMENTS	CET operator in open voice communication with CWSRS operator. Actions of CET are displayed to CWSRS. Information relayed via electrical cable or radio.	
CONTINGENCY REQUIREMENTS	Backup manual system available if control fails. Interlocks present so canister can't be lowered unless CTB is present and all gates are open.	
MAINTENANCE REQUIREMENTS	Develop operator checkout procedure for controls/displays to be performed periodically. Easy access to controls required for corrective maintenance.	
FEEDBACK REQUIREMENTS	Feedback that toggle is in position (detent). Feedback (white light) that canister is actually moving downward. Feedback (green light) that canister is at bottom of cask.	
INPUT/OUTPUT CHARACTERISTICS	Initial input is output from previous task. Operator input is discrete. Force requirements according to HFE toggle switch design. Display lights in proper relationship to control.	

Figure 4. Sample form for developing task descriptions.

Figure 5. An example Operational Sequence Diagram of the events (hypothetical) involved in aligning the CET with the CWSRS port gate. Accompanying symbology is shown in Figure 6.

LEGEND	LINKS
DECISION	A AURAL
RECEIVE VOICE COMMUNICATION	E ELECTRICAL
DISPLAY	V VISUAL
OPERATION	S SPEECH
TRANSMIT INFORMATION	P PHOTO IMAGE
OPERATOR TRAVEL	T TACTILE
MONITOR	K KEYBOARD ENTRY
STORE INFORMATION DOUBLE SYMBOL: CONTINUOUS/AUTOMATIC CONTROL	

Figure 6. Symbology for Operational Sequence Diagram in Figure 5.

operator actions of little or no consequence. Consequential actions are those which are either correct (within the context of the task lists developed earlier) or incorrect, but still have some potential impact on execution of the function. Only actions having real consequence should be included in the event tree analysis. The basic idea is to include only those actions and resulting events which have a meaningful impact (either positive or negative) on the function attempting to be performed. It is necessary for the analyst to weed out those actions which will not add to the utility of the analysis. Also, the size and number of elements of the event tree would grow far too rapidly if these constraints were not placed on the selection of actions to be included in the analysis.

CONTROL DESCRIPTION	
Two-directional toggle, 1.5 in. length, .2 in. width, 70° swing.	
CONTROL PURPOSE	
To raise and lower CET cask from retrieval (or transfer) position to transport position or vice versa.	
OPERATOR TASKS IN WHICH CONTROL IS IMPLEMENTED	
• Preparing for can removal at emplacement • Prepare for transport of CET after extraction • Prepare for transfer of can at CWSRS • Prepare for transport of CET after transfer • CET checkout	
CONTROL LOCATION	Control presently located in center console within arm's reach of both operator stations. Control is used frequently enough to merit this location. Overall assessment: Appropriate.
CONTROL OPERATION	Control presently moves up to raise cask and moves down to lower cask. Overall assessment: Appropriate.
CONTROL FEEDBACK	Control is coupled with auditory signal that cask is in motion. Indicator lights should present position of cask. Control has positive feedback when positioned. Overall assessment: Appropriate.
CONTROL CODING	Control presently not coded differently than other toggles on console. Overall assessment: Additional coding is required. Unique and distinguishable shape and color should be utilized.
CONTROL GROUPING	Control presently grouped with other controls used during extraction or transfer. Control arranged according to functional operation sequence. Overall assessment: Appropriate.
CONTROL LABELING	Control presently labeled appropriately—concise, visible, legible. However, label is susceptible to dirt and grime. Lettering should be etched and made more permanent. Overall assessment: Appropriate but needs minor modification.

Figure 7. Sample form for recording narrative comments on human factors engineering analysis of control.

Begin by listing (or drawing) the SYSTEM STATE with which the event tree will begin. Then, by referencing the listing of correct task and event sequences developed during STEP 3, draw or list the action considered to be the correct behavior. List or draw the appropriate resulting ending SYSTEM STATE from this ACTION. Although the probability of occurrence of this LINK is not determined until the next phase of the analysis, in most cases this first and top LINK will be the one with the highest probability.

Next, again starting with this very first SYSTEM STATE, list a maximum of six ACTIONS which the operator might take, each selected on the basis of its eventual effect on the system or on the basis of its estimated likelihood of occurrence. Remember that the operator's behavior is assumed to be purposeful, and that an attempt is not being made to subvert the system. The operator is initiating ACTIONS to accomplish a given TASK.

The maximum of seven ACTIONS emanating from this initial SYSTEM STATE should be ranked, from top to bottom, on the basis of the initial estimated likelihood of occurrence. In most cases, therefore, the correct action will be listed at the top and will be assigned the highest probability of occurrence. Each of the maximum of seven ACTIONS will result in a SYSTEM STATE. Therefore, a description of the state of the system should be provided for each of the seven ACTIONS. It is possible that two or more actions will result in the same SYSTEM STATE. A diagram of the hypothetical tree developed thus far is presented in Figure 8.

Each of these resulting SYSTEM STATES, in turn, can have as many as seven ACTIONS emanating outward to the right. With each, first list the ACTION which represents the operator's most likely course of action. If the system being modeled is such that the operator is supplied feedback that an error has been made, then the most likely course of action will be a correct behavior and will have a high likelihood of occurrence. If the ACTION was incorrect and the system being modeled is such that the operator is not provided feedback that an error has been made, then the next ACTION may be, in actuality, an incorrect behavior with a high likelihood of occurrence. Again, the importance of the analyst being

Figure 8. ACTIONS and resulting SYSTEM STATES emanating from the first SYSTEM STATE. Boided LINK represents the correct operator action.

thoroughly familiar with the system surfaces when these types of decision must be made.

After listing the most likely ACTION from the SYSTEM STATE, indicate, from top to bottom, the next most likely operator ACTIONS. It is possible for dissimilar ACTIONS emanating from different SYSTEM STATES to result in the same SYSTEM STATE, as illustrated in Figure 9.

It is also possible for an ACTION to be linked to a SYSTEM STATE which has already been listed. For example, if the system is such that after making a series of incorrect ACTIONS the operator is notified of his error and the incorrect state of the system, he may go back to the beginning of the task and, in essence, work through the event tree a second time. Again, the likelihood that this sort of event will occur is a function of the design of the system, with which the analyst must be totally familiar.

Each TASK is defined as a group of ACTIONS performed to fulfill a major step within a function. In the case of TASKS depicted in the CETAT event tree, the TASK boundaries define a group of ACTIONS and subsequent event paths, each performed with the purpose of completing the TASK. Although the task may or may not have been performed correctly, it is defined as being over when (a) the

Figure 9. Example of TASK event tree with LINKS having a previously occurring SYSTEM STATE.

TASK has been completed; (b) the operator believes the TASK has been completed but it is not; or, due to whatever circumstances, (c) the TASK events cannot proceed further.

It is very important that the analyst make every attempt to converge the ACTION branches into common SYSTEM STATE nodes as the last step in describing each TASK. Although the program is capable of handling 500 SYSTEM STATES, to keep the analysis within a manageable size it is necessary to place constraints on the branching of the "tree." Therefore, it is best to conceptualize the CETAT event tree as a number (maximum of 99) of modular event trees (TASKS), each containing a limited set of inputs and outputs. Within the confines of the TASK, however, there may be as many as 99 different SYSTEM STATES and a greater number of operator ACTIONS. Each LINK within the event tree has both a time and probability value associated with it.

ACTIONS emanating from a TASK may proceed to any one of the other 98 TASKS within the event tree. Individual event paths should continue until the TASK has been performed or an event of consequence (radioactive leak, endangered operator, damaged equipment, etc.) has occurred.

While the event tree is being developed, label each TASK with a two digit number. Also, label each of the SYSTEM STATES within each TASK with a two-digit number, starting with "01" with the first SYSTEM STATE of each TASK. To simplify the input of data during the next phase of the analysis, organize SYSTEM STATES within TASKS into rows and number them in increasing order from top to bottom (starting with the row on the left and proceeding to the row on the right).

Each SYSTEM STATE and each ACTION should be defined either on the event-tree diagram or on an associated listing. Although these written records can be as long as necessary, the computer input format provides space for a 29-character abbreviated description of each SYSTEM STATE and ACTION. Additional descriptive information can be entered into a notation file associated with each LINK file, as explained in Section III.

STEP 5. DEVELOP PROBABILITY AND TIME DATA

In developing the probability data to describe the likelihood of occurrence of each ACTIVITY emanating from a SYSTEM STATE, the analyst is required to (a) analyze the human engineering characteristics of the ACTIONS, (b) consult available baseline probability data, and (c) develop a probability value which reflects the special variables associated with the SYSTEM STATE and consequential ACTION. In developing the time data to estimate the elapsed time from one SYSTEM STATE to the next, the analyst must consult available engineering and human factors analysis reports for estimates on the durations of machine and operator operations.

The probability values for the set of ACTIONS emanating from each SYSTEM STATE should be developed as a group. First, establish the probability value to be associated with the LINK which represents the correct or normal course of action, if, of course, there is a "correct" ACTION emanating from the beginning SYSTEM STATE. If data are available from run-throughs with mockups

of the system, these should be acquired. In most circumstances, however, it will be necessary for the analyst to conduct a human factors engineering assessment of the correct operator ACTION. The most direct way of doing this is with the aid of the checklist provided in Figure 10. Four basic evaluation factors--(a) the ergonomics of controls and displays involved in the ACTION, (b) the design of the job performance aids related to the TASK, (c) the operator training related to performance of the TASK, and (d) the job situational factors related to performance of the ACTION--have been broken down into subtopics. Each subtopic or question should be evaluated, as it relates to the ACTION and/or the control which is the object of the action.

For example, assume that the proper ACTION to be performed at a particular SYSTEM STATE involves reading a display and adjusting a rotary knob. Recall that a CETAT analysis is to be performed on a system that can be described at the highest level of detail. The analyst must evaluate the controls and displays involved in the action (the knob and dial) on the basis of each subtopic in the checklist. Assume that the display, as presently designed, has a scale design which is not in accordance with the recommendations provided in **Volume II, A Compendium of Human Factors Design Data** (Casey, 1980a). Instead of having a linear scale, it has a nonlinear scale and the scale values do not advance in constant amounts (pages 79-82 in **Volume II**). Therefore, the analyst checks item 42 under controls and displays as a major problem, one which will influence the probability that the operator will read the correct information from the dial and provide the correct ACTION.

Similarly, assume that the rotary dial with which the operator responds operates (direction of motion) in a fashion contrary to the population stereotype (pages 29-33 in **Volume II**). The analyst would therefore check Item 12 under controls and displays as presenting a major problem, one which could drastically affect the probability of correctly performing this action.

In the same vein, the analyst must consider the level of training the operator has had in this procedure, and whether this action is performed frequently. An infrequently performed ACTION may be less likely to be performed correctly. Likewise, if the operator must consult a job performance aid (manual)

OPERATOR ACTION EVALUATION CHECKLIST				
ACTION DESCRIPTION				
BEGINNING SYSTEM STATE				
ENDING SYSTEM STATE				
EVALUATION FACTORS	HFE ASSESSMENT			
ERGONOMICS OF CONTROL(S) AND DISPLAY(S) INVOLVED IN ACTION	NO PROBLEM	MINOR PROBLEM	MODERATE PROBLEM	MAJOR PROBLEM
1. Control relationship to its display is apparent				
2. If functionally related to other controls, grouped with controls of similar function				
3. If part of group of controls, order of operation is top to bottom or left to right				
4. If part of group of controls, located according to functional sequence				
5. Control orientation is appropriate				
6. Control spacing is appropriate				
7. Control size is appropriate (consider gloved hand)				
8. Capacity to slip off of control				
9. Range of control movement appropriate				
10. Control feedback appropriately coded and at appropriate intensity				
11. Control and display motion correspondence appropriate				

Figure 10. Operator action evaluation checklist for assisting in assigning a probability value to a correct operator ACTION.

EVALUATION FACTORS (CONTINUED)	HFE ASSESSMENT			
ERGONOMICS OF CONTROL(S) AND DISPLAY(S) INVOLVED IN ACTION	NO PROBLEM	MINOR PROBLEM	MODERATE PROBLEM	MAJOR PROBLEM
12. Control direction-of-movement according to population stereotype 13. Control operation force requirement adequate 14. Control size coding appropriate 15. Control color coding appropriate 16. Control shape coding appropriate 17. Control label is clearly usable 18. Control label is clearly interpretable 19. Ambient lighting on control adequate 20. Control manipulation precision consistent with system requirements 21. If necessary, inadvertent operation protection of control 22. Control general location and orientation and potential for inadvertent activation 23. Display related to control 24. Display, if related to other displays, grouped according to relationships 25. Display designed for reading at required degree of accuracy 26. Display required viewing distance appropriate 27. Display pointer not to obscure index marks 28. Display parallax acceptable				

Figure 10. Operator action evaluation checklist for assisting in assigning a probability value to a correct operator ACTION (Continued).

EVALUATION FACTORS (CONTINUED)	HFE ASSESSMENT			
ERGONOMICS OF CONTROL(S) AND DISPLAY(S) INVOLVED IN ACTION	NO PROBLEM	MINOR PROBLEM	MODERATE PROBLEM	MAJOR PROBLEM
29. Minimum display coding required 30. Non-relevant information on display absent 31. Coding techniques on display uniform 32. Audio warning decipherable 33. Audio warning does not interfere with critical functions 34. Verbal warnings intelligible 35. Display illumination appropriate 36. Display face minimize reflection 37. If critical display, in optimal visual zone 38. Display contrast appropriate 39. If flashing light, rate 3-5/sec 40. Display coding appropriate 41. Presented information useful and needed information 42. Display scales linear, advance appropriately 43. Failure of display operation apparent 44. Labels placed on or near control or display 45. Labels do not cover other important information				

Figure 10. Operator action evaluation checklist for assisting in assigning a probability value to a correct operator ACTION (Continued).

EVALUATION FACTORS (CONTINUED)		HFE ASSESSMENT			
ERGONOMICS OF CONTROL(S) AND DISPLAY(S) INVOLVED IN ACTION		NO PROBLEM	MINOR PROBLEM	MODERATE PROBLEM	MAJOR PROBLEM
46. Label not behind control					
47. Label location consistent with other controls and displays					
48. Labels not easily covered or obscured by grime					
49. Labels are within specifications					
50. Label style within specifications					
51. Labels use familiar words					
52. Label good for life of equipment					
53. Label oriented vertically only when not critical for personnel safety, performance					
DESIGN OF JOB PERFORMANCE AIDS TO TASK					
1. Technical content of aids related to problem needs					
2. Technical level of aids equal comprehension of users					
3. Aid organized according to the way in which it will be used					
4. Aid durable enough to hold up under working conditions					
5. Format of individual instructions (written or pictorial) consistent with requirements of task (e.g., accurate or rapid task performance)					

Figure 10. Operator action evaluation checklist for assisting in assigning a probability value to a correct operator ACTION (Continued).

EVALUATION FACTORS (CONTINUED)		HFE ASSESSMENT			
DESIGN OF JOB PERFORMANCE AIDS RELATED TO TASK		NO PROBLEM	MINOR PROBLEM	MODERATE PROBLEM	MAJOR PROBLEM
6.	Illustrations clearly marked and drawn to required detail				
7.	Print legible under worst lighting conditions				
8.	Aid of manageable size and shape				
9.	Aid stored at workplace where it will be used				
10.	Aid information comprehensible in time allowed for task				
11.	Aid structured according to sequence of task performance				
OPERATOR TRAINING RELATED TO PERFORMANCE OF THE TASK					
1.	Training for task provided				
2.	Training for task overlearned				
3.	Training provide skill for meeting task requirements				
4.	Training content highly related to knowledge requirements				
5.	Training places highest skilled operators in job setting				
6.	Operator effectiveness evaluated at periodic intervals				
7.	Performance feedback provided to operator				
8.	Training method match type of material presented				
9.	Training provide necessary stress during task performance				

Figure 10. Operator action evaluation checklist for assisting in assigning a probability value to a correct operator ACTION (Continued).

EVALUATION FACTORS (CONTINUED)		HFE ASSESSMENT			
JOB SITUATIONAL FACTORS RELATED TO PERFORMANCE OF ACTION		NO PROBLEM	MINOR PROBLEM	MODERATE PROBLEM	MAJOR PROBLEM
1.	Operator placed under speed stress				
2.	Operator placed under load stress				
3.	Operator placed under physical or environmental stress				
4.	Task performed on an infrequent and irregular basis				
5.	Length of time operator at work station				

Figure 10. Operator action evaluation checklist for assisting in assigning a probability value to a correct operator ACTION.

to perform this activity, the design, content, and availability of this material must be evaluated. Finally, if the operator is placed under undue time or load stress while this ACTION is to be performed, the likelihood of this ACTION being performed correctly will be reduced.

While referencing the ACTION checklist, select a probability value which reflects (a) the design of the controls, displays, and task, (b) the design of the job performance aids, (c) the training provided to the operator, and (d) the job situational factors. An overlearned ACTION involving properly designed displays, controls, and job aids, and performed under low levels of stress, may have a probability value of between 0.9900 and 0.9999. On the other hand, when the displays and/or controls associated with an action have been designed against recommendations, as in the above example, the probability may be dropped to 0.50000 or 0.60000. These values are arbitrary, but, when summed over the length

of an extensive event path, will provide a valuable means of assessing the impact of important design changes.* Consulting the example human error probabilities in the Appendix should also help in defining the limits of probability values.

Although some data on the probability of incorrect ACTIONS are available in the Appendix, the analyst must still use a great deal of logic when establishing probability values for these ACTIONS. After having established the probability for a correct LINK, begin to establish the probability for each of the ACTIONS having the same beginning SYSTEM STATE as the correct ACTION for which the probability has been established. In all cases, the summed probabilities of all ACTIONS emanating from a common SYSTEM STATE should not exceed 1.0.

To identify the general probability base rate for each of these ACTIONS it is useful to consult the tables in Appendix A which provide data on human error rate probabilities. After having defined the nature of the ACTION and consulted the relevant data base, if available, select a probability of occurrence for each ACTION.

The time values associated with each LINK must be derived from engineering documents and walk-throughs performed with equipment mockups. The analyst has the choice of entering the worst case, most likely case, or best case time values for each LINK. In most analyses, however, the estimated average LINK completion time should be entered. This value will be:

TIME FROM ONSET OF FEEDBACK IN BEGINNING SYS- TEM STATE TO PERCEPTION OF FEEDBACK BY OPERATOR	TIME FROM PER- CEPTION OF FEEDBACK TO ARRIVAL AT ACTION DECISION	TIME FROM ONSET OF OPERATOR ACTION TO OFFSET OF OPERATOR ACTION	DURATION OF MACHINE EXECUTION = TIME

---

*One of the most valuable uses of CETAT is in the assessment of the potential impact of human engineering design changes. If, for example, a control which does not operate according to accepted direction-of-motion rules is redesigned, the resulting LINK probability will be modified, as will the probability of the total event path of which this LINK is a part.

As when establishing the probabilities, the analyst must take into account the control and display design, the job aids, training, and situational factors. If, for example, a SYSTEM STATE exists for which the operator has received very little training, the response times will be increased. As another example, if an important control has been guarded against accidental activation, more time will be required to activate the control.

SECTION III

DATA INPUT

The data input procedure of CETAT has been designed to be an iterative process, one in which the computer provides the instructions and formats for keying-in data. The analyst, in turn, must enter units of event-tree data comprised of individual LINK elements. If the analyst is working from an event-tree diagram, the LINKS and associated information must be checked-off as each is entered into the system.

Because most CETAT analyses are based on large numbers of LINKS (usually many hundreds of LINKS), the data input program has been designed to allow the analyst to stop inputting data at any time and resume at a later date. Also, if the analyst should choose to modify or edit an existing data base, the data input program allows re-entry into the files for the purpose of making major modifications.

INPUT OF NEW DATA BASE

The following instructions outline, in detail, the procedures to be followed when building a new CETAT data base. Because data are entered in units based on LINKS, and individual LINK descriptions are stored on the disk as soon as they are entered, the procedure for inputting data may be resumed by following the instructions in the section on data input continuation.

STEP 1: LOADING THE PROGRAM

After turning on the processor and printer, begin by entering the program disk in the left drive and the file disk (blank disk) in the right side. Each CETAT data base should be contained on a separate disk. Type the following command:

PROCI EXEC

In response, the system will display:

**THIS IS THE PROCEDURE FOR CREATING AND/OR EDITING A DATA
BASE**

**IS THIS A CONTINUATION OF AN OLD DATA BASE OR IS THIS A NEW
DATA BASE? (OLD/NEW)**

Respond by typing: **OLD** **EXEC**

or

NEW **EXEC**

Type **NEW** to begin entering a new data base.

In response, the system will display (flashing):

BE CERTAIN EMPTY DISKETTE IS IN DRIVE 2

To acknowledge and stop the message from flashing, press **ATTN**. Be certain that
an empty diskette is in Drive 2.

STEP 2. ENTERING THE CASE TITLE

To proceed, enter **GO** **EXEC**

The system will respond by displaying a template for entering the name of the
analyst, the name of the case, the month, day, and year:

NAME , CASE TITLE, MO, DA, YR

Respond by entering the analysts name, case title, month, day, and year in
the spaces provided. Add commas in the input file exactly as they are placed in
the template above and as in the following example:

NAME , CASE TITLE , MO , DA , YR
SMITH , CANISTER REMOVAL , 09 , 07 , 80

Press **EXEC**

STEP 3. ENTERING A UNIT OF LINK DATA

Each LINK unit consists of a TASK number, SYSTEM STATE number, a beginning SYSTEM STATE, an ACTION, an ending SYSTEM STATE, a PROBABILITY value, and a TIME value. Due to the length of this unit, it is entered in two separate lines. As in the following example, the responses are to be entered underneath the displayed headings:

After having pressed **[EXEC]** in Step 2, the system will display the following template for entering a unit of LINK data:

T#S#

Respond by typing the TASK and SYSTEM STATE number and pressing **[EXEC]**. If this SYSTEM STATE has not been previously described in the data base the following template will be shown:

T#S#, BEGINNING SYSTEM STATE ,ACTION
 0709, ,

Enter the beginning SYSTEM STATE description and the ACTION description. If the SYSTEM STATE has been previously entered into the data base, after entering the number and pressing **EXEC**, the beginning SYSTEM STATE description will be displayed automatically. This feature has been designed to reduce the amount of time required to input data.

After entering the ACTION and pressing **EXEC**, the following should be displayed on the screen:

T#S#, BEGINNING SYSTEM STATE ,ACTION
 0709,CAN UP GATES OPEN ,FLIP FLOOR FLG TGL DOWN
 T#S#

Enter the number of the ending SYSTEM STATE and press **EXEC**. If this SYSTEM STATE has been previously entered, the following will appear:

T#S#, BEGINNING SYSTEM STATE ,ACTION
 0709,CAN UP GATES OPEN ,FLIP FLOOR FLG TGL DOWN
 T#S#, ENDING SYSTEM STATE , .PROB ,HR,MI,SE,WSLNCE
 0710, , , , ,

In this case, enter the ending SYSTEM STATE, the probability value, hours, numbers, and seconds. If the ending SYSTEM STATE has been previously entered into the data base, after entering the number and pressing **EXEC** the ending SYSTEM STATE description will be displayed automatically. If this is the case, enter the probability value, hours, minutes, and seconds. At this point the following information should be displayed on the screen:

T#S#, BEGINNING SYSTEM STATE ,ACTION
 0709,CAN UP GATES OPEN ,FLIP FLOOR FLG TGL DOWN
 T#S#, ENDING SYSTEM STATE , .PROB ,HR,MI,SE,WSLNCE
 0710,CAN UP CET OPN FF CLOSED ,0.95000 ,00 ,00 ,00,

STEP 4. ENTERING LINK INPUT CODES AND COMMENTS

After entering the probability and time values, one of five single letter codes must be entered. These are: W,S,L,NC and E.

- W** (WRONG) If a major mistake has been made in the LINK input and it must be changed, enter **W EXEC** and the input will be removed and a new template will be displayed. At this point, re-enter the LINK information as desired.
- S** (SAME) If the next LINK to be entered will have the same beginning SYSTEM STATE as in this LINK, enter **S EXEC** to have this information automatically transferred to the next LINK file. After having entered **S EXEC**, the template for entering the next LINK will appear with the beginning SYSTEM STATE already printed on the screen.
- L** (LINK) If the next LINK to be entered will have the same beginning SYSTEM STATE as the ending SYSTEM STATE in this LINK, enter **L EXEC** to have this information automatically transferred to the next LINK. After having entered **L EXEC**, the template for entering the next LINK will appear with the beginning SYSTEM STATE already printed on the screen.
- C** (COMMENTS) If, for any reason, additional comments need to be written for this file, such as a longer SYSTEM STATE description, enter **C EXEC**. In response, the system will display a template for entering a line of comments. At the end of this line of comments, one of the five letter codes listed above must be entered in the space provided. If **W** (WRONG) is entered, the LINK description and comments are removed from the data base. If **S** is entered, it is assumed that no more comments are to be entered, and that the beginning SYSTEM STATE in the next LINK will be the same as the beginning system state in this LINK. If **L** is entered, it is assumed that no more comments are to be entered, and that the beginning SYSTEM STATE in the next LINK will be the same as the ending SYSTEM STATE in this LINK. If **C** is entered, a new template for adding another line of comments will appear, along with space for entering one of the five LINK input codes.
- N** If **N** (NEXT) is entered, the template for entering the next LINK is displayed.
- E** If the system is to be notified that this was the last LINK to be entered into the data base, enter **E EXEC**.

After having entered all information associated with the LINK and one of the final LINK input codes, the display should look like the following:

T#S#,BEGINNING SYSTEM STATE	,ACTION
0709,CAN UP GATES OPEN	,FLIP FLOOR FLG TGL DOWN
T#S#, ENDING SYSTEM STATE	,.PROB ,HR,MI,SE,WSLNCE
0710,CAN UP CET OPN FF CLOSED	,0.35000 ,00 ,00 ,45,N

Press **EXEC** and the template for entering the next LINK will be displayed. The LINK having just been entered will appear just above the new template, as in the following:

0709,CAN UP GATES OPEN	,FLIP FLOOR FLG TGL DOWN
0710,CAN UP CET OPN FF CLOSED	,0.95000 ,00,00,45

T#S#

STEP 5. REQUESTING A PRINTOUT OF A COMPLETED DATA BASE

After having typed E **EXEC** to signify the end of the data base, the system will respond by asking:

DO YOU WISH TO HAVE A PRINTOUT OF THE EXISTING DATA BASE?
(YES/NO)

Type either **YES** **EXEC**

or

NO **EXEC**

Type **NO** to terminate the program. Type **YES** to receive a printout of the existing data base. Reference the section on **EXAMINING THE PRINTOUT** in Section IV to continue.

DATA BASE INPUT CONTINUATION

Assuming that a large data base is entered into the system, in all probability the input procedure will take place over more than one sitting. To continue adding LINK information to an existing but incomplete data base, use the following procedure.

STEP 1. LOADING THE PROGRAM

After turning on the processor and printer, begin by placing the diskette with the existing but unfinished file in the right drive and the program diskette in the left drive. Type the following command:

PROC1 **EXEC**

In response, the system will display:

THIS IS THE PROCEDURE FOR CREATING AND/OR EDITING A DATA BASE.

IS THIS A CONTINUATION OF AN OLD DATA BASE OR IS THIS A NEW DATA BASE? (OLD/NEW)

Enter OLD **EXEC**

or

NEW **EXEC**

Enter OLD to continue to add LINK data to an existing data base.

In response, the system will display:

WOULD YOU LIKE TO EDIT THE EXISTING DATA BASE AND PROBABLY ADD MORE INFORMATION TO IT, OR WOULD YOU LIKE TO ADD TO THE INPUT? (EDIT/ADD)

Enter EDIT **EXEC**

or

ADD **EXEC**

Enter ADD to add new LINK data to an incomplete file.

STEP 2. ENTERING A UNIT OF LINK DATA

At this point, units of LINK data can be entered into the file as they were while a new data base was being entered. Enter only those LINKS which have not been entered before. Follow the five steps outlined in **INPUT OF NEW DATA BASE** in this section.

SECTION IV

DATA EDITING

The data editing program, actually part of the data input program described in Section III, allows the analyst to (a) delete and edit existing LINK files and comments, and (b) add new LINK data to the data base.

The first step in the editing process will be to obtain and examine a printout of the data base. When requested to do so, CETAT provides a listing of all entered data, both LINKS and associated comments, organized to help the analyst (a) identify missing data, (b) identify data errors, and (c) modify existing data files.

EXAMINING THE PRINTOUT

A printout of the data base is usually obtained after all or a portion of LINKS have been entered into the file, as described in Section III. Having worked through the four principal steps involved in entering a data base, and having entered E at the last LINK to signal the end of the input, the system will be ready to print the data base. This is performed when the procedures covered in Step 5 of **ENTERING A NEW DATA BASE** in Section III are implemented.

The printout organizes the event-tree data into three categories. First, each LINK which has been entered into the data base will be listed, including the beginning and ending SYSTEM STATES, the ACTION, and TIME and PROBABILITY values. Each LINK will have a printout number associated with it, as illustrated in Figure 11. This is the number to reference when editing or modifying LINKS. When an event path is being modified, as discussed in Section V, it is also this number which is used to identify LINKS which identify starting and ending points of paths.

The second category on the printout is a listing of all comments which have been entered. Each set of comments associated with each LINK is referenced by number. It is this number which is to be used when identifying comments to be modified. Figure 12 provides an example of the second portion of the printout.

Figure 1. Schematic diagram of the experimental setup. The subject is seated in a chair, viewing a video screen. The screen displays a target (a small circle) and a starting point (a small circle). The subject's hand is positioned at the starting point. The distance between the starting point and the target is 10 cm. The subject is instructed to move the hand from the starting point to the target. The video screen is 100 cm high and 100 cm wide. The starting point is 50 cm from the bottom edge of the screen. The target is 50 cm from the top edge of the screen. The subject's hand is 50 cm from the bottom edge of the screen. The distance between the starting point and the target is 10 cm. The subject is instructed to move the hand from the starting point to the target.

1. 2. 3. 4. 5. 6.

Figure 12. Example printout of comments listing.

Thirdly, the printout provides a LINK reference table. This listing indicates all incoming and outgoing LINKS associated with each SYSTEM STATE. This listing is of greatest use when debugging the data base. A sample LINK reference table is shown in Figure 13.

EDITING AND ADDING DATA AND COMMENTS

If the analyst wishes to edit any aspect of an existing data base and add new LINKS, the following procedure should be followed.

STEP 1. LOADING THE PROGRAM

Type the following command:

PROC1 EXEC

In response the system will display:

**THIS IS THE PROCEDURE FOR CREATING AND/OR EDITING A DATA
BASE**

**IS THIS A CONTINUATION OF AN OLD DATA BASE OR IS THIS A NEW
DATA BASE? (OLD/NEW)**

Enter **OLD EXEC**

or

NEW EXEC

Enter **OLD** to continue to add LINK data to an existing data base.

In response, the system will display:

**WOULD YOU LIKE TO EDIT THE EXISTING DATA BASE AND PROBABLY
ADD MORE INFORMATION TO IT, OR WOULD YOU LIKE TO ADD TO THE
INPUT? (EDIT/ADD)**

1007-1111-1000

41

Enter **EDIT** **EXEC**

or

ADD **EXEC**

Enter **EDIT** to edit and add files.

STEP 2. CHANGING THE TITLE

After having entered **EDIT** **EXEC** in the previous step, the system will respond by displaying:

WOULD YOU LIKE TO CHANGE THE TITLE? (YES/NO)

Respond by typing: **YES** **EXEC**

or

NO **EXEC**

If **NO** is typed, the program proceeds to the next step. If **YES** is typed, the system will respond by displaying the title of the file on the diskette. Make changes in the title as necessary and press **EXEC**.

STEP 3. DELETING LINES

After pressing **EXEC** in the previous step, the system will respond by displaying:

DO YOU WISH TO DELETE ANY LINES? (YES/NO)

Respond by typing: **YES** **EXEC**

or

NO **EXEC**

If **NO** is typed the program proceeds to the next step. If **YES** is typed, enter the line number from the printout of the data base of the LINK to be deleted and press **EXEC**. Continue this process until all LINKS to be deleted have been entered. Enter 0 **EXEC** when no more LINKS are to be deleted.

STEP 4. EDITING LINES

After having entered 0 **EXEC** in the previous step, the system will ask:

**DO YOU WISH TO CHANGE ANY OF
THE SYSTEM STATE NAMES? (YES/NO)**

Respond by typing: **YES** **EXEC**

or

NO **EXEC**

If **YES**, enter the SYSTEM STATE number (e.g., 0209), press **EXEC**, and make the changes to the name. Enter 0 **EXEC** when no more names are to be changed.

After having entered **NO** when asked to change names, the system will respond by displaying:

WOULD YOU LIKE TO EDIT ANY LINES? (YES/NO)

Respond by typing: **YES** **EXEC**

or

NO **EXEC**

If **NO** is typed, the program proceeds to the next step. If **YES** is typed, the system will respond by asking for the line number on the printout. Refer to the printout of the data base and enter the line number of the LINK to be edited. Press **EXEC**. Enter 0 **EXEC** when no more lines are to be edited.

STEP 5. ADDING ADDITIONAL COMMENTS

After having entered **EXEC** in the previous step, the system will respond by displaying:

DO YOU WISH TO ADD COMMENTS TO EXISTING LINKS? (YES/NO)

Respond by typing: **YES** **EXEC**

or

NO **EXEC**

If **NO** is typed, the program proceeds to the next step.

If **YES** is typed, the system will respond by asking for the LINK number to which comments are to be added.

Refer to the printout of the data base and enter the line number of the LINK to which comments are to be added. Press **EXEC**.

The system will respond by displaying a template for inputting new comments:

LINK, C#, COMMENTS

The line number will be listed underneath the appropriate space. Enter the line number of the comment line (if this is the first line of comments for this LINK enter 1, if the second enter 2, and so on) for the LINK. After entering the line of comments press **EXEC**. Continue to add comments to any LINK by following the above procedure. When all desired comments have been entered, type 0 **EXEC** when the system requests the next LINK line number to be referenced.

The system will then ask:

DO YOU WISH TO ADD NEW LINKS? (YES/NO)

Enter **YES** **EXEC**

or

NO **EXEC**

STEP 6. REPEATING THE EDIT PROCESS

This step allows the analyst to repeat the entire edit process. If, for example, it is noted that a SYSTEM STATE number must be changed, the analyst can start the edit process over, work through the questions until the program for modifying LINKS appears, and then initiate the procedure for editing a LINK.

After having entered **EXEC** in the previous step, the system responds by displaying:

DO YOU WISH TO REPEAT THE EDIT PROCESS? (YES/NO)

Respond by typing: **YES** **EXEC**

or

NO **EXEC**

If **NO** is entered, the program responds by proceeding to Step 5 of **INPUT OF A NEW DATA BASE** in Section III. If **YES** is entered, the program responds by proceeding to Step 2 of **EDITING AND ADDING DATA AND COMMENTS** of Section IV.

SECTION V

EVENT-TREE ANALYSIS

In the analysis of an event tree contained within a CETAT data base, the analyst has the capability of specifying any event path desired. To specify the event path to be analyzed, the analyst must first indicate the beginning SYSTEM STATE. The system in turn, displays all of the LINKS (maximum of seven) emanating from this SYSTEM STATE. After identifying which LINK of those displayed is to be followed, the system displays the amount of time taken to arrive at this SYSTEM STATE and the total probability of being at this SYSTEM STATE, given the path which has been specified. After having identified the entire path, which may consist of many hundreds of LINKS, the system provides a listing of the path which has been identified and the associated time and probability values.

If the analyst chooses to make a few modifications to an existing path, the program allows the analyst to re-structure the path where desired, and retain the structure of segments of the "old" path. This option is designed to simplify the analysis input requirements when, for example, the analyst chooses to determine the effect of taking an alternate path during a portion of a TASK. Instead of re-entering the entire path, the modifications to the "old" path need only be specified.

ENTERING A NEW LINK PATH

After having developed the data base, the analyst must load the program allowing an event path to be identified. As with other programs in CETAT, this program is interactive. The system informs the analyst of the event paths which can be taken at any choice point, and the analyst, in turn, responds by identifying which path will be taken. The system responds by identifying the resulting SYSTEM STATE, elapsed time, and accumulated probability.

STEP 1. LOADING THE PROGRAM

After turning on the processor and printer, begin by entering the program disk in the left drive and the file disk in the right drive. Type the following command:

LOAD 2 EXEC RUN EXEC

In response, the system will display:

MAKE SURE THE DISKETTE WITH THE DATA BASE IS IN THE DISKETTE DRIVE 2. TURN ON THE PRINTER. PLEASE GIVE THE NAME FOR THIS PATH.

The system will then ask for the title of this LINK path. Enter a maximum of 31 characters and press **EXEC**

The system will respond by displaying:

DO YOU WISH TO ENTER A NEW PATH OR MODIFY AN OLD ONE? (OLD/NEW)

Respond by typing **OLD EXEC**

or

NEW EXEC

Type **NEW** to enter a new path.

STEP 2. ENTERING A LINK PATH

After having pressed **NEW EXEC**, the system will display:

ENTER THE BEGINNING SYSTEM STATE T#S#

Respond by entering the number of the first LINK and pressing **EXEC**.

After pressing **EXEC**, the system will respond by displaying a listing of all the LINKS emanating from this SYSTEM STATE. Select the LINK to be followed and enter its number as displayed on the screen (1 through 7).

The system will display the selected LINK, along with (a) the total probability of being at the beginning SYSTEM STATE of that LINK, and (b) the total time required to perform the events on the path as described.

Because a given portion of a path may be passed over more than once, it may be desirable to modify the probability associated with that LINK when the second, third, or fourth pass is made. This is based on the assumption that in most cases an operator will be less likely to make the same "mistake" twice in a row. If these values are to be changed, indicate if PROBABILITY, TIME, or both TIME and PROBABILITY are to be changed and press **EXEC**. After requested to do so by the system, input the new values and press **EXEC**.

The system will respond by displaying all of the LINKS emanating from the ending SYSTEM STATE of the previous LINK. Once again choose the number of the LINK (1 through 7) to be taken. When you reach the point at which (a) you want a printout, or (b) the path does not proceed further, enter 0 **EXEC**. This terminates this phase of the program. You will then be asked if you want a listing of the selected path, along with the time and probability values associated with the path at each SYSTEM STATE.

MODIFYING AN OLD LINK PATH

After an event-tree path has been identified, the analyst may wish to examine the effects of some minor modifications on the outputs of this path. CETAT provides the capability of preserving selected portions of a path and modifying others. Use of this option can save a tremendous amount of time when a path similar to one described previously is to be analyzed.

Assume that the event tree in Figure 14 has been entered into the system and that an analysis has been performed on a selected path. The analyst has the capability of preserving selected sections of the path and modifying others, as illustrated in Figure 15. The following steps explain how to modify an old path.

Figure 14. Event tree with existing LINK path.

Figure 15. Event tree with modified LINK path in which selected portions of existing path were modified (---) and selected portions were unchanged (—).

STEP 1: LOADING THE PROGRAM

After loading the program as in Step 1 of **ENTERING A NEW LINK PATH** in this section, the system will respond by displaying:

MAKE SURE THE DISKETTE WITH THE DATA BASE IS IN THE DISKETTE DRIVE 2. TURN ON THE PRINTER. PLEASE GIVE THE NAME FOR THIS PATH.

Enter a maximum of 31 characters and press **EXEC**

The system will respond by displaying:

**DO YOU WISH TO ENTER A NEW PATH OR MODIFY AN OLD ONE?
(OLD/NEW)**

Respond by typing **OLD****EXEC**

or

NEW**EXEC**

Type **OLD** to modify an **OLD** path.

STEP 2: MODIFYING PROBABILITY AND TIME VALUES

After typing **OLD****EXEC** in the previous step, the system will respond by displaying:

**DO YOU WISH TO CHANGE PROBABILITY AND/OR TIME VALUES
IN ANY OF THE PATH LINKS? (YES/NO)**

Respond by typing **YES****EXEC**

or

NO**EXEC**

If **NO****EXEC** is typed, the program will proceed to the next step.

Type **YES** **EXEC** to change the time and/or probability values.

The system will respond by requesting (a) a path LINK number and (b) either P (Probability), T (Time), or B (Both). These should be separated by a comma as in the following example:

25,T **EXEC**

If **T** is entered, type the new time values for hours, minutes, and seconds (e.g., 01,23,30) when requested to do so. If **P** is entered, type the new probability value (e.g., 0.97500) when requested to do so. If **B** is entered, type the new probability and time values as instructed by the system.

If no more time and/or probability values are to be changed, enter **O,B** **EXEC**.

If the time and/or probability values for LINKS which are to remain in the new path are to be changed, it is important that these changes be made prior to restructuring the path. Although these values can be modified later, it is simpler to make the changes at this point.

STEP 3: MODIFYING THE LINK PATH

After pressing **EXEC** in the previous step, the system will respond by displaying:

**WILL THE FIRST LINK IN THE NEW PATH BE THE SAME AS THE FIRST
PATH LINK IN THE OLD PATH OR DIFFERENT? (SAME OR DIFF)**

Respond by typing **SAME** **EXEC**

or

DIFF **EXEC**

If **DIFF** is entered, the system will ask for the number of the beginning SYSTEM STATE. After pressing **EXEC**, the outgoing LINKS will be displayed as when a new path is being defined. Continue to identify the path in this fashion until the point at which the path merges with the existing path.

If **SAME** is entered, the system will display:

ENTER THE LAST PATH LINK BEFORE WHICH THE PATH WILL REMAIN THE SAME

Enter the LINK number which defines the first point up to which the path will remain the same. Press **EXEC**.

The system will respond by displaying:

IS THAT THE END OR DO YOU WISH TO ADD MORE LINKS? (END/MORE)

Respond by typing END **EXEC**

or

MORE **EXEC**

If **END** is entered, a printout of the path listing and associated computations will be provided.

If **MORE** is entered, the system will display all outgoing LINKS from the last SYSTEM STATE. Work through the event tree, identifying the path as described in Step 2 of **ENTERING A NEW LINK PATH** in this section.

When the point is reached where the modified portion of the path converges with the old path (which is to be retained), enter **MERGE** **EXEC** when asked for the next LINK number. The system will then display:

WHAT IS THE FIRST PATH LINK # AFTER WHICH THE PATH WILL REMAIN THE SAME?

Respond by entering this number and pressing **EXEC**.

The system will respond by displaying:

ENTER THE LAST PATH LINK NUMBER BEFORE WHICH THE PATH WILL REMAIN THE SAME

Enter the LINK number from the printout and press **EXEC**. As before, the system will respond by asking if this is the end of the path or if it is to be continued. By repeating this procedure, it is possible to retain as many portions as necessary of the existing LINK path, and re-structure the spaces in between.

Blank

SECTION VI

SAMPLE CETAT ANALYSIS

The following example has been included to (a) demonstrate the use of CETAT during the analysis of an event tree and (b) provide example CETAT outputs.

EVENT-TREE DEVELOPMENT AND INPUT

The event tree depicted in Figure 16 represents the hypothetical events involved in (a) indexing of the CET (Canister Extraction Transporter) with the port gate and (b) preparing for transfer of a canister to the CWSRS (Canister Waste Subsurface Receiving Station). The events have been greatly simplified for purposes of this example, and the tree is comprised of only two tasks. Assumptions have also been made about the workstation and the controls involved in the tasks. The probability and time values, as well, are strictly hypothetical.

EVENT-TREE ANALYSIS

After having entered the event tree into the system, as discussed in Section III, and obtained and corrected the data base printout, as discussed in Section IV, the tree is ready to be examined. The complete printout for this data base is shown in Figure 17. Note that SYSTEM STATE 0202 has not been included in the diagram. The program will sort and manipulate the data base even if a SYSTEM STATE number has been skipped. SYSTEM STATES within each TASK can be labeled with any two-digit number so long as a number is not used twice.

The first path to be analyzed is that involving the "correct" sequence of actions: SYSTEM STATES 0101, 0102, 0104, 0105, 0204, 0208, 0212, 0216, and 0218. The LINKS associated with these SYSTEM STATES were identified according to the procedures outlined in Section V. As can be seen on the printout (Figure 18), the probability and time values associated with each LINK in the path have been provided, as well as the cumulative values up to each LINK. Thus, according to the hypothetical and simplified example, the probability of performing the required ACTIONS in the proper sequence is 0.909 -- the value listed for the last LINK in the path.

Figure 16. Simplified event tree of CUT/cert gate alignment and canister transfer to CUSRS.

[illegible]

100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	1024	1025	1026	1027	1028	1029	1030	1031	1032	1033	1034	1035	1036	1037	1038	1039	1040	1041	1042	1043	1044	1045	1046	1047	1048	1049	1050	1051	1052	1053	1054	1055	1056	1057	1058	1059	1060	1061	1062	1063	1064	1065	1066	1067	1068	1069	1070	1071	1072	1073	1074	1075	1076	1077	1078	1079	1080	1081	1082	1083	1084	1085	1086	1087	1088	1089	1090	1091	1092	1093	1094	1095	1096	1097	1098	1099	1100	1101	1102	1103	1104	1105	1106	1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120	1121	1122	1123	1124	1125	1126	1127	1128	1129	1130	1131	1132	1133	1134	1135	1136	1137	1138	1139	1140	1141	1142	1143	1144	1145	1146	1147	1148	1149	1150	1151	1152	1153	1154	1155	1156	1157	1158	1159	1160	1161	1162	1163	1164	1165	1166	1167	1168	1169	1170	1171	1172	1173	1174	1175	1176	1177	1178	1179	1180	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190	1191	1192	1193	1194	1195	1196	1197	1198	1199	1200	1201	1202	1203	1204	1205	1206	1207	1208	1209	1210	1211	1212	1213	1214	1215	1216	1217	1218	1219	1220	1221	1222	1223	1224	1225	1226	1227	1228	1229	1230	1231	1232	1233	1234	1235	1236	1237	1238	1239	1240	1241	1242	1243	1244	1245	1246	1247	1248	1249	1250	1251	1252	1253	1254	1255	1256	1257	1258	1259	1260	1261	1262	1263	1264	1265	1266	1267	1268	1269	1270	1271	1272	1273	1274	1275	1276	1277	1278	1279	1280	1281	1282	1283	1284	1285	1286	1287	1288	1289	1290	1291	1292	1293	1294	1295	1296	1297	1298	1299	1300	1301	1302	1303	1304	1305	1306	1307	1308	1309	1310	1311	1312	1313	1314	1315	1316	1317	1318	1319	1320	1321	1322	1323	1324	1325	1326	1327	1328	1329	1330	1331	1332	1333	1334	1335	1336	1337	1338	1339	1340	1341	1342	1343	1344	1345	1346	1347	1348	1349	1350	1351	1352	1353	1354	1355	1356	1357	1358	1359	1360	1361	1362	1363	1364	1365	1366	1367	1368	1369	1370	1371	1372	1373	1374	1375	1376	1377	1378	1379	1380	1381	1382	1383	1384	1385	1386	1387	1388	1389	1390	1391	1392	1393	1394	1395	1396	1397	1398	1399	1400	1401	1402	1403	1404	1405	1406	1407	1408	1409	1410	1411	1412	1413	1414	1415	1416	1417	1418	1419	1420	1421	1422	1423	1424	1425	1426	1427	1428	1429	1430	1431	1432	1433	1434	1435	1436	1437	1438	1439	1440	1441	1442	1443	1444	1445	1446	1447	1448	1449	1450	1451	1452	1453	1454	1455	1456	1457	1458	1459	1460	1461	1462	1463	1464	1465	1466	1467	1468	1469	1470	1471	1472	1473	1474	1475	1476	1477	1478	1479	1480	1481	1482	1483	1484	1485	1486	1487	1488	1489	1490	1491	1492	1493	1494	1495	1496	1497	1498	1499	1500	1501	1502	1503	1504	1505	1506	1507	1508	1509	1510	1511	1512	1513	1514	1515	1516	1517	1518	1519	1520	1521	1522	1523	1524	1525	1526	1527	1528	1529	1530	1531	1532	1533	1534	1535	1536	1537	1538	1539	1540	1541	1542	1543	1544	1545	1546	1547	1548	1549	1550	1551	1552	1553	1554	1555	1556	1557	1558	1559	1560	1561	1562	1563	1564	1565	1566	1567	1568</

PORT INDEX AND TRANSFER									
PORT INDEX	STATE	PORT INDEX	STATE	PORT INDEX	STATE	PORT INDEX	STATE	PORT INDEX	STATE
01	AL	01	AL	01	AL	01	AL	01	AL
02	AK	02	AK	02	AK	02	AK	02	AK
03	CA	03	CA	03	CA	03	CA	03	CA
04	CO	04	CO	04	CO	04	CO	04	CO
05	CT	05	CT	05	CT	05	CT	05	CT
06	DE	06	DE	06	DE	06	DE	06	DE
07	FL	07	FL	07	FL	07	FL	07	FL
08	GA	08	GA	08	GA	08	GA	08	GA
09	HI	09	HI	09	HI	09	HI	09	HI
10	IL	10	IL	10	IL	10	IL	10	IL
11	IN	11	IN	11	IN	11	IN	11	IN
12	IO	12	IO	12	IO	12	IO	12	IO
13	KS	13	KS	13	KS	13	KS	13	KS
14	KY	14	KY	14	KY	14	KY	14	KY
15	LA	15	LA	15	LA	15	LA	15	LA
16	MA	16	MA	16	MA	16	MA	16	MA
17	MD	17	MD	17	MD	17	MD	17	MD
18	ME	18	ME	18	ME	18	ME	18	ME
19	MI	19	MI	19	MI	19	MI	19	MI
20	MO	20	MO	20	MO	20	MO	20	MO
21	NE	21	NE	21	NE	21	NE	21	NE
22	NH	22	NH	22	NH	22	NH	22	NH
23	NJ	23	NJ	23	NJ	23	NJ	23	NJ
24	NM	24	NM	24	NM	24	NM	24	NM
25	NY	25	NY	25	NY	25	NY	25	NY
26	OK	26	OK	26	OK	26	OK	26	OK
27	OR	27	OR	27	OR	27	OR	27	OR
28	PA	28	PA	28	PA	28	PA	28	PA
29	RI	29	RI	29	RI	29	RI	29	RI
30	SC	30	SC	30	SC	30	SC	30	SC
31	SD	31	SD	31	SD	31	SD	31	SD
32	TN	32	TN	32	TN	32	TN	32	TN
33	TX	33	TX	33	TX	33	TX	33	TX
34	UT	34	UT	34	UT	34	UT	34	UT
35	VA	35	VA	35	VA	35	VA	35	VA
36	VT	36	VT	36	VT	36	VT	36	VT
37	WA	37	WA	37	WA	37	WA	37	WA
38	WI	38	WI	38	WI	38	WI	38	WI
39	WY	39	WY	39	WY	39	WY	39	WY
40	ZZ	40	ZZ	40	ZZ	40	ZZ	40	ZZ

Figure 17. Data base reference listing for port index and transfer.

As another example, a path involving an incorrect and hazardous sequence of events has been analyzed. In this case the operator has driven the CET into the transfer room (0101), driven the CET over the port within tolerances (0102), indexed the CET over the port gate using the automatic indexing system (0104), turned off the CET drive power (0105), accessed the auxiliary electric power for the transfer operations (0204), raised the cask (0208), and opened the cask gate (0211) without having sealed the cask to the port gate, resulting in a potential radioactive leak. According to the event tree, the probability of this sequence of events is .00637601 and requires 17 minutes and 15 seconds (Figure 19). Although low, this value indicates that design changes must be implemented. Interlocks between the CET gates and port attachment mechanisms might be included in the design, or, more appropriately, the operator might be more thoroughly trained and provided a check list for performing the function. Thus, (a) changes can be made in hardware, making this sequence of events completely impossible, or, alternatively, (b) controls and displays can be redesigned and training and operating procedures can be improved to reduce the probabilities of certain ACTIONS. After having implemented these changes in the equipment, procedures, or training, the data base can be re-structured using the edit procedures and the LINK path can be re-examined with the analysis procedures. In this way, alternative designs can be evaluated before the system goes into operation.

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TABLE 1
PROBABILITIES OF ERROR FOR
ANNUNCIATED LEGEND LIGHTS

ACTION	ERROR PROBABILITY
Respond to an annunciated legend light (one of one)	.0001 (.00005 to .001)
Reading the message (this figure includes the probability of reading the wrong legend light)	.001 (.0005 to .005)
Resume attention to a legend light within 1 minute after an interruption (sound and blinking cancelled before interruption)	.001 (.0001 to .01)
Respond to a legend light if more than 1 minute elapses after an interruption (sound and blinking cancelled before interruption)	.95 (.5 to .99)

TABLE 2

PROBABILITY OF FAILURE TO RESPOND TO ONE
RANDOMLY SELECTED ANNUNCIATOR OF SEVERAL

NUMBER OF ANNUNCIATORS	ERROR PROBABILITY
1	.0001 (.00005 to .001)
2	.006 (.0006 to .06)
3	.001 (.0001 to .01)
4	.002 (.0002 to .02)
5	.003 (.0003 to .03)
6	.005 (.0005 to .05)
7	.009 (.0009 to .09)
8	.02 (.002 to .2)
9	.03 (.003 to .3)
10	.05 (.005 to .5)
11-15	.10 (.01 to .999)
16-20	.15 (.015 to .999)
21-40	.20 (.02 to .999)
40	.25 (.025 to .999)

TABLE 3
PROBABILITIES OF ERRORS OF COMMISSION IN READING
QUANTITATIVE INFORMATION FROM DISPLAYS

READING ACTION	ERROR PROBABILITY
Analog meter	.003 (.001 to .03)
Digital readout	.001 (.0005 to .01)
Chart recorder	.006 (.003 to .06)
Printing recorder with large number of parameters	.05 (.01 to .2)
Graphs	.01 (.005 to .05)
Values from indicator lamps that are used as quantitative displays	.001 (.0005 to .01)
Recognize that an instrument being read is jammed, if there are no indicators to alert the user	.1 (.01 to .2)

TABLE 4
PROBABILITIES OF ERRORS IN
RECORDING READINGS

NUMBER OF DIGITS TO BE RECORDED	ERROR PROBABILITY
≤ 3	Negligible
> 3	.001 (.005 to .01)

TABLE 5
PROBABILITIES OF ERRORS OF COMMISSION FOR
CHECK-READING DISPLAYS

CHECK-READING ACTION	ERROR PROBABILITY
Digital indicators (these must be read—there is no true check-reading function)	.001 (.005 to .01)
Analog meters with easily seen limit marks	.001 (.005 to .002)
Analog meters with difficult to see limit marks, such as scribed lines	.002 (.0005 to .003)
Analog meters without limit marks	.003 (.001 to .005)
Analog type chart recorders with limit marks	.002 (.0005 to .005)
Analog type chart recorders without limit marks	.006 (.003 to .01)
Confirming a status change on a status lamp	Negligible
Checking the wrong indicator lamp (in an array of lamps)	.003 (.0005 to .01)
Misinterpreting the indication on the indicator lamp	.001 (.0001 to .01)

TABLE 6

PROBABILITIES OF ERROR FOR INITIAL AUDIT (NO SPECIAL
ALERTING CUES, AND ONLY ONE DEVIANT DISPLAY)

ACTION	ERROR PROBABILITY
Deviant analog display with limit marks	.05 (.01 - .1)
Deviant analog display without limit marks	.15 (.03 - .3)
Annunciator light requiring action, which is no longer annunciated	.9 (.8 - .98)
Incorrect status of a legend light, other than an annunciator light	.98 (.96 - .996)
Incorrect status of an indicator lamp	.99 (.98 - .999)

TABLE 7
PROBABILITIES OF ERRORS OF COMMISSION IN
OPERATING MANUAL CONTROLS

ACTION	ERROR PROBABILITY
Select wrong control in a group of identical controls identified by labels only	.003 (.001 to .01)
Select wrong controls from a functionally grouped set of controls	.001 (.0005 to .01)
Select wrong control from a panel with clearly drawn mimic lines	.0005 (.0001 to .001)
Turn control in wrong direction (no violation of populational stereotypes)	.0005 (.0001 to .001)
Turn control in wrong direction (violates a strong populational stereotype)	.05 (.005 to .1)
Turn control in wrong direction under high stress (design violates a strong populational stereotype)	.5 (.1 to .9)
Set a multiposition selector switch to an incorrect setting	.001 (.0001 to .1)
Improperly mate a connector	.01 (.001 to .05)

TABLE 8
PROBABILITIES OF ERRORS IN RECALLING SPECIAL
INSTRUCTION ITEMS GIVEN ORALLY

ACTION	ERROR PROBABILITY
Failure to recall any given item, given the following number of items to remember:	
1	.001 (.0005 - .005)
2	.003 (.0015 - .015)
3	.01 (.0005 - .005)
4	.03 (.0015 - .015)
5	.1 (.005 - .05)
Unrecovered failure to recall first item if supervisor checks to see that the task was done	Negligible
<i>If item is written down by recipient:</i>	
Failure to recall any item (exclusive of errors in writing)	.001 (.0005 - .005)