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PHASER User's Manual
Version 2.10

Robert J. Roginski

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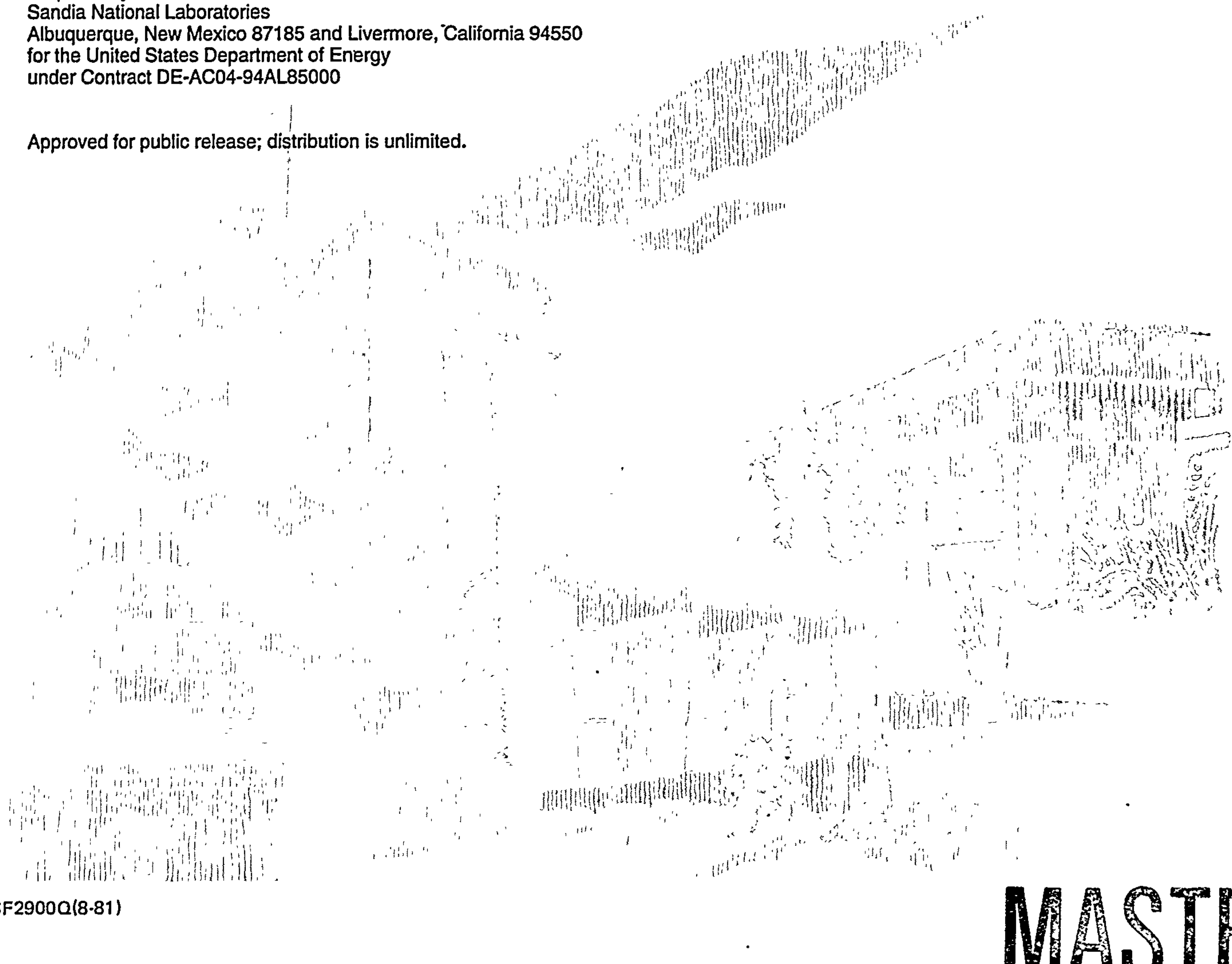

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Version 2.10

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Abstract

PHASER (Probabilistic Hybrid Analytical System Evaluation Routine) is a computer code for solving the top event probability of a system fault tree. It has the capability for easy migration of individual basic event probabilities from a zero-"scale"-factor (completely subjective) state to one in which the analyst has total knowledge (completely stochastic) about each basic event. The code implements a fuzzy algebra solution for subjective data, a probabilistic solution for stochastic data, and a hybrid mathematics solution for data that are partly subjective and partly stochastic. Events that are not completely subjective or completely stochastic are hybrid events and are internally handled as such. The stochastic and fuzzy ranges of uncertainty in the top event probability are also computed for the analyst. These are provided in the form of a fuzzy function for the subjective uncertainty, a probability density function (PDF) for the stochastic variability, and the overall "confidence" factors for the two constituents of uncertainty, giving a complete hybrid result. PHASER interfaces with other Sandia codes (SABLE, LHS and LHSPOST) to assist the user in determining cutsets, and to compute probability density functions.

ACKNOWLEDGMENTS

The author wishes to acknowledge J. Arlin Cooper of Sandia National Laboratories for his significant contribution to the development of PHASER. He developed the methodology utilized by the code for calculating scale and confidence factors and for determining the disjoint sets required for precise top event quantification. These are described in Reference 1. He also developed the methodology for considering dependencies in probability calculations, and for determining cutset importance and event sensitivity. These are described in Reference 2.

Gregory D. Wyss of Sandia National Laboratories defined the method and syntax which interface the LHS code to PHASER when the sampling of user-defined distributions is required. He also supplied the definition of the LHS File Format that appears in Appendix F.

Contents

List of Tables

List of Figures

PHASER User's Manual Version 2.10

1. Introduction

Probabilistic Risk Assessment (PRA) has been used in many studies at Sandia National Laboratories over the years. Traditional PRA software tools enable the analyst to calculate point estimate probabilities for the top event of a system fault tree. Some of these software tools have the capability to perform an uncertainty analysis on the fault tree using a simulation of probabilistic calculus. Calculating a probabilistic uncertainty spread normally requires either (1) a large amount of reliable data that can be used as direct input, or (2) specifications for distribution types for each basic event in the fault tree that will closely match the behavior of each corresponding event. In either case, a reasonably accurate assessment of each basic event's statistical probability is required in order to produce meaningful results.

Frequently, studies are conducted in which knowledge of certain events is not well defined or is completely unavailable. Events such as these may be highly subjective but still contribute to the probability of the top event of the fault tree. In at least some cases, conventional PRA techniques do not accurately portray the top event probability because of an inherent tendency to de-emphasize the extreme values dependent on ill-defined data.

The PHASER code implements a technique for combining well known data with subjective data to provide a more comprehensive analysis. PHASER is capable of solving problems conventionally, and it is also capable of including any degree of subjectivity in any or all of the basic events in the fault tree. This results in the derivation of a degree of subjectivity value for the top event. Some of the noteworthy features of PHASER include an "exact" (not rare-event) disjoint cutset top-event solution, and "constrained mathematics" ("exact") variability/uncertainty analysis (see Reference 1).

PHASER also implements a capability to define Event Dependencies. This is accomplished by allowing the user to specify one or more groups (subsets) of interdependent basic events in a Dependency Group statement. This important feature is frequently not considered by analysts because it is found to be either inadequate or lacking entirely in other analysis codes. The methodology for calculating Event Dependencies is described in Reference 2.

Analytical aids for determining Cutset Importance and Event Sensitivity are also implemented. Importance will allow the analyst to easily identify the cutsets that are the most significant contributors to the top event probability. Sensitivity will show at a glance the events that trigger the most change in the top event when adjusted by a known percentage of their respective individual probability values. The methodologies for determining Importance and Sensitivity are also described in Reference 2.

2. Description of PHASER

PHASER reads input information from two or more input files and directs output to various plotting devices in addition to creating output files. The type of output produced depends entirely on the output options selected by the user. This section gives a general description of each device or output file and its function. Information regarding problem size (i.e., program limits) and machine compatibility is also included in this section.

2.1 Input structure

There are two data files that are always required as PHASER input. These are the Keyword/Quantification File and the Cutset File. The Keyword/Quantification File is the primary input file to PHASER; it contains the keywords that set parameters and select various options. It also contains the fault tree quantification data required for execution. These data include the basic event probabilities, the event dependency group definitions, the fuzzy uncertainty and probability distribution definitions, and the scale factors (relative amount of stochastic information) that are required for hybrid events.

PHASER execution is controlled by the Keyword/Quantification File whose pathname is specified on the program execution command line. If no pathname is entered on the command line, PHASER will terminate immediately after alerting the user of this omission. The keywords contained in this file define input/output file specifications and other program options. The PHASER Keyword/Quantification File is read in a free format that is token-oriented. A token is defined as a grouping of one or more contiguous characters delimited by at least one tab or space character (or any combination of tabs and spaces). In most instances, the type of token required (character string, floating-point constant, or integer constant) is determined by the context of the input. All tokens are verified for correctness of syntax and for other relevant conditions as they are encountered in the current line of input.

The required Cutset File contains the cutset equation for the top event in minimum "sum of products" form. This is an eye-readable ASCII formatted file that is normally generated by the SABLE code. The format of the Cutset File is described in Section 3.2 beginning on Page 31.

Sampling Information Files are optional input files. These files are generated by LHS or by LHSPOST and contain the probability density function values that are used by PHASER when probabilistic or hybrid event definitions are found in the Keyword/Quantification File. Information in these files includes point estimate values and values computed for each observation of the sample. They also contain the symbolic information that allows PHASER to reference any and all values by name. A Sampling Information File is not required if all event definitions are totally fuzzy.

All PHASER input files are described in more detail in Section 3.

2.2 Output Structure

Excluding HPGL plot files, there are only two files created by PHASER:

QA Output File	This file contains QA (Quality Assurance) information such as run date/time along with an echo of the user's Keyword/Quantification File and an echo of the user-specified Cutset File. Warning messages and fatal diagnostics are also written to this file. If requested, optional debugging information will be found at the end of this file.
Disjoint Set File	This optional output file will contain the Disjoint Sets used by PHASER to compute the top event probability. This file can be rather large and should be requested only if it is required as input to some other code.

Both PHASER output files are described in further detail in Section 4. The QA Output File is always generated. The Disjoint Set File is only generated if the user has requested a precise top event quantification by specifying "PRECISERESULT = YES *DJsetfilename*" in the Keyword/Quantification Input File.

PHASER currently supports the following devices for graphical output:

CRT	The CRT (Cathode Ray Tube) device is the user's computer screen. If PHASER is executing on an IBM or compatible personal computer, all requested plots will be generated using standard VGA (Video Graphics Array) mode at a resolution of 640 x 480.
HPLJ	The HPLJ (Hewlett Packard LaserJet) device requires an HP LaserJet printer capable of printing at a resolution of 300 DPI (Dots per Inch).
HPGL	The HPGL (Hewlett Packard Graphics Language) device is actually a series of disk files that are easily identified by their .HGL file extension. These files are easily imported by almost every commercially available word processing program. This makes it possible for the user to incorporate PHASER plots directly into a report or manual.

These devices are described in further detail in Section 4. The user can specify zero, one or two plotting devices if the selection does not violate any of the rules defined in Section 4. The user can also inhibit plotting entirely (this is the default), if all six keywords pertaining to plot types are followed by "= NO" in the Keyword/ Quantification Input File.

2.3 Problem Size

The current limits of PHASER (Version 2.10) are defined in Table 1. A fatal error diagnostic will be written to the QA Output File if any of these limits is exceeded. In this case, execution will be immediately terminated. The limits shown are subject to change with each subsequent release of PHASER.

Basic Events	100
Basic Event References (All Cutsets)	800
Levels of Presumption (Fuzzy)	21
Cutsets	100
LHS Sampled Events	100
LHS Observations	1000
LHS File Paths	16
Plotting Devices	3
Dependency Group Definitions	50

Table 1. PHASER Version 2.10 Limits.

There are also limits associated with the internal generation of Disjoint Sets. These are usually not of concern to the user, but an appropriate fatal diagnostic will be issued to the QA Output File if any of them are exceeded.

2.4 Machine Compatibility

Version 2.10 of PHASER runs only on an IBM or compatible personal computer (PC) having a 386 or later central processing unit (CPU). It can also execute without a numeric coprocessor. If a coprocessor is detected at runtime, however, it will be used and will execute faster than it would without a coprocessor installed. The coprocessor is highly recommended because some of the options are extremely compute intensive. Without a coprocessor, PHASER execution time for large problems may not be acceptable to the user.

The PHASER executable code is currently compiled with Microsoft Fortran PowerStation Ver. 1.0a and requires approximately 8M (megabytes) of extended RAM (random access memory). The PHASER executable requires the presence of the DOS extender file DOSXMSF.EXE in a directory that is always searched via the DOS PATH statement. All memory requirements are subject to change with each new release of PHASER.

PHASER utilizes Version 7.00 of the Integrated Graphics Library INGRAF by Sutrasoft to produce all graphical output. The Sutrasoft copyright statement is displayed on the CRT each time PHASER begins a new plot. This is required under the terms and conditions of the Sutrasoft program licensing agreement.

Future requirements may also dictate the need to port PHASER to additional platforms such as UNIX, Windows 95, Windows NT, etc. Conversion to these systems is not difficult because PHASER is written using portable Fortran 77 statements in all but a few instances. The only obstacle to porting would be acquiring a version of the INGRAF library for the target platform.

3. Input Files

3.1 Keyword/Quantification Input File

PHASER obtains its execution options and instructions from a series of Keyword Statements in a file whose pathname is specified on the program execution command line. If no pathname is specified, PHASER will alert the user and immediately terminate. If the pathname is only a filename, PHASER will expect to find the file in the user's current directory. Some keywords set flags while others indicate that a value (numeric or character) is to be read. In this case, a missing or illegal value will cause PHASER to abort execution and to write a fatal error message to the QA output file.

Keywords recognized by PHASER are described in Section 3.1.2. The Quantification Statements that define the basic event probabilities are explained in Section 3.1.3. Although not shown by example, the Keyword and Quantification Statements may be interspersed within the file. This is left to the discretion of the user. Examples of Keyword/Quantification Files are listed in Appendices A through E.

3.1.1 General Considerations

The Keyword/Quantification File consists of column-independent records (or lines) that can be up to 2000 characters in length. The records consist of tokens that are delimited by at least one space or tab character or any combination of these two characters. A complete PHASER Keyword Statement must begin with one of the recognized keywords and must adhere to the syntax defined for that keyword. Any statement beginning with a token that is not a recognized keyword is assumed to be a fuzzy event definition (quantification) statement.

Most keyword command tokens may be followed by an optional '=' (equal sign) for improved readability. Use of the '=' is illustrated in many of the examples that follow. Numeric tokens (values) may also use a ',' (comma) as a delimiter. Keywords that are also recognized by the LHS code must not be followed by '=' or a fatal error will occur during LHS execution[1].

The keywords currently recognized by PHASER are described in Section 3.1.2. The keywords shown there are all in upper case, but PHASER will accept any combination of upper or lower case, as long as the spelling agrees. This is also holds true for basic event names and character string constants (such as Yes, No and Wait) that are required to define the various execution options.

The remainder of this section consists of four subsections that define the use of features common to all keyword or quantification statements. Respectively, these features are Comments, Continuation Lines, Numeric Constants, and Statement Errors.

3.1.1.1 Comments

Comments can be placed anywhere in the Keyword/Quantification File using any of three different methods. A trailing comment may be added to a line by appending a '$' at the end of the desired line. In this case, however, the '$' must be preceded by at least one space or tab character so that is not interpreted as part of the previous token. PHASER will then ignore the '$' and everything that follows it on that line. Whole line comments are allowed if a '$' is the first non-blank, non-tab character on a line. However, the '$' must not start beyond Column 30 for compatibility reasons. The third method of commenting is the use of totally blank lines that may contain only spaces or tab characters.

3.1.1.2 Continuation Lines

Continuation lines are also possible in the Keyword/Quantification File. Any line can be continued by placing a continuation line character ('#' or '%') as the last character on the line. The continuation character must be preceded by at least one space or tab character. When PHASER detects the continuation character as the last token on the line, it will read the next line from the file and continue processing tokens. Continuations are particularly useful if the user must prepare the input file with a text editor having a line size limit which is smaller than 2000 characters. Two thousand characters is the maximum line size allowed by PHASER. Trailing comments are legal on continuation lines as long as there is at least one tab or space character between the continuation character and the '$' that indicates the beginning of the trailing comment.

[1] The interfaces between PHASER, LHS, LHSPOST and other input/output functions is shown graphically on Page 95 (Appendix F).

3.1.1.3 Numeric Constants

Numeric constants are required input at several places in the Keyword/Quantification File. The required constant may be either an integer or a real number. In places where an integer value is expected, the decimal point, with or without trailing digits, must not be contained in the constant. If a real value is expected, PHASER will accept the value in any of three formats: fixed point, floating point (E-format), or integer. In this case, the value will be converted to a Fortran double precision real variable regardless of the format used.

3.1.1.4 Statement Errors

All keyword and quantification statements are checked for validity before PHASER begins processing. As previously stated, any statement beginning with a keyword not recognized by PHASER or by LHS is assumed to be a Fuzzy Event Definition Statement. All parameters following the keyword are also checked for validity. Any parameter that is not recognized or does not fall within the expected range will also generate a fatal error diagnostic. This applies to both the keyword and the quantification statements. Some errors encountered by PHASER are not fatal and therefore will not cause execution to terminate, but will generate a warning diagnostic. Both fatal and warning diagnostics will be found in Part 1 (echo of Keyword/ Quantification Input File) of the QA Output File. Some diagnostics will immediately follow the erroneous statement while others will appear at the end of Part 1.

3.1.2 Keyword Statements

The Keyword Statements described in this section allow the user to define options and/or set parameters in PHASER or LHS. Some keywords are recognized by both codes. Unless indicated otherwise, a default value will be assumed for any missing keyword statement. These default values are also defined in this section. As previously stated, the optional (indicated by square brackets) '=' (equal sign) is not permitted in statements that must also be read by the LHS code. The keywords that are required for LHS execution are described in this document for user convenience. The user can refer to Reference 3 for the definition and syntax of all other LHS keywords (and distribution types).

Fuzzy Event Definition Statements are explained in Section 3.1.3. Probabilistic Event Definition Statements (event distributions) are also explained in Section 3.1.3.

CUTSETFILE [=] *csfile* — Specifies *csfile* as the name of the Cutset File that will be used as cutset input by PHASER. The parameter *csfile* may specify a full path of 50 characters in length. If the user specifies only a filename, the file must be found in the current directory.

In medium and large size fault trees, this file is typically generated by executing the SABLE code. SABLE will create this file if the user checks the option box for "Write Unquantified Cut Sets to a Separate File", and enters a filename in the text box to the right of the button labeled "Write File".

For smaller fault trees, the user may wish to manually create the file using his or her text editor. This is allowed as long as the file conforms to the expected format. Example Cutset File listings appear in Appendices A through E.

Because PHASER always requires cutset information, specifying the CUTSETFILE Keyword Statement is mandatory.

Example: `CUTSETFILE = D:\STUDY-1\TREE-CS.DAT`
Default: `Not Applicable (A filename must be specified)`

CUTSETLIMIT [=] *limit* Specifies an integer parameter *limit* to be the maximum number of cutsets to be displayed in composite plots. The minimum allowable value of *limit* currently is 1; the maximum value is 10. If the value specified for *limit* exceeds the actual number of cutsets, then all cutsets will be displayed.

Example: `CUTSETLIMIT = 4`
Default: `CUTSETLIMIT = 10`

DEBUGINFO [=] Yes/No Instructs PHASER to add debugging (program variable) information to the end of the QA Output File.

Example: `DEBUGINFO = Yes`
Default: `DEBUGINFO = No`

Do not change DEBUGINFO to Yes unless you suspect a malfunction (bug) in the program. After rerunning PHASER with "DEBUGINFO = Yes", the QA Output File may be discussed with a person familiar with the code details. The user should also be aware that specifying "DEBUGINFO = Yes" will always increase the size of the QA Output File. Even in a medium size fault tree of 50-60 cutsets, this file can easily exceed several megabytes.

DELAY [=] *value*/Wait — Defines a time delay of *value* seconds for holding a plot on the user's CRT or instructs the code to hold the plot on the CRT until any key is pressed.

Examples: 1) `DELAY = 25`
2) `DELAY = Wait`

Default: `DELAY = 10`

The delay is not a maximum value because it may take longer than this to actually complete the plot. If the value indicated is less than the time required, the CRT will clear immediately upon completing the plot. In Example 2 shown above, the parameter "Wait" may be any combination of upper and lower case characters.

Plotting will normally take one or two seconds depending on the complexity of the plot and the speed of the computer's CPU. The DELAY Keyword Statement is ignored if CRT has not been selected or defaulted for output. See Keyword OUTPUTDEVICE for additional details.

DEPENDENCY-GROUP: — Specifies the beginning of a multi-line event dependency definition statement. This allows the user to define a group (subset) of interdependent basic events. The following file fragment illustrates the use of this feature.

```
PRECISERESULT  =  Yes

A  =  0.8       0.9     A=0.9
    Data:  A  BOUNDED NORMAL  0.9  0.9  1.0E-20  0.99999
B  =  0.6       0.8     A=0.7
    Data:  B  BOUNDED NORMAL  0.6  0.6  1.0E-20  0.99999
C  =  0.2       0.4     A=0.4
    Data:  C  BOUNDED NORMAL  0.2  0.2  1.0E-20  0.99999

Dependency-Group:   A   B   C
    A   B     0.7
    A   C     0.5
    B   C     0.3
End-Group

D  =  0.2       0.7     A=0.5
    Data:  D   BOUNDED NORMAL  0.5  0.5  1.0E-20  0.99999
E  =  0.2       0.4     A=0.2
    Data:  E   BOUNDED NORMAL  0.3  0.3  1.0E-20  0.99999
F  =  0.2       0.4     A=0.2
    Data:  F   BOUNDED NORMAL  0.3  0.3  1.0E-20  0.99999
```

```
Dependency-Group:   E   F
    E   F   0.1
End-Group
```

The line beginning with the token "Dependency-Group:" indicates the beginning of a dependency. This token is followed by the names of the events that are members of this group. The token "End-Group" terminates the dependency definition. Each line found between the two group delimiters specifies the relative amount of dependence between one pair of events in the group. Each unique event pair in the group must be specified in this manner. The number of event pairs (substatements) is determined as follows. If there are N events in a dependency group, then there are N(N-1)/2 event pairs that must be defined by the user. PHASER will perform tests to ensure that all required event pairs have been properly defined. Any error(s) of omission or invalid syntax will be reported in the user's QA Output File.

Another requirement is that the Fuzzy Event Definition Statements that correspond to the events in a dependency group must precede that particular dependency group definition in the user's Keyword/Quantification Input File. In the preceding example, the Probabilistic Event Definition Statements also precede their respective dependency groups, but this is not required.

Any given event name must not appear in more than one dependency group. This would be an attempt to coalesce two groups into one larger group. If this condition is detected, a fatal error diagnostic will be written to the user's QA Output File and execution will terminate. If the events of both groups are actually interdependent, the user must define all of them in a single dependency group.

Dependency group definitions are not allowed using the default "Rare Event" top event quantification technique. This feature would not be compatible with the top event probability calculation. For this reason, the user must include the statement "PRECISERESULT = Yes" in his or her Keyword/Quantification Input File as shown in the preceding example. A fatal error will be reported if this statement is missing and one or more dependency group definitions are present.

The dependency value indicated for the event pair must be greater than 0.0 and must not exceed 1.0. A zero value would indicate complete independence and therefore is not allowed (i.e., the event should not be a member of any dependency group if it is truly independent of all other events). A value of 1.0 indicates complete dependence. Dependency values of 1.0 are accepted by PHASER but should be used with caution. If both events in the pair are completely dependent on each other, then the user should consider combining them into a single event.

Any event whose name does not appear in any dependency group definition is assumed to be an independent event and is treated as such. In the preceding example, Event D is the only independent event.

ECHOCUTSETFILE [=] Yes/No

Instructs PHASER to enable or suppress the listing of the Cutset File in Part 2 of the QA Output File. Echoing this file is strongly recommended. Therefore, the user will most likely not want to specify "ECHOCUTSETFILE = No" unless the Cutset File is extremely large.

Example: `ECHOCUTSETFILE = No`
Default: `ECHOCUTSETFILE = Yes`

LHSMSG *lhsmsgfile*

Specifies parameter *lhsmsgfile* as the name of the file that will be used by the LHS code for user information and possible error diagnostics. The parameter *lhsmsgfile* may specify a full path of 50 characters in length. If event distributions must be evaluated by the LHS code, a message file must be specified by the parameter *lhsmsgfile* in a statement beginning with Keyword LHSMSG.

Example: `LHSMSG C:\STUDY-1\LHSMSG.DAT`
Default: `Not Applicable (A filename must be specified)`

LHSOBS *nobs*

Specifies parameter *nobs* as the number of observations (iterations) to be sampled. It must be an integer value in the range of 1 to 1000. If event distributions must be evaluated by the LHS code, the number of observations must be specified by the parameter *nobs* in a statement beginning with Keyword LHSOBS.

Example: `LHSOBS 200`
Default: `Not Applicable (A value must be specified)`

LHSOUT *lhsoutfile* — Specifies *lhsoutfile* as the name of the file that will be the LHS output file. The parameter *lhsoutfile* may specify a full path of 50 characters in length. PHASER reads this file to obtain values associated with distributions calculated by the LHS code. If event distributions are evaluated by the LHS code, an output file must be specified by the parameter *lhsoutfile* in a statement beginning with Keyword LHSOUT.

Example: `LHSOUT C:\STUDY-1\LHSOUT.DAT`
Default: `Not Applicable (A filename must be specified)`

LHSPOST *lhspstfile* — Specifies *lhspstfile* as the name of the file that will be the LHS postprocessor output file. The parameter *lhpstfile* may specify a full path of 50 characters in length. PHASER reads this file to obtain the values of expressions that are evaluated by the LHS postprocessor code LHSPOST. If expressions containing the names of event distributions are to be evaluated by the LHSPOST code, a postprocessor output file must be specified by the parameter *lhspstfile* in a statement beginning with Keyword LHSPOST.

Example: `LHSPOST C:\STUDY-1\LHSPOST.DAT`
Default: `Not Applicable (A filename must be specified)`

MAXDECIMALS [=] *ndpl* — Specifies parameter *ndpl* as the maximum number of decimal places to be used in displaying the probability values in any of the plot types. Parameter *ndpl* must be an integer value in the range of 1 to 6.

Example: `MAXDECIMALS = 2`
Default: `MAXDECIMALS = 6`

MAXPROBABILITY [=] *maxvalue* — Specifies parameter *maxvalue* as the upper limit of the range of integration for Probability Density Functions (PDFs). Parameter *maxvalue* must be greater than 0.0, less than or equal to 1.0, and also greater than the parameter *minvalue* specified (or defaulted) by using Keyword MINPROBABILITY.

Example: `MAXPROBABILITY = 1.0E-2`
Default: `MAXPROBABILITY = 1.0`

Narrowing the range of probabilistic integration using Keywords MINPROBABILITY and MAXPROBABILITY can result in smoother PDFs in probabilistic and hybrid plots. However, the user (if unsure) should first use a wider (i.e., the default) range in order to determine the limits of all PDFs.

MINPROBABILITY [=] *minvalue*

Specifies parameter *minvalue* as the lower limit of the range of integration for Probability Density Functions. Parameter *minvalue* must be greater than 0.0, less than 1.0, and also less than the parameter *maxvalue* specified (or defaulted) by using Keyword MAXPROBABILITY.

Example: `MINPROBABILITY = 1.0E-9`
Default: `MINPROBABILITY = 1.0E-48`

Narrowing the range of probabilistic integration using Keywords MINPROBABILITY and MAXPROBABILITY can result in smoother PDFs in probabilistic and hybrid plots. However, the user (if unsure) should first use a wider (i.e., the default) range in order to determine the limits of all PDFs.

OMITTOPEVENT [=] Yes/No

Instructs PHASER to suppress plotting of the top event in composite plots. Both the Fuzzy and the Probabilistic Top Event Plots are suppressed (omitted) in composite plots of hybrid results.

Example: `OMITTOPEVENT = Yes`
Default: `OMITTOPEVENT = No`

Specifying "OMITTOPEVENT = Yes" will allow the analyst to see all cutsets more clearly; especially in cases where one cutset is the dominant contributor to the top event. When the top event is present, it has a tendency to obscure (overlay) this dominant cutset.

NLINES [=] *nlevs*

Specifies parameter *nlevs* as the number of equally spaced lines (or levels) of presumption to be evaluated in all fuzzy algebra calculations. Parameter *nlevs* must be an integer value in the range of 2 to 21.

Example: `NLINES = 10`
Default: `NLINES = 2`

OUTPUTDEVICE [=] *dev1* [*dev2*]

Instructs PHASER to select one or two of the three supported output devices for subsequent plotting. If one or more of the four plot types (Events, Cutsets, Top Event or Composite) is requested, and Keyword OUTPUTDEVICE is not found, all plots are displayed on the CRT by default.

Examples:
1) `OUTPUTDEVICE = HPLJ $ Ok`
2) `OUTPUTDEVICE = CRT HPLJ $ Ok`
3) `OUTPUTDEVICE = HPLJ CRT $ Ok`
4) `OUTPUTDEVICE = HPLJ HPLJ $ Warning Issued`
5) `OUTPUTDEVICE = CRT HPGL $ Ok`
6) `OUTPUTDEVICE = HPLJ HPGL $ Fatal Error`

Default: `OUTPUTDEVICE = CRT $ If plots were requested`

Example 1 above selects HPLJ (Hewlett Packard LaserJet) for plotting.

Examples 2 and 3 select both CRT and HPLJ. In both examples, PHASER will always plot to the CRT before plotting to the HPLJ device.

Example 4 selects HPLJ and issues a warning diagnostic to the QA Output File.

Example 5 will select CRT and HPGL (Hewlett Packard Graphics Language File. See Section 4.2.3 beginning on Page 38 for an explanation of the HPGL file naming convention used by PHASER.

Example 6 will cause a fatal diagnostic to be written to the QA Output File because one of the two devices must be the CRT if two devices are specified.

PLOTCOMPOSITE [=] Yes/No

Instructs PHASER to request or suppress generation of a Composite Plot for all devices referenced in the OUTPUTDEVICE Keyword Statement. The Composite plot shows the top event along with cutsets that are the greatest contributors to the top event probability.

Example: `PLOTCOMPOSITE = Yes`
Default: `PLOTCOMPOSITE = No`

The user must specify "PLOTCOMPOSITE = Yes" to request a Composite Plot. The number of cutsets to be shown in the Composite Plot is determined by Keyword CUTSETLIMIT.

PLOTCUTSETS [=] Yes/No

Instructs PHASER to request or suppress generation of all Cutset Plots for all devices referenced in the OUTPUTDEVICE keyword command statement. Each Cutset Plot will be identified by the Cutset Number along with the names of the events referenced in the cutset.

Example: `PLOTCUTSETS = Yes`
Default: `PLOTCUTSETS = No`

The user must specify "PLOTCUTSETS = Yes" to request Cutset Plots.

PLOTEVENTS [=] Yes/No

Instructs PHASER to request or suppress generation of all Event Plots for all devices referenced in the OUTPUTDEVICE keyword command statement. Each Event Plot will be identified by Event Name.

Examples: `PLOTEVENTS = Yes`
Default: `PLOTEVENTS = No`

The user must specify "PLOTEVENTS = Yes" to request Event Plots.

PLOTIMPORTANCE [=] Yes/No [*nranks*]

Instructs PHASER to produce a plot that displays the importance rankings (relative to the top event) of cutsets. All cutsets in the fault tree are ranked if the optional parameter *nranks* is omitted. If present, *nranks* must specify an integer value in the range of 1 to N, where N is the total number of cutsets in the fault tree.

Examples:
```
PLOTIMPORTANCE = Yes
PLOTIMPORTANCE = Yes 20
```
Default: `PLOTIMPORTANCE = No`

The first example above will display all cutsets defined in the fault tree using a horizontal bar graph format. The second example will display the 20 largest contributors to the top event probability in descending order of relative importance.

The plot shown below is an example of the graphical output produced by use of the Keyword PLOTIMPORTANCE. The 20 most "important" cutsets in a 55-cutset fault tree are displayed.

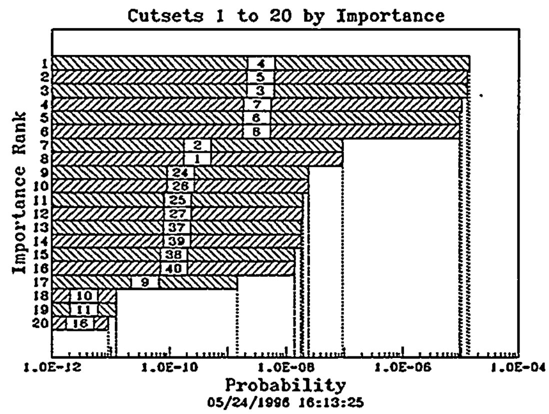

Figure 1. Importance Plot Example.

The number that appears in the middle of each bar is the number of the cutset. This is the number that is assigned to cutsets (by PHASER) in the order of their appearance in the user's Cutset Input File. The cutset number will be placed to the right of any bar that is not wide enough to accommodate the number internally.

A maximum of 20 cutset ranks will be displayed on a single plot. If the number of specified (or defaulted) ranks is greater than 20, PHASER will generate as many continuation plots as required to satisfy the request. If the user has requested HPGL file output by specifying "OUTPUTDEVICE = HPGL" in the Keyword/ Quantification Input File, the Importance Plot Filenames will use the format "IMP-nnnn", where "nnnn" is the continuation plot number in the sequence padded with leading zeros. This number will be a minimum of 0001 (*nranks* = 1 to 20) and a maximum of 0005 (*nranks* = 81 to 100).

Importance Plots will allow the analyst to easily identify the cutsets that are the most significant contributors to the uppermost extreme top event probability. The user-specified scale values (refer to Section 3.1.3.1) are used in the Cutset Importance calculations.

PLOTSENSITIVITY [=] Yes/No [*nranks*]

Instructs PHASER to produce a plot that displays the sensitivity rankings (relative to the top event) of events. All events in the fault tree are ranked if the optional parameter *nranks* is omitted. If present, *nranks* must specify an integer value in the range of 1 to N, where N is the total number of events in the fault tree.

Examples:
```
PLOTSENSITIVITY = Yes
PLOTSENSITIVITY = Yes 20
```
Default:
```
PLOTSENSITIVITY = No
```

The first example above will display all events defined in the fault tree using a horizontal bar graph format. The second example will display the 20 most "sensitive" events in descending order of the calculated sensitivities.

The plot shown below is an example of the graphical output produced by use of the Keyword PLOTSENSITIVITY. The 20 most "sensitive" events in a 55-cutset fault tree are displayed.

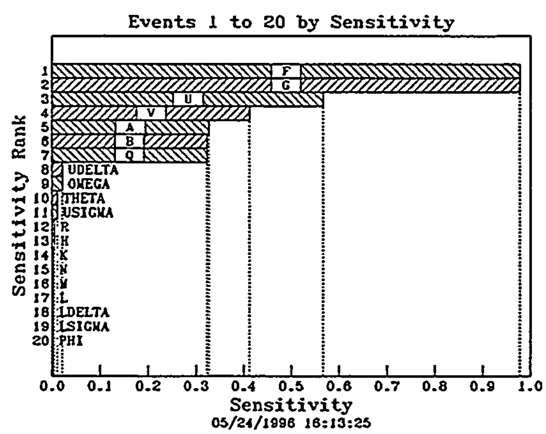

Figure 2. Sensitivity Plot Example.

The identifier that appears in the middle of each bar is the name of the event. This is the name that is assigned by the user in the Keyword/Quantification Input File. As shown above, the event name will be placed to the right of any bar that is not wide enough to accommodate the name internally.

A maximum of 20 event ranks will be displayed on a single plot. If the number of specified (or defaulted) ranks is greater than 20, PHASER will generate as many continuation plots as required to satisfy the request. If the user has requested HPGL file output by specifying "OUTPUTDEVICE = HPGL" in the Keyword/ Quantification Input File, the Sensitivity Plot Filenames will use the format "SEN-nnnn", where "nnnn" is the continuation plot number in the sequence padded with leading zeros. This number will be a minimum of 0001 (*nranks* = 1 to 20) and a maximum of 0005 (*nranks* = 81 to 100).

Sensitivity Plots will show at a glance the events that trigger the most change in the uppermost extreme of the top event probability when adjusted by a known percentage of their respective individual probability values. The user-specified scale values (refer to Section 3.1.3.1) are used in the Event Sensitivity calculations.

PLOTTOPEVENT [=] Yes/No

Instructs PHASER to request or suppress generation of a Top Event Plot for all devices referenced in the OUTPUTDEVICE keyword command statement. The Top Event Plot will be identified by the Top Event Name.

Example: `PLOTTOPEVENT = Yes`
Default: `PLOTTOPEVENT = No`

The user must specify "PLOTTOPEVENT = Yes" to request a Top Event Plot.

PRECISERESULT [=] Yes/No/F/P [*DJsetfilename*]

Instructs PHASER to calculate the Top Event probability using an "exact" (not rare event) technique. Specifying "PRECISERESULT = Yes" will always result in longer execution times. The optional parameter *DJsetfilename* indicates the name of the disk file to which the disjoint set equation will be written. The parameter *DJsetfilename* may specify a full path of 50 characters in length.

Examples:
1) `PRECISERESULT = Yes`
2) `PRECISERESULT = Yes D:\STUDY-1\TREE.DJS`
3) `PRECISERESULT = No`
4) `PRECISERESULT = F`
5) `PRECISERESULT = P`

Default: `PRECISERESULT = No`

Example 1 above instructs PHASER to calculate an "exact" Top Event probability by generating and evaluating (in memory) the disjoint set equation for the Top Event. In addition, Example 2 specifies that the disjoint set equation to be written to the file TREE.DJS in the STUDY-1 subdirectory of drive D. Example 3 instructs PHASER to use the rare event approximation technique (the default) to compute the Top Event probability. Example 4 instructs PHASER to calculate an "exact" Top Event for only the Fuzzy component. Example 5 selects only the Probabilistic component for "exact" computation.

As previously stated, the Disjoint Set File has the potential to be a very large file. For this reason, the time required to write this file to disk may add several minutes to the total execution time. Additional details regarding the Disjoint Set File are described in Section 4.1.2 on Page 37.

SAMMOD [=] *option*

Instructs PHASER to select parameter *option* to determine the source of the probabilistic point estimate values related to the LHS code. Parameter *option* must be one of the three case-insensitive character string constants shown in the examples below.

Examples:
1) `SAMMOD = User`
2) `SAMMOD = LHS`
3) `SAMMOD = UserOverride`

Default: `SAMMOD = User`

Example 1 above instructs PHASER to use the point estimate values supplied in all DATA: statements or the DATASET: segment where the probabilistic event distributions are defined. If "SAMMOD = User" is specified, a point estimate value is mandatory in all probabilistic event definitions. Refer to Section 3.1.3.2 beginning on Page 28.

Example 2 instructs PHASER to use the point estimate values calculated by LHS. These values are read from the point estimate (first) section of the LHS or LHSPOST output file that contains the definition for these events.

Up to 18 different files can be specified by the user for PHASER sampling input. Refer to Section 3.1.3.2 beginning on Page 28.

Example 3 is similar to Example 1 in that it instructs PHASER to use the point estimate values supplied by the user. However, if a point estimate value is omitted for a given event, then PHASER will use the LHS calculated point estimate for that particular event (as described above in Example 2). Refer to Section 3.1.3.2 beginning on Page 28.

The user should note that Keyword SAMMOD has no bearing on the fuzzy point estimates used in PHASER. These are always calculated from the fuzzy probability values specified for each event in the Keyword/ Quantification Input File.

SMOOTHFACTOR [=] *value*/Auto

Instructs PHASER to use a smoothing factor of *value* when drawing Probability Density Functions (PDFs) in Hybrid or totally probabilistic plots. The parameter *value* can be a real number in the range of 1.0 to 5.0 inclusive. If the case-insensitive character string Auto is specified, PHASER will calculate an appropriate value for each individual PDF.

Examples:
1) `SMOOTHFACTOR = 3.75`
2) `SMOOTHFACTOR = 1.0`
3) `SMOOTHFACTOR = Auto`

Default: `SMOOTHFACTOR = 1.0`

Example 1 Instructs PHASER to use a smoothing factor of 3.75. Example 2 selects a smoothing factor of 1.0 (the default value). Example 3 will instruct PHASER to calculate individual smoothing factors for all PDFs drawn in all plots.

A larger smoothing factor *value* will produce a smoother looking PDF curve, but has a tendency to reduce all the frequency values. For this reason, a smoothing factor *value* greater than 5.0 will not be accepted (or Auto-calculated) by PHASER.

3.1.3 Quantification Statements

The event definitions are specified by the user in Quantification Statements that must adhere to the rules and syntax described in the next two subsections. A Fuzzy Event Definition Statement is normally required for each basic event in the fault tree. The single exception to this is explained in Subsection 3.1.3.1. A Probabilistic Event Definition Statement is required only if a non-zero A-factor (scale) value is specified in the corresponding Fuzzy Event Definition Statement.

Examples of Quantification Statements in the next two subsections will show the fuzzy definition immediately followed by the probabilistic definition. As previously stated, these definitions may be interspersed within the file. The only exception to this rule is the DATASET: segment; which, if used, must not be followed by anything other than a series of Probabilistic Event Definition Statements for the remainder of the file. An example of this is illustrated in Subsection 3.1.3.2.

3.1.3.1 Fuzzy Event Definition Statements

Each basic event in the user's fault tree must be described (or defaulted) using a Fuzzy Event Definition Statement. The complete syntax of this statement is as follows.

event_name [=] *prob1* [*prob2* [*prob3* [*prob4*]]] [A=*scale_value*]

Obviously, the parameter *event_name* defines the name of the basic event. The *event_name* parameter must be a combination of 1 to 16 case-insensitive characters that cannot be interpreted as a numeric constant under the ANSI Fortran standard. It must also be unique within all Fuzzy Event Definition Statements. Also, none of the PHASER or LHS Keywords should be used as *event_name* parameters. This will cause a fatal error diagnostic to be written to the user's QA Output File. These rules are strictly enforced in order to establish the required event linkage with the other codes that interface with PHASER (SEATREE, SABLE, LHS and LHSPOST).

As shown above, only the first of the four parameter *prob* values is required. These are the probability values that specify the fuzzy uncertainty spread for the event identified as *event_name*. If only one value is specified, a single point estimate value of *prob1* is assumed by PHASER (i.e., no uncertainty). If two values are specified, a square fuzzy number is indicated. Three *prob* values indicate a triangular fuzzy number and all four *prob* values indicate a trapezoidal fuzzy number. When two or more *prob* values are specified, they must appear in ascending order so that they form the vertices of the fuzzy functions they define. All *prob* values must be greater than zero and less than or equal to one.

The optional A-factor parameter *scale_value* specifies the amount of stochastic knowledge associated with the event. The *scale_value* can range from zero, indicating a completely fuzzy event, to a value of one, indicating a completely stochastic event. If the A-factor parameter is omitted, a default value of zero will be used by PHASER for the *scale_value*, thus assuming a completely fuzzy event. These A-factor values will be mathematically propagated through the tree using methodology described in Reference 1. These A-factor results will be displayed in the individual Cutset and Top Event Plots if the user has requested these by respectively specifying the Keyword Statements "PLOTCUTSETS = Yes", and "PLOTTOPEVENT = Yes". The plots that appear in Appendices A through E illustrate the results of these calculations. The overall probabilistic confidence result is indicated by the value that immediately follows "a=" on the plot. Conversely, the overall fuzzy confidence value will immediately follow "b=". Cutset or Top Event Plots that do not display confidence results are either entirely fuzzy (b=1.0) or entirely stochastic (a=1.0).

There is only one circumstance in which the Fuzzy Event Definition Statement can be omitted entirely. A Probabilistic Event Definition Statement for this event is specified. In this case, PHASER will internally generate a fuzzy definition for the event and assume a *scale_value* parameter of one. This scenario will also generate a warning diagnostic in the user's QA Output File.

3.1.3.2 Probabilistic Event Definition Statements

3.1.3.2.1 DATA: Statement

The DATA: statement is the one of two methods for specifying the Probabilistic Event Definitions that are related to LHS sampling. The second is the DATASET: segment of the Keyword/Quantification File that is described on Page 30. Examples of DATA: statements can be found in Example Analyses 3, 4 and 5 in Appendices C, D and E respectively.

The DATA: statement is a probabilistic definition of one event related to the LHS (or LHSPOST) code. PHASER allows DATA: statements anywhere in the Keyword/ Quantification File, except following the DATASET: segment.

There are four different syntax forms of the DATA: statement. The first three parameters of a DATA: statement are identical in the first three syntax forms. The first parameter is the case-insensitive token DATA:. The second parameter specifies the name of the event. This name must adhere to the same rules that define the event name in the Fuzzy Event Definition Statement. The event name must also be unique within all probabilistic event definitions, but the spelling must agree if there is an <u>intended</u> link to a corresponding fuzzy definition; i.e., the two parts of a Hybrid Event must refer to the same basic event by name. The optional third parameter *point_value* specifies a numeric real constant that is the probabilistic point estimate value used when either of the Keyword Statements "SAMMOD = User", or "SAMMOD = UserOverride" is specified. When "SAMMOD = User" is specified, the parameter *point_value* is mandatory (refer to Keyword SAMMOD on Page 25).

Syntax 1: DATA: *event_name* [*point_value*] FILE *path_name*

Examples:

```
DATA: Sample_1 0.429 File C:\STUDY1\LHSFILE1.DAT
DATA: Sample_2 0.265 File C:\STUDY1\LHSFILE1.DAT
DATA: IMP_ANGLE FILE FLDATA.DAT
```

In Syntax 1 above, presence of the case-insensitive parameter FILE indicates that the next parameter to be read (*path_name*) will be the name of an LHS-like file that must be subsequently read by PHASER. The path or file associated with *path_name* may be repeated in other DATA: statements (as shown above) if two or more event names are defined in that particular file. However, the number of unique paths or files specified by *path_name* is currently limited to 16. The parameter *path_name* is case-insensitive and may be 1 to 50 characters in length. If *path_name* specifies only a filename, PHASER will expect to find the file in the current drive and directory.

Syntax 2: DATA: *event_name* [*point_value*] *dist_name* *param_list*

Examples:

```
DATA: RLOSP-1 0.05 Lognormal 0.02 3.00
DATA: RLOSP-2 0.05 Beta 0.0 0.5 1.0 2.0
DATA: X-Range Normal 75.0 5.5
```

In Syntax 2 above, the parameter *dist_name* must be the name of a distribution for LHS (see Ref. 4). The parameters that follow *dist_name* must be appropriate for the distribution selected. PHASER currently does not perform any validity checks on *dist_name* or the parameters that follow. In this syntax, the LHS symbol identified by *name* must be found in the LHS Output File (refer to Keyword LHSOUT on Page 18).

Syntax 3: DATA: *event_name* [*point_value*] = *lhs_expression*

Examples:

```
DATA: RL-Fails 0.10 = RL1 + RL2 + RL3 + RL4
DATA: Max-X-Range 75.0 = X-Maximum + X-Tolerance
DATA: Diagonal = SQRT ( Length ** 2 + Width ** 2 )
```

In Syntax 3 above, the required '=' (equal sign) specifies that the next parameter to be read is an expression containing at least one previously-defined LHS symbol (event name). As shown, the *lhs_expression* may contain ANSI standard Fortran numerical operators and intrinsic function references. Each numerical operator in the *lhs_expression* must be preceded and followed by at least one space or tab character. PHASER currently does not perform any validity checks on the *lhs_expression*; this occurs in the LHS postprocessor code LHSPOST at evaluation time. When Syntax 3 is used, PHASER expects to find the LHS symbol *event_name* defined in the LHS Postprocessor Output File (refer to Keyword LHSPOST on Page 18). PHASER also expects to find a value of the associated *lhs_expression* for each requested observation whenever LHS sampling is performed.

Syntax 4: DATA: CORRELATE *item1_name item2_name corr_value*

Examples: DATA: Correlate Alpha-Dist StmExp-Lop 0.999
DATA: Correlate Alpha-Dist StmExp-Hip 0.999

In Syntax 4 above, the case-insensitive parameter CORRELATE allows the user to define a correlation between two LHS data items. The two data items are LHS symbols (event names) that must be defined in other DATA: statements as LHS distributions using Syntax 2. Using Syntax 1 or 3 to define either correlated item will cause LHS to abort with a fatal diagnostic. The parameter *corr_value* specifies the value that defines the correlation between the two items. The definition of *corr_value* and other details regarding correlation are explained in Reference 2.

Additionally, the following rules apply to all syntax forms of the DATA: statement.

A. Trailing comments are permitted following any line in the statement (refer to Section 3.1.1.1 on Page 12).

B. The statement may be continued in two or more lines using a '#' or '%' (refer to Section 3.1.1.2 on Page 12).

3.1.3.2.2 DATASET: Segment

The DATASET: Information Segment is the second of two methods specifying Probabilistic Event Definitions. The first method is the DATA: statement that is described on Page 28 of this manual.

The DATASET: Information Segment is a multi-line information block consisting of the file segment marker DATASET: followed by statements defining one or more data items (events) related to the LHS code. The following is an example of a DATASET: Information Segment. Although not used in this example, comment lines and continuation lines are both supported in this segment.

```
DATASET:
     Gas-Flow-2  20.0  File D:\STUDY-1\EXAMPLE\LHS.LSP
     Gas-Flow-3  20.0  File D:\STUDY-1\EXAMPLE\LHS.LSP
     CD  0.2  Normal  0.2  0.03
```

Syntactically, the statements that define the events are nearly identical to the DATA: statements described on Page 28. The only difference is the absence of the token DATA: at the beginning of each statement. The token DATA: is not required (or accepted) here because the file marker DATASET: defines the beginning of this segment of the Keyword/Quantification File. Apart from this single notable exception, the syntax of these statements is defined in Subsection 3.1.3.2.1 beginning on Page 28.

The DATASET: Information Segment may define as many events (LHS symbols) as required within the current limits of PHASER (see Table 1 on Page 10). However, the user must be aware that PHASER does not differentiate in any manner events defined in the DATASET: Information Segment from those defined in preceding DATA: statements. The two methods are provided only to offer flexibility in defining the fault tree. In a very large fault tree, it may be convenient to define a probabilistic function for an event at values near the corresponding fuzzy function. Some users may prefer to place all Probabilistic Event Definitions in the DATASET: Information Segment. A combination of the two methods is also permitted. The only restriction regarding the DATASET: Information Segment is that it must be the last segment in the Keyword/Quantification Input File.

3.1.3.3 Dependency-Group: Definition Statement

PHASER has the capability to define event dependencies. This important feature is frequently not considered by analysts because it is found to be either inadequate or lacking entirely in other analysis codes. The user-specified dependency values are used by PHASER in calculating probabilities for the top event and for all cutsets. Both the fuzzy and the probabilistic probabilities are affected by the presence of dependency group definitions.

The syntax details of the Dependency-Group: Definition Statement are described completely in Section 3.1.2 under the "Dependency-Group:" Keyword starting on Page 15. The technique for evaluating the dependencies consists of mathematical operations that are based on the classical Frechet Bounds (see Reference 2).

3.2 Cutset File

The Cutset File must define the combinations of basic events that will cause the Top Event of the fault tree to occur. Because this file is required as PHASER input, a statement such as "CUTSETFILE = C:\STUDY-1\TREE-CS.DAT" must appear in the user's Keyword/Quantification Input File. The Cutset File is an eye-readable ASCII file that can be manually prepared with a text editor (recommended only for very small fault trees), or generated by the SABLE code. The cutsets in this file must be defined in minimum sum of products format and adhere to specific syntax rules. The following is an example of a Cutset File that agrees with this format.

```
LOSS-OF-SAFETY =
LAC-POWER * AMAC-INPUT * MISSILE-TRAJ +
LAC-POWER * PREARM-RANDOM * MISSILE-TRAJ +
LAC-POWER * 2969-PRE-CLOSED * MISSILE-TRAJ +
LAC-POWER * AMAC-INPUT * 2935-PRE-CLOSED +
LAC-POWER * PREARM-RANDOM * 2935-PRE-CLOSED +
LAC-POWER * 2969-PRE-CLOSED * 2935-PRE-CLOSED +
LAC-POWER * AMAC-INPUT * TSSG-SW-PRE * TRAJ-CORRECT-RAN +
LAC-POWER * PREARM-RANDOM * TSSG-SW-PRE * TRAJ-CORRECT-RAN +
LAC-POWER * 2969-PRE-CLOSED * TSSG-SW-PRE * TRAJ-CORRECT-RAN .
```

This is Cutset File EX-S-CS.DAT generated by the SABLE code for use in Example Analyses 1 to 3. For user convenience, it is also listed in Appendices A through C. The first line defines the name of the Top Event and must be followed by an '=' (equal sign). The event names within a cutset are separated by the Boolean logical "and" operator '*'. Each cutset (except the last) is terminated with the Boolean "or" operator '+'. As shown, the last cutset in the file must be terminated with a '.' (period). Also as shown, each operator must be preceded and followed by at least one space. The event names, including the Top Event name must adhere to the syntax rules described in Section 3.1.3.1 beginning on Page 27.

In the example Cutset File shown above, all nine cutsets are within the 80 character line limit for the Cutset File. The following Cutset File fragment illustrates the correct syntax for cutsets that require two or more lines.

```
FSA-FAIL-WITHOL =
MC3028-SRV-ENV * MC3098-XFER-EE * MC3160-ENV-ENB * EE-TO-MC3098 *
      MC3109-XFER-ENER * ESSG-ENB-MC2969 +
MC3028-SRV-ENV * MC3098-XFER-EE * MC3160-ENV-ENB * EE-TO-MC3098 *
      MC3109-XFER-ENER * MC2969-INST-ENB +

                  (File cut here)

MC3028-SRV-ENV * LOSS-GND-ZONE3 * MC3160-ELEC-BKDN * MC2969-BYPASSED *
      MC3098-XFER-EE * EE-TO-MC3098 * MC3109-XFER-ENER +
MC3028-SRV-ENV * LOSS-GND-ZONE3 * MC3160-ELEC-BKDN * MC2969-ELEC-BKDN *
      MC3098-XFER-EE * EE-TO-MC3098 * MC3109-XFER-ENER .
```

The cutset continuation line is shown indented six spaces for improved readability, but this is not necessary. The SABLE code will always indent in this manner when it generates the Cutset File. Each event name must be fully contained within the 80 character line and must be followed by one of the three operators. Another rule is that each line must be terminated by one of the three operators. For additional information, refer to Keyword CUTSETFILE on Page 13.

Complement event references are not permitted in the Cutset File. Any attempt to define a complement event reference (by prefixing the event name with a '/') will generate a fatal error diagnostic in the user's QA Output File.

3.3 Sampling Information Files

PHASER computes the Probability Density Functions (PDFs) for completely probabilistic or hybrid events by interfacing with the LHS program. LHS is used to perform a simulation that generates an output file containing these event probability values for each observation (sometimes referred to as an iteration) of the simulation. These event names and distributions must be defined using Syntax 2 of the Data: Statement or Dataset: Segment of the Keyword/Quantification Input File. This syntax is described on Page 29. The name of the LHS Output File is specified by Keyword LHSOUT in the Keyword/Quantification File. Use of Keyword LHSOUT is explained on Page 18.

The LHS postprocessor program LHSPOST can be used to evaluate LHS expressions defined in the Keyword/Quantification File. The postprocessor output file is an LHS-like file that uses the same format and syntax. LHSPOST reads the PHASER Keyword/Quantification File and the LHS output file, evaluates all LHS expressions, then writes these values to an LHS-like file whose name is specified by Keyword LHSPOST in the PHASER Keyword/Quantification Input File. Use of Keyword LHSPOST is explained on Page 18. The user must be aware that an LHS expression is defined in the Data: Statement or in the Dataset: Segment of the Keyword/ Quantification File. These LHS expressions must conform to Syntax 3 of the Data: Statement (or Dataset: Segment) described on Page 29.

Additionally, the user may specify up to 16 other LHS-like files from which PHASER must read hybrid event probabilities. These files (or file paths) are also specified in the Data: Statements or in the Dataset: Segment of the Keyword/Quantification File. An event name whose sampled probability values are to be read from one of these "User" files, must be specified using Syntax 1 of the Data: Statement (or Dataset: Segment) described on Page 29.

The user need not be concerned with examining any of the LHS-like sampling files because PHASER will automatically read them and generate the requested output. However, the following example of an LHS Output File is provided for user reference.

```
$ LHS File Format Version 1.00
$
$ This LHS run was executed on 12/20/95 at 10:16:01.01
$ with LHS Version: 2.00 Release 1, Compiled 01/28/1994
$ The run title was:
$
$
$ Message output file for this run: LHS-EX-S.MSG
$
$ Input file(s) for this run: EX-S-HY.DAT
$ and EX-S-HY.DAT
$
$
$ Point Values for the distributions follow:
$
$ All point values represent mean values that
$ were calculated from the actual LHS sample.
$
    2935-PRE-CLOSED        4.5047858E-04
    2969-PRE-CLOSED        4.5074167E-04
    LAC-POWER              1.2876371E-04
    MISSILE-TRAJ           1.2870504E-03
    PREARM-RANDOM          6.4352082E-07
    TRAJ-CORRECT-RAN       4.8925762E-05
    TSSG-SW-PRE            1.2881486E-01
    AMAC-INPUT             6.4408425E-07
$
@UNCERTAINTY
  @OBSERVATIONS    500
  @VARIABLES       8
    2935-PRE-CLOSED:
    2969-PRE-CLOSED:
    LAC-POWER:
    MISSILE-TRAJ:
```

```
    PREARM-RANDOM:
    TRAJ-CORRECT-RAN:
    TSSG-SW-PRE:
    AMAC-INPUT:
@SAMPLEDATA
         1           8   0.248001E-03   0.112995E-02   0.176610E-03
  0.127505E-02   0.111985E-05   0.684186E-04   0.176056        0.841762E-06
         2           8   0.187208E-03   0.870153E-03   0.138465E-03
  0.415995E-03   0.178661E-05   0.545248E-04   0.321786E-01   0.974342E-06
         3           8   0.649538E-03   0.562084E-03   0.149344E-03
  0.943915E-03   0.542143E-06   0.226640E-04   0.873710E-01   0.590694E-06

                       (File cut Here)

       498           8   0.309261E-03   0.155580E-03   0.102449E-03
  0.188826E-02   0.131973E-06   0.542889E-04   0.232926        0.436447E-06
       499           8   0.356192E-03   0.213304E-03   0.127579E-04
  0.786793E-03   0.841676E-06   0.122753E-03   0.234792        0.980705E-06
       500           8   0.465564E-03   0.202003E-03   0.705146E-04
  0.855799E-03   0.150235E-06   0.329353E-04   0.180857        0.100740E-05
```

This is an abbreviated listing of File LHS-EX-S.DAT taken from Example Analysis 3 in Appendix C. It shows the three blocks of an LHS-like data file. These blocks (or sections) are described in Appendix G, along with the precise format of an LHS-like file. The first of these blocks is also explained here because of its relationship to the PHASER Keyword SAMMOD.

As described in the comment lines of the file, the first block contains the point estimate values computed by LHS for each probabilistic (or hybrid) event definition in the Keyword/Quantification File. The values in this block are <u>sometimes</u> used by PHASER in determining a confidence factor (A-factor) for the Top Event of the tree. This depends entirely on the user-specified or defaulted parameter that follows Keyword SAMMOD in the Keyword/Quantification File. In Example Analysis 3, the Keyword Statement "SAMMOD = LHS" instructs PHASER to use the probabilistic point estimates found in the point estimate block of the above file. Complete details regarding Keyword SAMMOD are explained on Page 25.

4. PHASER Program Output

The output of PHASER can be either of two forms. The first form of output is one or two ASCII text files that contain a variety of information and analytic results. The second is a series of plots that is normally directed to a device capable of producing graphical output. All output files and devices are explained in the two sections that follow. A third section explains computer screen output during PHASER execution.

4.1 Output Files

4.1.1 QA (Quality Assurance) Output File

Generally speaking, the QA Output File is best described as an activity log file of the PHASER execution that is currently taking place. As previously stated in Section 2.2, this file contains QA information such as run date/time and line-numbered listings of the user's Keyword and Cutset Files.

The QA Output File will also contain the version number of PHASER in use, and a description of the system software used. These informative QA-related items are found in a header at the beginning of the file. The following partial file listing is an example of this header.

```
+------------------------------------+
|       PHASER    VERSION  2.10      |
|             07/26/1996             |
|------------------------------------|
|          <<< AUTHORS >>>           |
|   Bob Roginski        Org. 12333   |
|   J. Arlin Cooper     Org. 12331   |
+------------------------------------+

  Run date & time = 07/30/1996 12:03:37
  Compiler Used   = MS Pwr Sta V1.0a
```

A description of the Keyword/Quantification Input File and the QA Output File follows the header in the QA Output File. The user should be aware that execution will terminate immediately if PHASER is not able to locate any of the required input files. The following partial listing is an example of this description.

```
BASIC EVENT FILE  IS  EX-S-HY.DAT
QA / ERROR FILE   IS  EX-S-HY.QAF
.
```

The line-numbered listing of the user's Keyword/Quantification File is the next item of interest to be found in the QA Output File. All keyword-related warning messages and many of the possible fatal error diagnostics can be found in this portion of the file. Refer to Section 3.1.1.4 starting on Page 13 regarding Statement Errors. The following partial listing is an example of the "echo" of a user's Keyword/Quantification Input File.

```
                <<< Part 1>>>
   Echo of Basic Event File EX-S-HY.DAT with Diagnostics

 1  $  This is an example Fuzzy Math Data Input FIle.
 2  $
 3  $  The format is column-independent and supports the use of comments and
 4  $  continuation lines.  Certain keywords have special meaning to the
 5  $  program and must NOT be used as a basic event name.  The next several
 6  $  lines are examples of recognized keywords.
 7
 8  CUTSETFILE      =  EX-S-CS.DAT     $ Associated Cutset File (SABLE Output)
 9  NLINES          =  3               $ No. of Calculation Value Lines
10  DEBUGINFO       =  No              $ Add Debugging Info. to QA File
11  PLOTEVENTS      =  Yes
12  PLOTTOPEVENT    =  Yes
13  PLOTCUTSETS     =  Yes
14  PLOTCOMPOSITE   =  Yes
15  OUTPUTDEVICE    =  CRT  HPGL       $ CRT, HPLJ or HPGL are Valid Devices
16  DELAY           =  Wait            $ Hold Plots on CRT for this long
17  SAMMOD          =  LHS             $ Can be USER, LHS or USEROVERRIDE
18  ECHOCUTSETFILE  =  Yes             $ Turn off Echo if file is large
19  SMOOTHFACTOR    =  Auto            $ Smoothing Factor for PDF Plots
20  CUTSETLIMIT     =  10
```

```
PRECISERESULT  =  Yes  EX-S.DJS   $ Precise Top Event requested

$  Some of the following keywords are read by PHASER, but all are required
$  if LHS is to be invoked (i.e., the fault tree is at least partially
$  probabilistic).  Note the '=' (equal sign) must NOT follow the key-
$  word because LHS will not accept this syntax.

LHSOBS              500              $ No. of Observations in LHS Sample
LHSOUT              LHS-EX-S.DAT     $ Name of LHS Output File
LHSMSG              LHS-EX-S.MSG     $ Name of LHS Message File
LHSSEED             1                $ Start of LHS Random Number Generator

$  These are the Basic Event Definitions.  This is assumed because the
$  first token in each statement is not recognized as a keyword.

2935-Pre-Closed     =  1.0E-6   1.0E-5   1.0E-4   1.0E-3   A=0.7
    Data:  2935-Pre-Closed   BOUNDED NORMAL  3.5E-4  3.5E-4  1.0E-20  0.99999
2969-Pre-Closed     =  1.0E-6   1.0E-5   1.0E-4   1.0E-3   A=0.7
    Data:  2969-Pre-Closed   BOUNDED NORMAL  3.5E-4  3.5E-4  1.0E-20  0.99999
LAC-Power           =  1.0E-6   1.0E-5   1.0E-4   1.0E-3   A=0.1
    Data:  LAC-Power         BOUNDED NORMAL  1.0E-4  1.0E-4  1.0E-20  0.99999
Missile-Traj        =  1.0E-5   1.0E-2                     A=0.1
    Data:  Missile-Traj      BOUNDED NORMAL  1.0E-3  1.0E-3  1.0E-20  0.99999
Prearm-Random       =  1.0E-12  1.0E-9   1.0E-6            A=0.5
    Data:  Prearm-Random     BOUNDED NORMAL  0.5E-6  0.5E-6  1.0E-20  0.99999
Traj-Correct-Ran    =  1.0E-6   1.0E-3                     A=0.5
    Data:  Traj-Correct-Ran  BOUNDED NORMAL  3.8E-5  3.8E-5  1.0E-20  0.99999
TSSG-Sw-Pre         =  1.0E-3   1.0E-1                     A=0.1
    Data:  TSSG-Sw-Pre       BOUNDED NORMAL  1.0E-1  1.0E-1  1.0E-20  0.99999
AMAC-Input          =  1.0E-9   1.0E-8   1.0E-4   1.0E-3   A=0.1
    Data:  AMAC-Input        BOUNDED NORMAL  0.5E-6  0.5E-6  1.0E-20  0.99999
```

The next item to be found in the QA Output File is a line-numbered listing of the Cutset File to be used. After reading the Cutset File, PHASER will verify that all referenced events have been defined in the Keyword/Quantification File. Omission of a definition for any referenced event will generate a fatal error diagnostic. Refer to Section 3.1.1.4 starting on Page 13 regarding Statement Errors. Also, a warning diagnostic will be issued for each event that is defined but not referenced in the Cutset File. These extraneous event definitions will not result in abnormal termination of PHASER, but should be removed because they count against the total event limit (see Table 1 on Page 10). The following partial file listing is an example of the "echo" of a user's Cutset File.

```
                   <<< Part 2>>>
Echo of Cutset File EX-S-CS.DAT with Diagnostics

LOSS-OF-SAFETY =
LAC-POWER * AMAC-INPUT * MISSILE-TRAJ +
LAC-POWER * PREARM-RANDOM * MISSILE-TRAJ +
LAC-POWER * 2969-PRE-CLOSED * MISSILE-TRAJ +
LAC-POWER * AMAC-INPUT * 2935-PRE-CLOSED +
LAC-POWER * PREARM-RANDOM * 2935-PRE-CLOSED +
LAC-POWER * 2969-PRE-CLOSED * 2935-PRE-CLOSED +
LAC-POWER * AMAC-INPUT * TSSG-SW-PRE * TRAJ-CORRECT-RAN +
LAC-POWER * PREARM-RANDOM * TSSG-SW-PRE * TRAJ-CORRECT-RAN +
LAC-POWER * 2969-PRE-CLOSED * TSSG-SW-PRE * TRAJ-CORRECT-RAN .
```

The "echo" of the user's Cutset File can be suppressed by inserting the statement "ECHOCUTSETFILE = No" in the Keyword/Quantification File. This, however, is not considered to be good QA practice and should be avoided unless the Cutset File is extremely large. The use of Keyword ECHOCUTSETFILE is explained on Page 17.

Part 3 of the QA Output File (debugging information) is also optional. It will be generated only if "DEBUGINFO = Yes" is specified in the Keyword/Quantification Input File. If requested, Part 3 will contain many tables of variable values that can help in the process of locating a suspected code malfunction. Refer to Keyword DEBUGINFO on Page 14 for the details. Because debugging information is typically quite lengthy, an example of Part 3 is not listed here, but it can be easily generated (by inserting the statement "DEBUGINFO = Yes") if the user is curious.

4.1.2 Disjoint Set File

The Disjoint Sets that are used by PHASER to calculate an "exact" Top Event probability can be written to a file if the user selects this option. The user must specify a Keyword Statement such as "PRECISERESULT = Yes *DJsetfilename*", where the parameter *DJsetfilename* is the name (or path) of the file that will contain the Disjoint Set information. The details regarding Keyword PRECISERESULT are explained on Page 24. The following is an example of a Disjoint Set File generated by PHASER.

```
LOSS-OF-SAFETY =
AMAC-INPUT * MISSILE-TRAJ * LAC-POWER +
PREARM-RANDOM * MISSILE-TRAJ * LAC-POWER * /AMAC-INPUT +
LAC-POWER * 2969-PRE-CLOSED * 2935-PRE-CLOSED * /MISSILE-TRAJ +
AMAC-INPUT * LAC-POWER * 2935-PRE-CLOSED * /2969-PRE-CLOSED * /MISSILE-TRAJ +
MISSILE-TRAJ * LAC-POWER * 2969-PRE-CLOSED * /PREARM-RANDOM * /AMAC-INPUT +
TRAJ-CORRECT-RAN * TSSG-SW-PRE * AMAC-INPUT * LAC-POWER * /2935-PRE-CLOSED *
      /MISSILE-TRAJ +
PREARM-RANDOM * LAC-POWER * 2935-PRE-CLOSED * /2969-PRE-CLOSED *
      /MISSILE-TRAJ * /AMAC-INPUT +
TRAJ-CORRECT-RAN * TSSG-SW-PRE * PREARM-RANDOM * LAC-POWER * /2935-PRE-CLOSED *
      /MISSILE-TRAJ * /AMAC-INPUT +
TRAJ-CORRECT-RAN * TSSG-SW-PRE * LAC-POWER * 2969-PRE-CLOSED *
      /2935-PRE-CLOSED * /MISSILE-TRAJ * /PREARM-RANDOM * /AMAC-INPUT .
```

This is Disjoint Set File EX-S.DJS generated in Example Analyses 1, 2 and 3 found in Appendices A, B and C respectively. These three analyses generate the same Disjoint Sets because they all use the same Cutset File as input. This particular Disjoint Set File is small in size, but this is not typical. For this reason, the Disjoint Set File should be requested only if it is required as input to another software program.

As seen in the example above, the Disjoint Set File is written using the same format that defines the Cutset File. This format is described in Section 3.2 beginning on Page 31. The Disjoint Set File cannot be generated if "PRECISERESULT = No" has been specified (or defaulted) because this Keyword Statement instructs PHASER to use the rare event approximation for calculating the Top Event probability. Since the rare event approximation does not require Disjoint Sets, they are not internally generated by PHASER in this case, and consequently, not available for file output.

4.2 Output Devices

4.2.1 Output Device CRT

As previously stated in Section 2.2, the CRT (Cathode Ray Tube) device is the user's computer screen. All requested plots will be generated using standard VGA (Video Graphics Array) mode at a resolution of 640 x 480. The quality of the CRT plot is considerably lower than that required for publication. This is because the CRT is intended to be a preview device. It gives the user an opportunity to view one or more plots before generating a series of high quality plots using either of the other output devices.

Each plot is displayed on the screen for a user-specified (or defaulted) number of seconds. Refer to the explanation of Keyword DELAY beginning on Page 15. The user will also notice that the fuzzy results and corresponding PDFs are plotted using the same color in composite plots of hybrid results. This makes it easier for the user to visually identify both components of a particular hybrid result.

4.2.2 Output Device HPLJ

The HPLJ (Hewlett Packard LaserJet) device requires an HP LaserJet printer capable of printing at a resolution of 300 DPI (Dots per Inch). The high quality of the plots produced by selecting this device is suitable for creating transparencies (sometimes referred to as View Graphs). The user should be aware that plotting to the HPLJ device can take a considerable amount of time; up to several minutes depending on the type and complexity of the plot.

4.2.3 Output Device HPGL

As previously stated in Section 2.2, the HPGL (Hewlett Packard Graphics Language) information is actually a series of disk files that are easily identified by their .HGL file extension. These files are easily imported by almost every commercially available word processing program. This makes it possible for the user to incorporate PHASER plots directly into a report or manual (as was done in this manual).

PHASER will generate one or more files for each type of plot requested. Because the total number of HPGL plot files can be somewhat large, it is necessary to describe the file naming convention that is used when plotting to the HPGL device. The following shows an MS-DOS directory listing of HPGL plot files created by a PHASER execution. All plot types except Importance and Sensitivity have been requested, thereby creating a total of nineteen plot files for this particular fault tree.

```
Volume in drive D is DRIVE-D
Volume Serial Number is 3329-16F5
Directory of D:\PHASER\PH
```

```
COMPOSIT HGL        211,360 07-30-96  12:11p
CS-0001  HGL        148,278 07-30-96  12:06p
CS-0002  HGL        154,982 07-30-96  12:07p
CS-0003  HGL        152,378 07-30-96  12:07p
CS-0004  HGL        153,274 07-30-96  12:08p
CS-0005  HGL        158,373 07-30-96  12:08p
CS-0006  HGL        159,352 07-30-96  12:08p
CS-0007  HGL        162,699 07-30-96  12:09p
CS-0008  HGL        170,998 07-30-96  12:09p
CS-0009  HGL        170,406 07-30-96  12:10p
EV-0001  HGL        124,936 07-30-96  12:03p
EV-0002  HGL        124,934 07-30-96  12:04p
EV-0003  HGL        113,611 07-30-96  12:04p
EV-0004  HGL        116,574 07-30-96  12:05p
EV-0005  HGL        134,597 07-30-96  12:05p
EV-0006  HGL        133,393 07-30-96  12:05p
EV-0007  HGL        116,603 07-30-96  12:06p
EV-0008  HGL        131,293 07-30-96  12:06p
RESULT   HGL        146,397 07-30-96  12:06p
       19 file(s)      2,784,438 bytes
                     351,535,104 bytes free
```

As indicated, the graphical output for the Composite Plot is always written to an HPGL file named COMPOSIT.HGL. If the Composite Plot is requested (by specifying "PLOTCOMPOSITE = Yes" in the Keyword/Quantification File) only one plot file is generated. A plot of each cutset in the fault tree is generated by specifying "PLOTCUTSETS = Yes". The cutset filenames will use the format "CS-nnnn.HGL", where "nnnn" is the number of the cutset padded with leading zeros. As shown, the basic event plots use the similar format "EV-nnnn.HGL", where "nnnn" is the number of the basic event. Basic event plots are requested by specifying "PLOTEVENTS = Yes". Although not indicated, Importance Plot Filenames will use the format "IMP-nnnn.HGL" and Sensitivity Plot Filenames will use the format "SEN-nnnn.HGL". In the case of Importance and Sensitivity Plot Filenames, "nnnn" is the continuation plot number in the sequence padded with leading zeros. Finally, a plot of the Top Event is generated if "PLOTTOPEVENT = Yes" is specified in the Keyword/Quantification File. Because there is only one Top Event plot file generated, its name will always be RESULT.HGL. It should be noted that the event order and cutset order used in the HPGL file numbering sequence is established by the order of their definition (appearance) in the two primary input files. Respectively, these are the Keyword/Quantification File and the Cutset File.

Because PHASER will always use this HPGL file naming convention, each subsequent execution will overwrite any existing HPGL files with the same names. For this reason, it is extremely important for the user to rename any HPGL files before the next PHASER execution is initiated (necessary only if the next execution also specifies "PLOTDEVICE = HPGL" in the Keyword/Quantification File).

To import an HPGL file into a word processing or a desktop publishing application, the user should consult the user's manual for the application chosen to create the document.

4.3 Computer Screen Output

PHASER produces only a modest amount of output on the user's computer screen. All screen output consists of QA-related items and program status indicators. These indicators are provided to ensure the user that their machine has not "locked up", but is currently reading/writing a lengthy disk file, or performing a compute-intensive process. The following is an example listing like a user might see on the computer screen while PHASER is executing.

```
          +-----------------------------------+
          !      PHASER    VERSION  2.10      !
          !           07/26/1996              !
          !-----------------------------------!
          !          <<< AUTHORS >>>          !
          !   Bob Roginski       Org. 12333   !
          !   J. Arlin Cooper    Org. 12331   !
          +-----------------------------------+

            Run date & time = 07/30/1996 15:56:45
            Compiler Used   = MS Pwr Sta V1.0a

            BASIC EVENT FILE  IS  BIG-VER.DAT
            QA / ERROR FILE   IS  BIG-VER.QAF

                 Reading File  BIG-VER.DAT
                 Reading LHS Sampling Files
                 Reading File  BIG-V-CS.DAT

                 Generating Disjoint Sets

                 Defining Substitute Events
                 Cumulative CPU time =       .0 seconds

                 Performing Problem Subdivision
                 Cumulative CPU time =      1.3 seconds

                 This problem is subdivided on
                 the following 10 events:
                 G                 (Referenced in  66 Cutsets)
                 F                 (Referenced in  48 Cutsets)
                 U                 (Referenced in  33 Cutsets)
                 V                 (Referenced in  33 Cutsets)
                 R                 (Referenced in  24 Cutsets)
                 H                 (Referenced in  12 Cutsets)
                 I                 (Referenced in  12 Cutsets)
                 J                 (Referenced in  12 Cutsets)
                 K                 (Referenced in  12 Cutsets)
                 L                 (Referenced in  12 Cutsets)

                 Solving 1024 Subproblems for  200 Observations

                 Solving Subproblem 1024 of 1024
                 Cumulative CPU time =    932.3 seconds

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Copying Plot   1 to HPGL file RESULT.HGL


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Copying Plot   2 to HPGL file COMPOSIT.HGL
```

```
                    Writing File  BIG-VER.QAF

                    No Errors Detected

        Stop - Program terminated.
```

This is the execution sequence that is displayed on the user's computer screen for Example Analysis 4 in Appendix D. The Keyword/Quantification Input File for this particular Analysis (listed in Appendix D) instructs PHASER to plot to both the CRT and HPGL devices.

In general, if PHASER was instructed to produce plots on the user's computer screen, some of the above status indicators will not be displayed long enough for the user to read. This, however, is not necessary, because program status is indicated when PHASER initiates a screen plot.

The last item displayed on the screen will inform the user if the execution was successful. PHASER will generate all requested output even if warning messages are indicated. However, if fatal diagnostics are indicated, the requested plots and output files will not be produced. If either warning messages or fatal diagnostics are indicated, the user will be instructed to examine the contents of the QA Output File to determine the exact nature of all problems detected.

5. Debugging Considerations

Debugging using PHASER is straightforward. The user must observe all the syntax rules when preparing the Keyword/Quantification Input File. More than one iteration of corrections and reruns may be required in order to locate and correct all fatal errors in the Keyword/Quantification Input File. Once all errors have been corrected, PHASER will generate the requested plots and output files.

If a user suspects a code malfunction, the problem should be reported to the author or to the equivalent point of contact so that the possible need for a suitable remedy can be determined for a subsequent maintenance release version of PHASER.

6. Getting Started with PHASER

A default (or template) file is available to assist the user in the initial preparation of the Keyword/Quantification Input File. This file (TEMPLATE.DAT) contains statements that set all optional keywords to their default values. It describes the fault tree used in Example Analysis 3 found in Appendix C. The user must edit a <u>copy</u> of this file in order to change parameter values associated with the mandatory keywords and any optional keywords whose default values are not acceptable. The user must also revise both the fuzzy and the probabilistic event definition statements to agree with his or her new list of basic events. A new Cutset File must be prepared in accordance with the syntax rules described in Section 3.2, and must be properly referenced using the Keyword CUTSETFILE.

This template file also contains comments that explain all keywords and their parameters; this minimizes the need for the user to consult this manual for an explanation of any keyword. The user can obtain a copy of TEMPLATE.DAT on floppy disk from the author or equivalent point of contact.

Collectively, the analysis examples in Appendices A through E utilize all features currently available in PHASER. At least one example of each plot type is also shown. These examples are intended to provide the user with enough information to begin using PHASER with a minimum degree of difficulty. Suggestions for feature modifications and new feature additions are always welcome. These should be directed to J. Arlin Cooper, (505) 845-9168, Robert (Bob) J. Roginski, (505) 844-0177, or an equivalent point of contact.

References

1. J. A. Cooper, 'Theoretical Description of Methodology in PHASER (Probabilistic Hybrid Analytical System Evaluation Routine)', SAND96-0022, Sandia National Laboratories, January 1996.

2. J. A. Cooper, 'PHASER 2.10 Methodology for Dependence, Importance, and Sensitivity; The Role of Scale Factors, Confidence Factors, and Extremes', SAND96-____, Sandia National Laboratories, August 1996.

3. Ronald L. Iman, Michael J. Shortencarier, 'A FORTRAN 77 Program and User's Guide for the Generation of Latin Hypercube and Random Samples for Use With Computer Models', NUREG/CR-3624, SAND83-2365, March 1984.

4. Sharon L. Daniel, Gregory D. Wyss, 'FAULT TREE ANALYSIS USING SEATree AND SABLE', Risk Assessment and Systems Modeling Department 6412.

5. B. Bingham, J. Hutchinson, B. Lopez, 'SEATREE Version 2.6 User Manual', Science and Engineering Associates Inc., Prepared for Los Alamos National Laboratory, Submitted September 1993.

Appendices

Appendix A contains an example fault tree analysis that illustrates how a point estimate Top Event probability can be determined using PHASER. It begins with an example execution sequence (computer screen output) for the example, followed by a plot of the fault tree used. The same fault tree is also used in Examples 2 and 3, but is shown only once in Appendix A. Appendix A contains listings of all required input files and generated output files. Finally, it shows the Top Event plot generated by the PHASER execution for Example Analysis 1.

Example Analysis 2 in Appendix B portrays a Fuzzy Uncertainty Analysis of the same fault tree used in Appendix A. In this analysis, each basic event is assigned a fuzzy number (or spread) for an input probability. This analysis illustrates how these input uncertainties propagate up the tree to the top event.

Appendix C takes the same fault tree analysis one step further by adding probabilistic (stochastic) input data to each basic event. In this example, all four plot types are requested and shown for user reference. Because this analysis generates results that are hybrid values, the Sampling Information File generated by the LHS code is also listed, but listed using an abbreviated form due to the large number of requested observations.

Appendix D illustrates another example of a fault tree that uses hybrid probability spreads as input values and generates hybrid probability spreads as output values. This is the same type of analysis as illustrated in Appendix C, except that a much larger fault tree is analyzed in order to invoke the Disjoint Set subdivision process. Because this tree contains a large number of basic events and cutsets, only the Top Event and Composite Plots are requested and displayed. All input and output files are also listed, although the lengthier ones are abbreviated as in Appendix C.

Appendix E illustrates another partially probabilistic (hybrid) fault tree that utilizes the Dependency Feature. This analysis also calculates Cutset Importance and Event Sensitivity and displays the results in bar graph plots.

Appendix F contains a block diagram that graphically illustrates the relationships between the various fault tree codes and how they relate to PHASER. As illustrated, some of these codes interface directly (SABLE, LHS and LHSPOST) and others indirectly (SEATREE), but all of them are useful tools for an analyst.

Appendix G defines the format of LHS-like Sampling Information Files that are generated as output by LHS and LHSPOST, and are sometimes required as input files to PHASER.

The PHASER plots found in Appendices A through E were generated using the HPGL device as indicated by the Statement "OUTPUTDEVICE = CRT HPGL" found in each of the five Keyword/Quantification Input Files. These plots have been reduced to

45% of their original size. The two fault tree plots found in Appendices A and D were created using version 2.62 of the SEATREE code.

Appendix A - Example Analysis 1 - Hypothetical Model Point Estimate

PHASER Execution Sequence (Screen Output)

The following execution sequence is an example of a point estimate calculation using PHASER. Refer to Section 4.3 beginning on Page 40 for an explanation of Computer Screen Output. This Analysis performs an "exact" Top Event quantification and requests that the Disjoint Sets be generated in file EX-S.DJS. Only the Top Event plot is requested in this Analysis. It is displayed on the user's CRT and also written to the HPGL device (file RESULT.HGL).

```
          +-----------------------------------+
          |       PHASER    VERSION  2.10      |
          |            07/26/1996              |
          |-----------------------------------|
          |          <<< AUTHORS >>>           |
          |    Bob Roginski       Org. 12333   |
          |    J. Arlin Cooper    Org. 12331   |
          +-----------------------------------+

            Run date & time = 07/30/1996 11:47:13
            Compiler Used   = MS Pwr Sta V1.0a

            BASIC EVENT FILE  IS  EX-S-PE.DAT
            QA / ERROR FILE   IS  EX-S-PE.QAF

                 Reading File  EX-S-PE.DAT
                 Reading File  EX-S-CS.DAT

                 Generating Disjoint Sets

                 Defining Substitute Events
                 Cumulative CPU time =       .0 seconds

                 Performing Problem Subdivision
                 Cumulative CPU time =       .0 seconds
                 Writing File  EX-S.DJS

                 No Problem subdivision is required

                 Solving    1 Subproblems

                 Solving Subproblem    1 of    1
                 Cumulative CPU time =       .1 seconds

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Copying Plot   1 to HPGL file RESULT.HGL


                 Writing File  EX-S-PE.QAF

                 No Errors Detected

Stop - Program terminated.
```

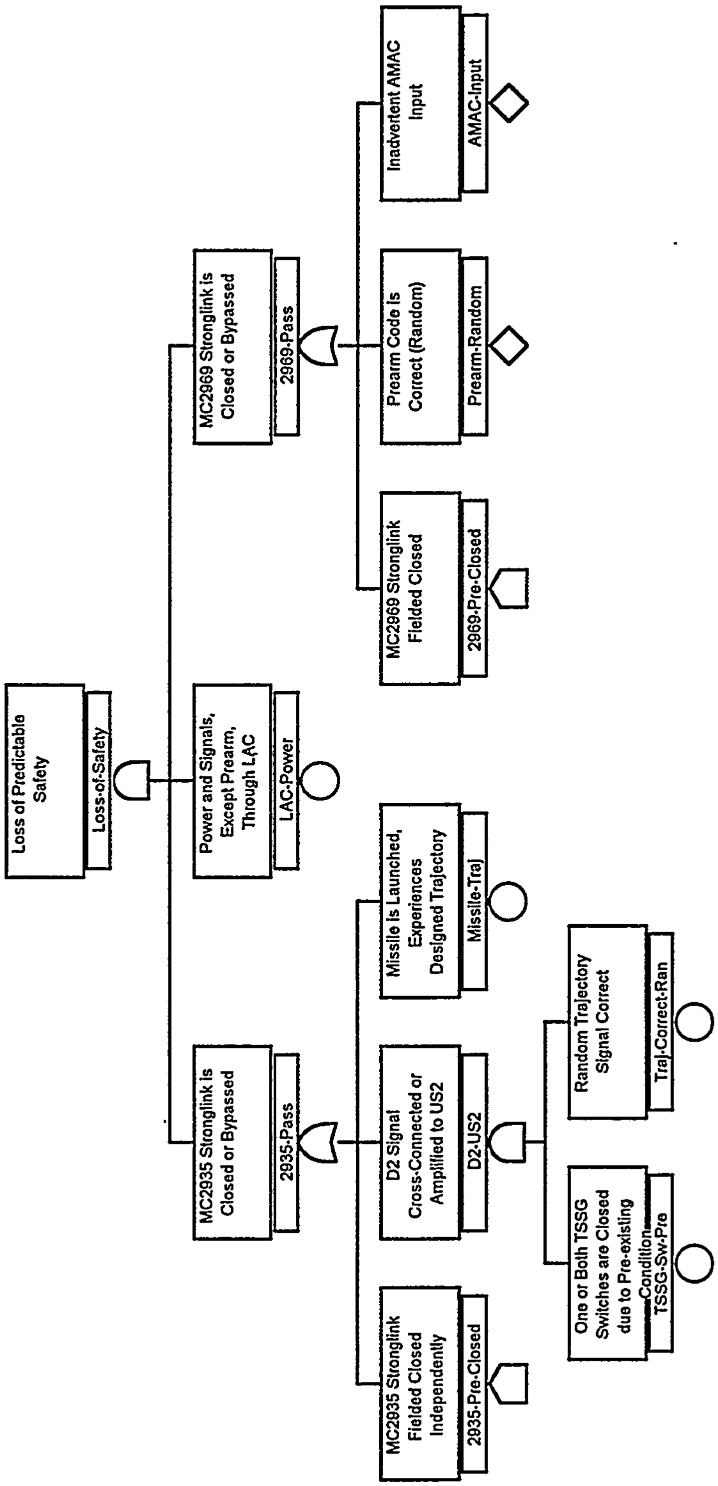

Hypothetical Model Fault Tree

Figure 3. Hypothetical Model Fault Tree for Example Analyses 1, 2 and 3.

Keyword/Quantification Input File Listing

The following is a listing of the Keyword/Quantification Input File EX-S-PE.DAT used in this example point estimate analysis.

```
$  This is an example Fuzzy Math Data Input File.
$
$  The format is column-independent and supports the use of comments and
$  continuation lines.  Certain keywords have special meaning to the
$  program and must NOT be used as a basic event name.  The next several
$  lines are examples of recognized keywords.

CUTSETFILE      =  EX-S-CS.DAT      $ Associated Cutset File (SABLE Output)
NLINES          =  3                $ No. of Calculation Value Lines
DEBUGINFO       =  No               $ Add Debugging Info. to QA File
PLOTEVENTS      =  No
PLOTTOPEVENT    =  Yes
PLOTCUTSETS     =  No
PLOTCOMPOSITE   =  No
OUTPUTDEVICE    =  CRT  HPGL        $ CRT, HPLJ or HPGL are Valid Devices
DELAY           =  Wait             $ Hold Plots on CRT for this long
SAMMOD          =  LHS              $ Can be USER, LHS or USEROVERRIDE
ECHOCUTSETFILE  =  Yes              $ Turn off Echo if file is large
SMOOTHFACTOR    =  Auto             $ Smoothing Factor for PDF Plots
CUTSETLIMIT     =  10
MAXDECIMALS     =   1
PRECISERESULT   =  Yes  EX-S.DJS    $ Precise Top Event requested

$  These are the Basic Event Definitions.  This is assumed because the
$  first token in each statement is not recognized as a keyword.

2935-Pre-Closed     =  3.5E-4
2969-Pre-Closed     =  3.5E-4
LAC-Power           =  1.0E-4
Missile-Traj        =  1.0E-3
Prearm-Random       =  0.5E-6
Traj-Correct-Ran    =  3.8E-5
TSSG-Sw-Pre         =  1.0E-1
AMAC-Input          =  0.5E-6
```

Cutset Input File Listing

The following is a listing of the Cutset Input File EX-S-CS.DAT used in this example point estimate analysis. This file was generated by an execution of the SABLE code. This Cutset File is also used in Examples 2 and 3. This listing appears in Appendices A, B and C for user convenience.

```
LOSS-OF-SAFETY =
LAC-POWER * AMAC-INPUT * MISSILE-TRAJ +
LAC-POWER * PREARM-RANDOM * MISSILE-TRAJ +
LAC-POWER * 2969-PRE-CLOSED * MISSILE-TRAJ +
LAC-POWER * AMAC-INPUT * 2935-PRE-CLOSED +
LAC-POWER * PREARM-RANDOM * 2935-PRE-CLOSED +
LAC-POWER * 2969-PRE-CLOSED * 2935-PRE-CLOSED +
LAC-POWER * AMAC-INPUT * TSSG-SW-PRE * TRAJ-CORRECT-RAN +
LAC-POWER * PREARM-RANDOM * TSSG-SW-PRE * TRAJ-CORRECT-RAN +
LAC-POWER * 2969-PRE-CLOSED * TSSG-SW-PRE * TRAJ-CORRECT-RAN .
```

Disjoint Set Output File Listing

The following is a listing of the Disjoint Set Output File EX-S.DJS generated by this point estimate analysis. The Disjoint Set File generated in Examples 2 and 3 is identical because all three problems use the same Cutset File as input. However, a listing of the Disjoint Set Output File appears in Appendices A, B and C for user convenience.

```
LOSS-OF-SAFETY =
AMAC-INPUT * MISSILE-TRAJ * LAC-POWER +
PREARM-RANDOM * MISSILE-TRAJ * LAC-POWER * /AMAC-INPUT +
LAC-POWER * 2969-PRE-CLOSED * 2935-PRE-CLOSED * /MISSILE-TRAJ +
AMAC-INPUT * LAC-POWER * 2935-PRE-CLOSED * /2969-PRE-CLOSED * /MISSILE-TRAJ +
MISSILE-TRAJ * LAC-POWER * 2969-PRE-CLOSED * /PREARM-RANDOM * /AMAC-INPUT +
TRAJ-CORRECT-RAN * TSSG-SW-PRE * AMAC-INPUT * LAC-POWER * /2935-PRE-CLOSED *
      /MISSILE-TRAJ +
PREARM-RANDOM * LAC-POWER * 2935-PRE-CLOSED * /2969-PRE-CLOSED *
      /MISSILE-TRAJ * /AMAC-INPUT +
TRAJ-CORRECT-RAN * TSSG-SW-PRE * PREARM-RANDOM * LAC-POWER * /2935-PRE-CLOSED *
      /MISSILE-TRAJ * /AMAC-INPUT +
TRAJ-CORRECT-RAN * TSSG-SW-PRE * LAC-POWER * 2969-PRE-CLOSED *
      /2935-PRE-CLOSED * /MISSILE-TRAJ * /PREARM-RANDOM * /AMAC-INPUT .
```

QA Output File Listing

The following is a listing of the QA Output File EX-S-PE.QAF generated by this point estimate analysis problem. This listing illustrates the details regarding the QA Output File. These details are described in Section 4.1.1 starting on Page 34.

```
+-----------------------------------+
|       PHASER    VERSION  2.10     |
|             07/26/1996            |
|-----------------------------------|
|           <<< AUTHORS >>>         |
|     Bob Roginski       Org. 12333 |
|   . J. Arlin Cooper    Org. 12331 |
+-----------------------------------+

  Run date & time = 07/30/1996 11:47:13
  Compiler Used   = MS Pwr Sta V1.0a

  BASIC EVENT FILE  IS  EX-S-PE.DAT
  QA / ERROR FILE   IS  EX-S-PE.QAF


            <<< Part 1>>>
  Echo of Basic Event File EX-S-PE.DAT with Diagnostics

1  $  This is an example Fuzzy Math Data Input FIle.
2  $
3  $  The format is column-independent and supports the use of comments and
4  $  continuation lines.  Certain keywords have special meaning to the
5  $  program and must NOT be used as a basic event name.  The next several
6  $  lines are examples of recognized keywords.
7
8  CUTSETFILE      =  EX-S-CS.DAT      $ Associated Cutset File (SABLE Output)
9  NLINES          =  3                $ No. of Calculation Value Lines
```

```
DEBUGINFO       =  No              $ Add Debugging Info. to QA File
PLOTEVENTS      =  No
PLOTTOPEVENT    =  Yes
PLOTCUTSETS     =  No
PLOTCOMPOSITE   =  No
OUTPUTDEVICE    =  CRT  HPGL       $ CRT, HPLJ or HPGL are Valid Devices
DELAY           =  Wait            $ Hold Plots on CRT for this long
SAMMOD          =  LHS             $ Can be USER, LHS or USEROVERRIDE
ECHOCUTSETFILE  =  Yes             $ Turn off Echo if file is large
SMOOTHFACTOR    =  Auto            $ Smoothing Factor for PDF Plots
CUTSETLIMIT     =  10
MAXDECIMALS     =   1
PRECISERESULT   =  Yes  EX-S.DJS   $ Precise Top Event requested

$  These are the Basic Event Definitions.  This is assumed because the
$  first token in each statement is not recognized as a keyword.

2935-Pre-Closed     =  3.5E-4
2969-Pre-Closed     =  3.5E-4
LAC-Power           =  1.0E-4
Missile-Traj        =  1.0E-3
Prearm-Random       =  0.5E-6
Traj-Correct-Ran    =  3.8E-5
TSSG-Sw-Pre         =  1.0E-1
AMAC-Input          =  0.5E-6
```

<<< Part 2>>>

Echo of Cutset File EX-S-CS.DAT with Diagnostics

```
LOSS-OF-SAFETY =
LAC-POWER * AMAC-INPUT * MISSILE-TRAJ +
LAC-POWER * PREARM-RANDOM * MISSILE-TRAJ +
LAC-POWER * 2969-PRE-CLOSED * MISSILE-TRAJ +
LAC-POWER * AMAC-INPUT * 2935-PRE-CLOSED +
LAC-POWER * PREARM-RANDOM * 2935-PRE-CLOSED +
LAC-POWER * 2969-PRE-CLOSED * 2935-PRE-CLOSED +
LAC-POWER * AMAC-INPUT * TSSG-SW-PRE * TRAJ-CORRECT-RAN +
LAC-POWER * PREARM-RANDOM * TSSG-SW-PRE * TRAJ-CORRECT-RAN +
LAC-POWER * 2969-PRE-CLOSED * TSSG-SW-PRE * TRAJ-CORRECT-RAN .
```

Output Plots

The only plot requested in Example Analysis 1 (the Top Event plot) is shown below.

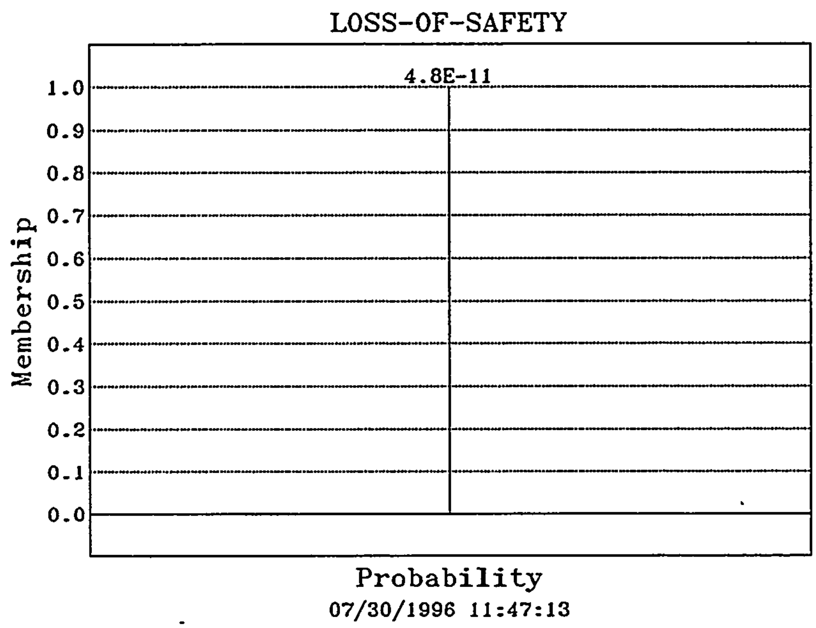

Figure 4. Top Event Point Estimate Plot for Example Analysis 1.

Appendix B - Example Analysis 2 - Hypothetical Model Fuzzy Uncertainty

PHASER Execution Sequence (Screen Output)

The following execution sequence is an example of a fuzzy uncertainty calculation using PHASER. Refer to Section 4.3 beginning on Page 40 for an explanation of Computer Screen Output. In this analysis, PHASER performs an "exact" Top Event quantification and requests the Disjoint Sets to be generated in file EX-S.DJS. Only the Top Event plot is requested in this analysis. It is displayed on the user's CRT and also written to the HPGL device (file RESULT.HGL).

```
+------------------------------------+
|       PHASER    VERSION  2.10      |
|            07/26/1996              |
|------------------------------------|
|          <<< AUTHORS >>>           |
|   Bob Roginski       Org. 12333    |
|   J. Arlin Cooper    Org. 12331    |
+------------------------------------+

  Run date & time = 07/30/1996 11:49:09
  Compiler Used   = MS Pwr Sta V1.0a

  BASIC EVENT FILE   IS  EX-S-FU.DAT
  QA / ERROR FILE    IS  EX-S-FU.QAF

       Reading File  EX-S-FU.DAT
       Reading File  EX-S-CS.DAT

       Generating Disjoint Sets

       Defining Substitute Events
       Cumulative CPU time =       .0 seconds

       Performing Problem Subdivision
       Cumulative CPU time =       .0 seconds
       Writing File  EX-S.DJS

       No Problem subdivision is required

       Solving    1 Subproblems


       Solving Subproblem    1 of    1
       Cumulative CPU time =       .1 seconds

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Copying Plot   1 to HPGL file RESULT.HGL


       Writing File  EX-S-FU.QAF

       No Errors Detected

Stop - Program terminated.
```

Fault Tree used in Hypothetical Model Fuzzy Uncertainty Analysis

The fault tree used in this analysis is the same tree that is used in Examples 1 and 3. This fault tree is shown in Figure 1 on Page 47.

Keyword/Quantification Input File Listing

The following is a listing of the Keyword/Quantification Input File EX-S-FU.DAT used in this example fuzzy uncertainty analysis.

```
$  This is an example Fuzzy Math Data Input File.
$
$  The format is column-independent and supports the use of comments and
$  continuation lines.  Certain keywords have special meaning to the
$  program and must NOT be used as a basic event name.  The next several
$  lines are examples of recognized keywords.

CUTSETFILE      =  EX-S-CS.DAT     $ Associated Cutset File (SABLE Output)
NLINES          =  3               $ No. of Calculation Value Lines
DEBUGINFO       =  No              $ Add Debugging Info. to QA File
PLOTEVENTS      =  No
PLOTTOPEVENT    =  Yes
PLOTCUTSETS     =  No
PLOTCOMPOSITE   =  No
OUTPUTDEVICE    =  CRT  HPGL       $ CRT, HPLJ or HPGL are Valid Devices
DELAY           =  Wait            $ Hold Plots on CRT for this long
SAMMOD          =  LHS.            $ Can be USER, LHS or USEROVERRIDE
ECHOCUTSETFILE  =  Yes             $ Turn off Echo if file is large
SMOOTHFACTOR    =  Auto            $ Smoothing Factor for PDF Plots
CUTSETLIMIT     =  10
MAXDECIMALS     =   1
PRECISERESULT   =  Yes  EX-S.DJS   $ Precise Top Event requested

$  These are the Basic Event Definitions.  This is assumed because the
$  first token in each statement is not recognized as a keyword.

2935-Pre-Closed      =  1.0E-6   1.0E-5   1.0E-4   1.0E-3
2969-Pre-Closed      =  1.0E-6   1.0E-5   1.0E-4   1.0E-3
LAC-Power            =  1.0E-6   1.0E-5   1.0E-4   1.0E-3
Missile-Traj         =  1.0E-5   1.0E-2
Prearm-Random        =  1.0E-12  1.0E-9   1.0E-6
Traj-Correct-Ran     =  1.0E-6   1.0E-3
TSSG-Sw-Pre          =  1.0E-3   1.0E-1
AMAC-Input           =  1.0E-9   1.0E-8   1.0E-4   1.0E-3
```

Cutset Input File Listing

The following is a listing of the Cutset Input File EX-S-CS.DAT used in this example fuzzy uncertainty analysis. This file was generated by an execution of the SABLE code. This Cutset File is also used in Examples 1 and 3. This listing appears in Appendices A, B and C for user convenience.

```
LOSS-OF-SAFETY =
LAC-POWER * AMAC-INPUT * MISSILE-TRAJ +
LAC-POWER * PREARM-RANDOM * MISSILE-TRAJ +
LAC-POWER * 2969-PRE-CLOSED * MISSILE-TRAJ +
LAC-POWER * AMAC-INPUT * 2935-PRE-CLOSED +
```

```
LAC-POWER * PREARM-RANDOM * 2935-PRE-CLOSED +
LAC-POWER * 2969-PRE-CLOSED * 2935-PRE-CLOSED +
LAC-POWER * AMAC-INPUT * TSSG-SW-PRE * TRAJ-CORRECT-RAN +
LAC-POWER * PREARM-RANDOM * TSSG-SW-PRE * TRAJ-CORRECT-RAN +
LAC-POWER * 2969-PRE-CLOSED * TSSG-SW-PRE * TRAJ-CORRECT-RAN .
```

Disjoint Set Output File Listing

The following is a listing of the Disjoint Set Output File EX-S.DJS generated by this fuzzy uncertainty analysis. The Disjoint Set File generated in Analyses 1 and 3 is identical because all three analyses use the same Cutset File as input. However, a listing of the Disjoint Set Output File listing appears in Appendices A, B and C for user convenience.

```
LOSS-OF-SAFETY =
AMAC-INPUT * MISSILE-TRAJ * LAC-POWER +
PREARM-RANDOM * MISSILE-TRAJ * LAC-POWER * /AMAC-INPUT +
LAC-POWER * 2969-PRE-CLOSED * 2935-PRE-CLOSED * /MISSILE-TRAJ +
AMAC-INPUT * LAC-POWER * 2935-PRE-CLOSED * /2969-PRE-CLOSED * /MISSILE-TRAJ +
MISSILE-TRAJ * LAC-POWER * 2969-PRE-CLOSED * /PREARM-RANDOM * /AMAC-INPUT +
TRAJ-CORRECT-RAN * TSSG-SW-PRE * AMAC-INPUT * LAC-POWER * /2935-PRE-CLOSED *
      /MISSILE-TRAJ +
PREARM-RANDOM * LAC-POWER * 2935-PRE-CLOSED * /2969-PRE-CLOSED *
      /MISSILE-TRAJ * /AMAC-INPUT +
TRAJ-CORRECT-RAN * TSSG-SW-PRE * PREARM-RANDOM * LAC-POWER * /2935-PRE-CLOSED *
      /MISSILE-TRAJ * /AMAC-INPUT +
TRAJ-CORRECT-RAN * TSSG-SW-PRE * LAC-POWER * 2969-PRE-CLOSED *
      /2935-PRE-CLOSED * /MISSILE-TRAJ * /PREARM-RANDOM * /AMAC-INPUT .
```

QA Output File Listing

The following is a listing of the QA Output File EX-S-FU.QAF generated by this fuzzy uncertainty analysis. This listing illustrates the details regarding the QA Output File. These details are described in Section 4.1.1 starting on Page 34.

```
+-------------------------------------+
|        PHASER    VERSION  2.10      |
|             07/26/1996              |
|-------------------------------------|
|          <<< AUTHORS >>>            |
|    Bob Roginski        Org. 12333   |
|    J. Arlin Cooper     Org. 12331   |
+-------------------------------------+

  Run date & time = 07/30/1996 11:49:09
  Compiler Used   = MS Pwr Sta V1.0a

  BASIC EVENT FILE  IS  EX-S-FU.DAT
  QA / ERROR FILE   IS  EX-S-FU.QAF


            <<< Part 1>>>
   Echo of Basic Event File EX-S-FU.DAT with Diagnostics

1  $  This is an example Fuzzy Math Data Input FIle.
2  $
```

```
$ The format is column-independent and supports the use of comments and
$ continuation lines.  Certain keywords have special meaning to the
$ program and must NOT be used as a basic event name.  The next several
$ lines are examples of recognized keywords.

CUTSETFILE      = EX-S-CS.DAT     $ Associated Cutset File (SABLE Output)
NLINES          = 3               $ No. of Calculation Value Lines
DEBUGINFO       = No              $ Add Debugging Info. to QA File
PLOTEVENTS      = No
PLOTTOPEVENT    = Yes
PLOTCUTSETS     = No
PLOTCOMPOSITE   = No
OUTPUTDEVICE    = CRT  HPGL       $ CRT, HPLJ or HPGL are Valid Devices
DELAY           = Wait            $ Hold Plots on CRT for this long
SAMMOD          = LHS             $ Can be USER, LHS or USEROVERRIDE
ECHOCUTSETFILE  = Yes             $ Turn off Echo if file is large
SMOOTHFACTOR    = Auto            $ Smoothing Factor for PDF Plots
CUTSETLIMIT     = 10
MAXDECIMALS     =  1
PRECISERESULT   = Yes  EX-S.DJS   $ Precise Top Event requested

$ These are the Basic Event Definitions.  This is assumed because the
$ first token in each statement is not recognized as a keyword.

2935-Pre-Closed     = 1.0E-6   1.0E-5   1.0E-4   1.0E-3
2969-Pre-Closed     = 1.0E-6   1.0E-5   1.0E-4   1.0E-3
LAC-Power           = 1.0E-6   1.0E-5   1.0E-4   1.0E-3
Missile-Traj        = 1.0E-5   1.0E-2
Prearm-Random       = 1.0E-12  1.0E-9   1.0E-6
Traj-Correct-Ran    = 1.0E-6   1.0E-3
TSSG-Sw-Pre         = 1.0E-3   1.0E-1
AMAC-Input          = 1.0E-9   1.0E-8   1.0E-4   1.0E-3
```

<<< Part 2>>>

Echo of Cutset File EX-S-CS.DAT with Diagnostics

```
LOSS-OF-SAFETY =
LAC-POWER * AMAC-INPUT * MISSILE-TRAJ +
LAC-POWER * PREARM-RANDOM * MISSILE-TRAJ +
LAC-POWER * 2969-PRE-CLOSED * MISSILE-TRAJ +
LAC-POWER * AMAC-INPUT * 2935-PRE-CLOSED +
LAC-POWER * PREARM-RANDOM * 2935-PRE-CLOSED +
LAC-POWER * 2969-PRE-CLOSED * 2935-PRE-CLOSED +
LAC-POWER * AMAC-INPUT * TSSG-SW-PRE * TRAJ-CORRECT-RAN +
LAC-POWER * PREARM-RANDOM * TSSG-SW-PRE * TRAJ-CORRECT-RAN +
LAC-POWER * 2969-PRE-CLOSED * TSSG-SW-PRE * TRAJ-CORRECT-RAN .
```

Output Plots

The only plot requested in Example Analysis 2 (the Top Event plot) is shown below.

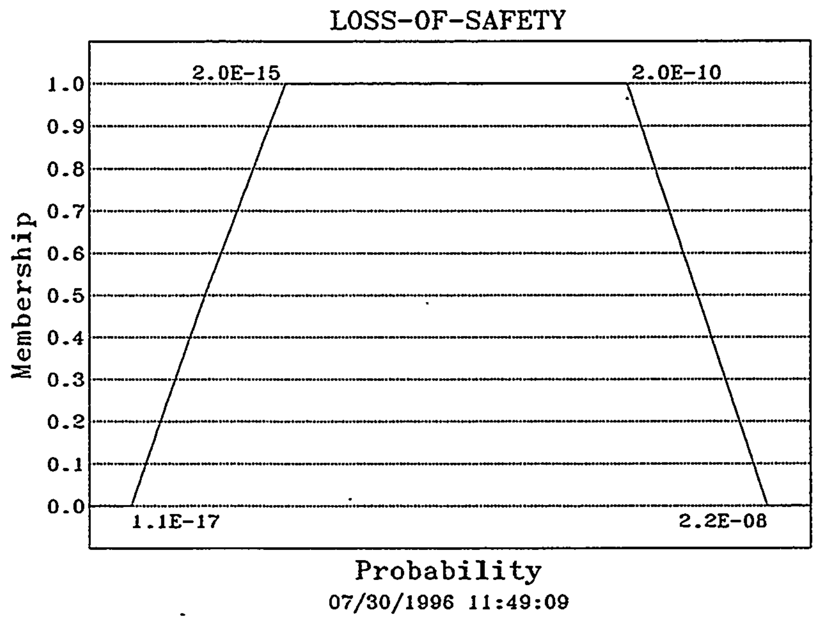

Figure 5. Top Event Fuzzy Uncertainty Plot for Example Analysis 2.

Appendix C - Example Analysis 3 - Hypothetical Model Hybrid Analysis

PHASER Execution Sequence (Screen Output)

The following execution sequence is an example of a hybrid analysis calculation using PHASER. Refer to Section 4.3 beginning on Page 40 for an explanation of Computer Screen Output. In this analysis, PHASER performs an "exact" Top Event quantification and requests that the Disjoint Sets be generated in file EX-S.DJS. All plot types are requested in this analysis. They are displayed on the user's CRT and are also written to the HPGL device (a file identified by its .HGL file extension).

```
+-----------------------------------+
|       PHASER    VERSION  2.10      |
|             07/26/1996             |
|-----------------------------------|
|           <<< AUTHORS >>>          |
|    Bob Roginski        Org. 12333  |
|    J. Arlin Cooper     Org. 12331  |
+-----------------------------------+

  Run date & time = 07/30/1996 12:03:37
  Compiler Used   = MS Pwr Sta V1.0a

  BASIC EVENT FILE  IS  EX-S-HY.DAT
  QA / ERROR FILE   IS  EX-S-HY.QAF

       Reading File  EX-S-HY.DAT
       Reading LHS Sampling Files
       Reading File  EX-S-CS.DAT

       Generating Disjoint Sets

       Defining Substitute Events
       Cumulative CPU time =       .0 seconds

       Performing Problem Subdivision
       Cumulative CPU time =       .0 seconds
       Writing File  EX-S.DJS

       No Problem subdivision is required

       Solving    1 Subproblems for  500 Observations

       Solving Subproblem    1 of    1
       Cumulative CPU time =       .1 seconds
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Copying Plot   1 to HPGL file EV-0001.HGL


INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft

Copying Plot   2 to HPGL file EV-0002.HGL
```

```
INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft

Copying Plot   3 to HPGL file EV-0003.HGL

INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft

Copying Plot   4 to HPGL file EV-0004.HGL

INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft

Copying Plot   5 to HPGL file EV-0005.HGL

INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft

Copying Plot   6 to HPGL file EV-0006.HGL

INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft

Copying Plot   7 to HPGL file EV-0007.HGL

INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft

Copying Plot   8 to HPGL file EV-0008.HGL

INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft

Copying Plot   9 to HPGL file RESULT.HGL

INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft

Copying Plot  10 to HPGL file CS-0001.HGL

INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft

Copying Plot  11 to HPGL file CS-0002.HGL

INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft

Copying Plot  12 to HPGL file CS-0003.HGL

INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft

Copying Plot  13 to HPGL file CS-0004.HGL

INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft

Copying Plot  14 to HPGL file CS-0005.HGL

INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft

Copying Plot  15 to HPGL file CS-0006.HGL

INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft

Copying Plot  16 to HPGL file CS-0007.HGL

INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft
```

```
Copying Plot  17 to HPGL file CS-0008.HGL

INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft

Copying Plot  18 to HPGL file CS-0009.HGL

INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft

Copying Plot  19 to HPGL file COMPOSIT.HGL

                 Writing File  EX-S-HY.QAF

                 No Errors Detected

Stop - Program terminated.
```

Fault Tree used in Hypothetical Model Hybrid Analysis

The fault tree used in this analysis is the same tree that is used in Analyses 1 and 2. This fault tree is shown in Figure 1 on Page 47.

Keyword/Quantification Input File Listing

The following is a listing of the Keyword/Quantification Input File EX-S-HY.DAT used in this example hybrid analysis.

```
$  This is an example Fuzzy Math Data Input FIle.
$
$  The format is column-independent and supports the use of comments and
$  continuation lines.  Certain keywords have special meaning to the
$  program and must NOT be used as a basic event name.  The next several
$  lines are examples of recognized keywords.

CUTSETFILE     =  EX-S-CS.DAT     $ Associated Cutset File (SABLE Output)
NLINES         =  3               $ No. of Calculation Value Lines
DEBUGINFO      =  No              $ Add Debugging Info. to QA File
PLOTEVENTS     =  Yes
PLOTTOPEVENT   =  Yes
PLOTCUTSETS    =  Yes
PLOTCOMPOSITE  =  Yes
OUTPUTDEVICE   =  CRT  HPGL       $ CRT, HPLJ or HPGL are Valid Devices
DELAY          =  Wait            $ Hold Plots on CRT for this long
SAMMOD         =  LHS             $ Can be USER, LHS or USEROVERRIDE
ECHOCUTSETFILE =  Yes             $ Turn off Echo if file is large
SMOOTHFACTOR   =  Auto            $ Smoothing Factor for PDF Plots
CUTSETLIMIT    =  10
PRECISERESULT  =  Yes  EX-S.DJS   $ Precise Top Event requested

$  Some of the following keywords are read by PHASER, but all are required
$  if LHS is to be invoked (i.e., the fault tree is at least partially
$  probabilistic).  Note the '=' (equal sign) must NOT follow the key-
$  word because LHS will not accept this syntax.

LHSOBS            500             $ No. of Observations in LHS Sample
LHSOUT            LHS-EX-S.DAT    $ Name of LHS Output File
```

```
LHSMSG          LHS-EX-S.MSG    $ Name of LHS Message File
LHSSEED         1               $ Start of LHS Random Number Generator

$  These are the Basic Event Definitions.  This is assumed because the
$  first token in each statement is not recognized as a keyword.

2935-Pre-Closed      =  1.0E-6   1.0E-5   1.0E-4   1.0E-3   A=0.7
    Data:  2935-Pre-Closed   BOUNDED NORMAL  3.5E-4  3.5E-4  1.0E-20  0.99999
2969-Pre-Closed      =  1.0E-6   1.0E-5   1.0E-4   1.0E-3   A=0.7
    Data:  2969-Pre-Closed   BOUNDED NORMAL  3.5E-4  3.5E-4  1.0E-20  0.99999
LAC-Power            =  1.0E-6   1.0E-5   1.0E-4   1.0E-3   A=0.1
    Data:  LAC-Power         BOUNDED NORMAL  1.0E-4  1.0E-4  1.0E-20  0.99999
Missile-Traj         =  1.0E-5   1.0E-2                     A=0.1
    Data:  Missile-Traj      BOUNDED NORMAL  1.0E-3  1.0E-3  1.0E-20  0.99999
Prearm-Random        =  1.0E-12  1.0E-9   1.0E-6            A=0.5
    Data:  Prearm-Random     BOUNDED NORMAL  0.5E-6  0.5E-6  1.0E-20  0.99999
Traj-Correct-Ran     =  1.0E-6   1.0E-3                     A=0.5
    Data:  Traj-Correct-Ran  BOUNDED NORMAL  3.8E-5  3.8E-5  1.0E-20  0.99999
TSSG-Sw-Pre          =  1.0E-3   1.0E-1                     A=0.1
    Data:  TSSG-Sw-Pre       BOUNDED NORMAL  1.0E-1  1.0E-1  1.0E-20  0.99999
AMAC-Input           =  1.0E-9   1.0E-8   1.0E-4   1.0E-3   A=0.1
    Data:  AMAC-Input        BOUNDED NORMAL  0.5E-6  0.5E-6  1.0E-20  0.99999
```

Cutset Input File Listing

The following is a listing of the Cutset Input File EX-S-CS.DAT used in this example fuzzy uncertainty analysis. This file was generated by an execution of the SABLE code. This Cutset File is also used in Examples 1 and 2. This listing appears in Appendices A, B and C for user convenience.

```
LOSS-OF-SAFETY =
LAC-POWER * AMAC-INPUT * MISSILE-TRAJ +
LAC-POWER * PREARM-RANDOM * MISSILE-TRAJ +
LAC-POWER * 2969-PRE-CLOSED * MISSILE-TRAJ +
LAC-POWER * AMAC-INPUT * 2935-PRE-CLOSED +
LAC-POWER * PREARM-RANDOM * 2935-PRE-CLOSED +
LAC-POWER * 2969-PRE-CLOSED * 2935-PRE-CLOSED +
LAC-POWER * AMAC-INPUT * TSSG-SW-PRE * TRAJ-CORRECT-RAN +
LAC-POWER * PREARM-RANDOM * TSSG-SW-PRE * TRAJ-CORRECT-RAN +
LAC-POWER * 2969-PRE-CLOSED * TSSG-SW-PRE * TRAJ-CORRECT-RAN .
```

Disjoint Set Output File Listing

The following is a listing of the Disjoint Set Output File EX-S.DJS generated by this hybrid analysis. The Disjoint Set File generated in Analyses 1 and 2 is identical because all three analyses use the same Cutset File as input. However, a listing of the Disjoint Set Output File appears in Appendices A, B and C for user convenience.

```
LOSS-OF-SAFETY =
AMAC-INPUT * MISSILE-TRAJ * LAC-POWER +
PREARM-RANDOM * MISSILE-TRAJ * LAC-POWER * /AMAC-INPUT +
LAC-POWER * 2969-PRE-CLOSED * 2935-PRE-CLOSED * /MISSILE-TRAJ +
AMAC-INPUT * LAC-POWER * 2935-PRE-CLOSED * /2969-PRE-CLOSED * /MISSILE-TRAJ +
MISSILE-TRAJ * LAC-POWER * 2969-PRE-CLOSED * /PREARM-RANDOM * /AMAC-INPUT +
TRAJ-CORRECT-RAN * TSSG-SW-PRE * AMAC-INPUT * LAC-POWER * /2935-PRE-CLOSED *
      /MISSILE-TRAJ +
PREARM-RANDOM * LAC-POWER * 2935-PRE-CLOSED * /2969-PRE-CLOSED *
      /MISSILE-TRAJ * /AMAC-INPUT +
```

```
TRAJ-CORRECT-RAN * TSSG-SW-PRE * PREARM-RANDOM * LAC-POWER * /2935-PRE-CLOSED *
      /MISSILE-TRAJ * /AMAC-INPUT +
TRAJ-CORRECT-RAN * TSSG-SW-PRE * LAC-POWER * 2969-PRE-CLOSED *
      /2935-PRE-CLOSED * /MISSILE-TRAJ * /PREARM-RANDOM * /AMAC-INPUT .
```

QA Output File Listing

The following is a listing of the QA Output File EX-S-HY.QAF generated by this hybrid analysis. This listing illustrates the details regarding the QA Output File. These details are described in Section 4.1.1 starting on Page 34.

```
          +-------------------------------------+
          |       PHASER    VERSION  2.10       |
          |             07/26/1996              |
          |-------------------------------------|
          |            <<< AUTHORS >>>          |
          |    Bob Roginski       Org. 12333    |
          |    J. Arlin Cooper    Org. 12331    |
          +-------------------------------------+

            Run date & time = 07/30/1996 12:03:37
            Compiler Used   = MS Pwr Sta V1.0a

            BASIC EVENT FILE  IS  EX-S-HY.DAT
            QA / ERROR FILE   IS  EX-S-HY.QAF


                      <<< Part 1>>>
      Echo of Basic Event File EX-S-HY.DAT with Diagnostics

   1  $  This is an example Fuzzy Math Data Input FIle.
   2  $
   3  $  The format is column-independent and supports the use of comments and
   4  $  continuation lines.  Certain keywords have special meaning to the
   5  $  program and must NOT be used as a basic event name.  The next several
   6  $  lines are examples of recognized keywords.
   7
   8  CUTSETFILE      =  EX-S-CS.DAT     $ Associated Cutset File (SABLE Output)
   9  NLINES          =  3               $ No. of Calculation Value Lines
  10  DEBUGINFO       =  No              $ Add Debugging Info. to QA File
  11  PLOTEVENTS      =  Yes
  12  PLOTTOPEVENT    =  Yes
  13  PLOTCUTSETS     =  Yes
  14  PLOTCOMPOSITE   =  Yes
  15  OUTPUTDEVICE    =  CRT  HPGL       $ CRT, HPLJ or HPGL are Valid Devices
  16  DELAY           =  Wait            $ Hold Plots on CRT for this long
  17  SAMMOD          =  LHS             $ Can be USER, LHS or USEROVERRIDE
  18  ECHOCUTSETFILE  =  Yes             $ Turn off Echo if file is large
  19  SMOOTHFACTOR    =  Auto            $ Smoothing Factor for PDF Plots
  20  CUTSETLIMIT     =  10
  21  PRECISERESULT   =  Yes  EX-S.DJS   $ Precise Top Event requested
  22
  23  $  Some of the following keywords are read by PHASER, but all are required
  24  $  if LHS is to be invoked (i.e., the fault tree is at least partially
  25  $  probabilistic).  Note the '=' (equal sign) must NOT follow the key-
  26  $  word because LHS will not accept this syntax.
  27
  28  LHSOBS             500             $ No. of Observations in LHS Sample
  29  LHSOUT             LHS-EX-S.DAT    $ Name of LHS Output File
  30  LHSMSG             LHS-EX-S.MSG    $ Name of LHS Message File
  31  LHSSEED            1               $ Start of LHS Random Number Generator
  32
  33  $  These are the Basic Event Definitions.  This is assumed because the
```

```
$  first token in each statement is not recognized as a keyword.

2935-Pre-Closed      =  1.0E-6   1.0E-5   1.0E-4   1.0E-3   A=0.7
    Data:  2935-Pre-Closed   BOUNDED NORMAL  3.5E-4  3.5E-4  1.0E-20  0.99999
2969-Pre-Closed      =  1.0E-6   1.0E-5   1.0E-4   1.0E-3   A=0.7
    Data:  2969-Pre-Closed   BOUNDED NORMAL  3.5E-4  3.5E-4  1.0E-20  0.99999
LAC-Power            =  1.0E-6   1.0E-5   1.0E-4   1.0E-3   A=0.1
    Data:  LAC-Power         BOUNDED NORMAL  1.0E-4  1.0E-4  1.0E-20  0.99999
Missile-Traj         =  1.0E-5   1.0E-2                     A=0.1
    Data:  Missile-Traj      BOUNDED NORMAL  1.0E-3  1.0E-3  1.0E-20  0.99999
Prearm-Random        =  1.0E-12  1.0E-9   1.0E-6            A=0.5
    Data:  Prearm-Random     BOUNDED NORMAL  0.5E-6  0.5E-6  1.0E-20  0.99999
Traj-Correct-Ran     =  1.0E-6   1.0E-3                     A=0.5
    Data:  Traj-Correct-Ran  BOUNDED NORMAL  3.8E-5  3.8E-5  1.0E-20  0.99999
TSSG-Sw-Pre          =  1.0E-3   1.0E-1                     A=0.1
    Data:  TSSG-Sw-Pre       BOUNDED NORMAL  1.0E-1  1.0E-1  1.0E-20  0.99999
AMAC-Input           =  1.0E-9   1.0E-8   1.0E-4   1.0E-3   A=0.1
    Data:  AMAC-Input        BOUNDED NORMAL  0.5E-6  0.5E-6  1.0E-20  0.99999
```

```
                  <<< Part 2>>>
Echo of Cutset File EX-S-CS.DAT with Diagnostics

LOSS-OF-SAFETY =
LAC-POWER * AMAC-INPUT * MISSILE-TRAJ +
LAC-POWER * PREARM-RANDOM * MISSILE-TRAJ +
LAC-POWER * 2969-PRE-CLOSED * MISSILE-TRAJ +
LAC-POWER * AMAC-INPUT * 2935-PRE-CLOSED +
LAC-POWER * PREARM-RANDOM * 2935-PRE-CLOSED +
LAC-POWER * 2969-PRE-CLOSED * 2935-PRE-CLOSED +
LAC-POWER * AMAC-INPUT * TSSG-SW-PRE * TRAJ-CORRECT-RAN +
LAC-POWER * PREARM-RANDOM * TSSG-SW-PRE * TRAJ-CORRECT-RAN +
LAC-POWER * 2969-PRE-CLOSED * TSSG-SW-PRE * TRAJ-CORRECT-RAN .
```

Sampling Information File

This example analysis requires sampling to be performed by the LHS code because probabilistic event definitions have been specified in the Keyword/Quantification Input File. The following is an abbreviated listing of the file LHS-EX-S.DAT that was generated by a preceding execution of the LHS code for this fault tree analysis.

```
$ LHS File Format Version 1.00
$
$ This LHS run was executed on 12/20/95 at 10:16:01.01
$ with LHS Version: 2.00 Release 1, Compiled 01/28/1994
$ The run title was:
$
$
$ Message output file for this run: LHS-EX-S.MSG
$
$ Input file(s) for this run: EX-S-HY.DAT
$ and EX-S-HY.DAT
$
$
$ Point Values for the distributions follow:
$
$ All point values represent mean values that
$ were calculated from the actual LHS sample.
$
   2935-PRE-CLOSED       4.5047858E-04
   2969-PRE-CLOSED       4.5074167E-04
   LAC-POWER             1.2876371E-04
   MISSILE-TRAJ          1.2870504E-03
```

```
    PREARM-RANDOM          6.4352082E-07
    TRAJ-CORRECT-RAN       4.8925762E-05
    TSSG-SW-PRE            1.2881486E-01
    AMAC-INPUT             6.4408425E-07
$
@UNCERTAINTY
  @OBSERVATIONS     500
  @VARIABLES      8
    2935-PRE-CLOSED:
    2969-PRE-CLOSED:
    LAC-POWER:
    MISSILE-TRAJ:
    PREARM-RANDOM:
    TRAJ-CORRECT-RAN:
    TSSG-SW-PRE:
    AMAC-INPUT:
@SAMPLEDATA
          1           8   0.248001E-03   0.112995E-02   0.176610E-03
   0.127505E-02   0.111985E-05   0.684186E-04   0.176056        0.841762E-06
          2           8   0.187208E-03   0.870153E-03   0.138465E-03
   0.415995E-03   0.178661E-05   0.545248E-04   0.321786E-01   0.974342E-06
          3           8   0.649538E-03   0.562084E-03   0.149344E-03
   0.943915E-03   0.542143E-06   0.226640E-04   0.873710E-01   0.590694E-06
          4           8   0.391923E-03   0.959781E-03   0.277548E-03
   0.293486E-02   0.630593E-06   0.849576E-04   0.207711        0.454334E-06
          5           8   0.943431E-03   0.621131E-04   0.838785E-04
   0.151361E-02   0.162958E-05   0.379774E-04   0.262928E-01   0.418910E-06
          6           8   0.536566E-04   0.974369E-03   0.187626E-03
   0.138527E-02   0.100906E-05   0.801760E-04   0.260995        0.500754E-06
          7           8   0.889042E-03   0.247851E-03   0.867129E-04
   0.605060E-03   0.677749E-06   0.610879E-04   0.586505E-01   0.473414E-06
          8           8   0.472719E-03   0.475392E-03   0.772564E-04
   0.328220E-03   0.726373E-06   0.865045E-04   0.202027        0.240681E-06
          9           8   0.107184E-03   0.550235E-03   0.125436E-03
   0.269894E-02   0.643363E-06   0.617811E-04   0.263424        0.762784E-06
         10           8   0.118701E-03   0.449475E-03   0.219717E-03
   0.198047E-02   0.116446E-05   0.567440E-04   0.140470        0.331517E-06

                    (File cut Here)

        491           8   0.213599E-03   0.641513E-03   0.961652E-05
   0.172034E-02   0.961612E-06   0.639105E-04   0.879314E-01   0.607272E-06
        492           8   0.695576E-03   0.443133E-03   0.350953E-03
   0.101930E-03   0.105824E-05   0.775323E-04   0.236575        0.136943E-05
        493           8   0.739642E-03   0.297789E-03   0.434701E-04
   0.303389E-03   0.766541E-06   0.105626E-04   0.199744        0.298506E-06
        494           8   0.482804E-04   0.393287E-04   0.255894E-03
   0.639908E-04   0.710143E-06   0.797064E-04   0.232309        0.136146E-05
        495           8   0.296909E-03   0.157557E-03   0.120039E-03
   0.140001E-03   0.515179E-06   0.102095E-03   0.274658        0.111003E-05
        496           8   0.104336E-03   0.854016E-03   0.163439E-03
   0.163109E-02   0.287696E-06   0.437805E-04   0.602723E-01   0.720556E-06
        497           8   0.679694E-04   0.496651E-03   0.234581E-03
   0.826997E-03   0.439897E-07   0.114165E-04   0.224942        0.391646E-06
        498           8   0.309261E-03   0.155580E-03   0.102449E-03
   0.188826E-02   0.131973E-06   0.542889E-04   0.232926        0.436447E-06
        499           8   0.356192E-03   0.213304E-03   0.127579E-04
   0.786793E-03   0.841676E-06   0.122753E-03   0.234792        0.980705E-06
        500           8   0.465564E-03   0.202003E-03   0.705146E-04
   0.855799E-03   0.150235E-06   0.329353E-04   0.180857        0.100740E-05
```

The Sampling Information File is described in Section 3.3 beginning on Page 32. The complete definition of this file format can be found in Appendix G.

Output Plots

All plot types have been requested in Example Analysis 3. They are displayed here in the order in which they were generated by the PHASER execution shown on Page 57.

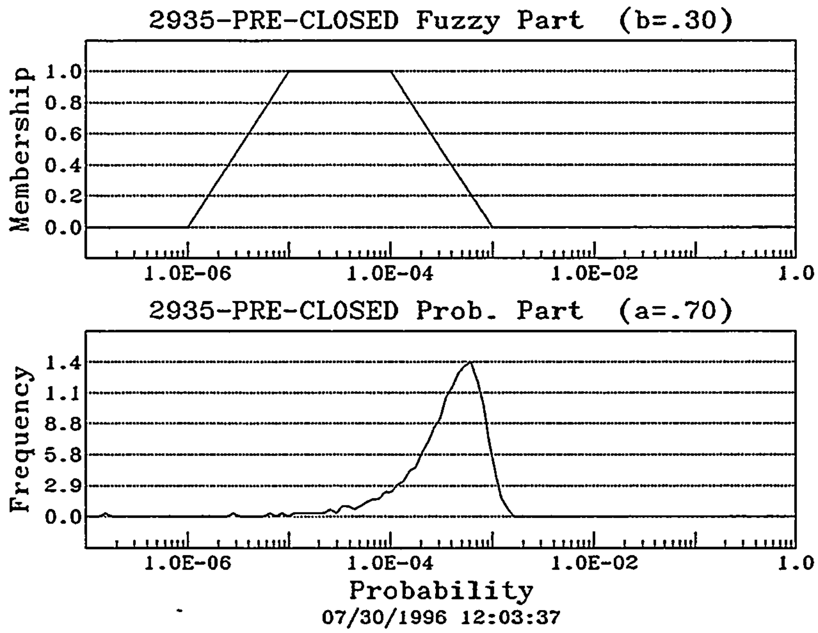


Figure 6. Event 1 Hybrid Plot for Example Analysis 3.

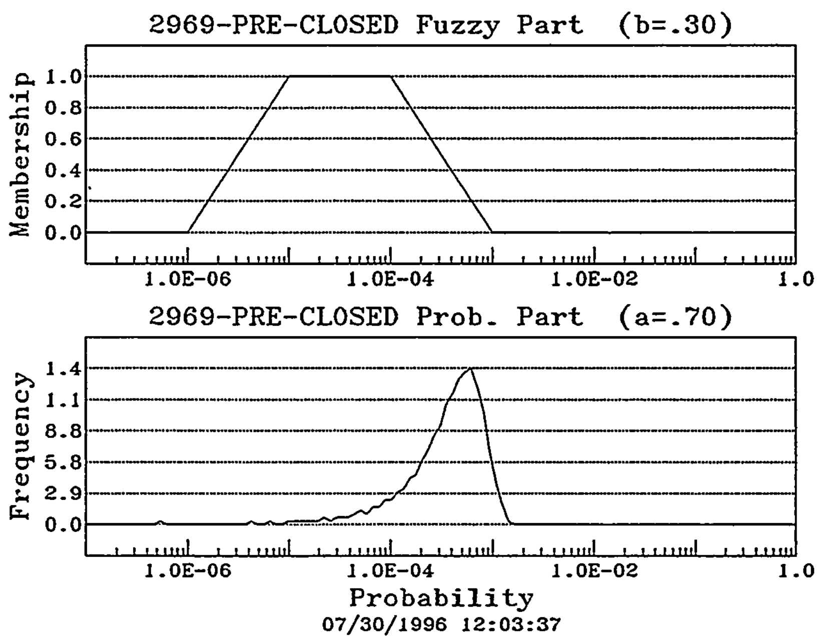


Figure 7. Event 2 Hybrid Plot for Example Analysis 3.

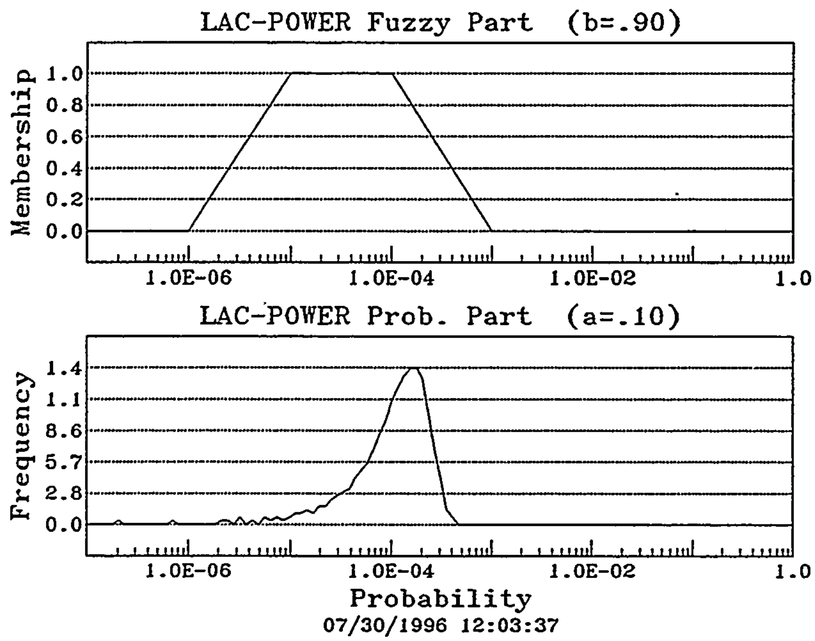


Figure 8. Event 3 Hybrid Plot for Example Analysis 3.

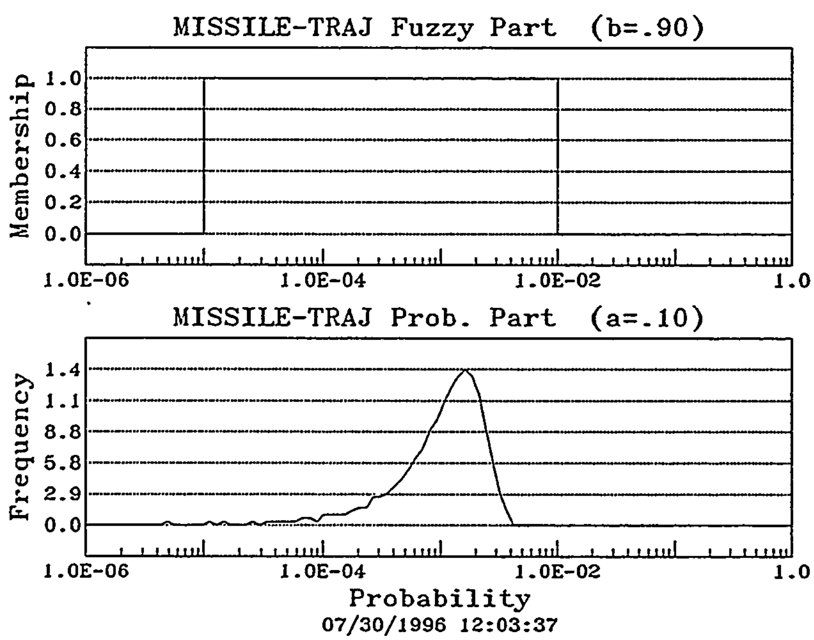


Figure 9. Event 4 Hybrid Plot for Example Analysis 3.

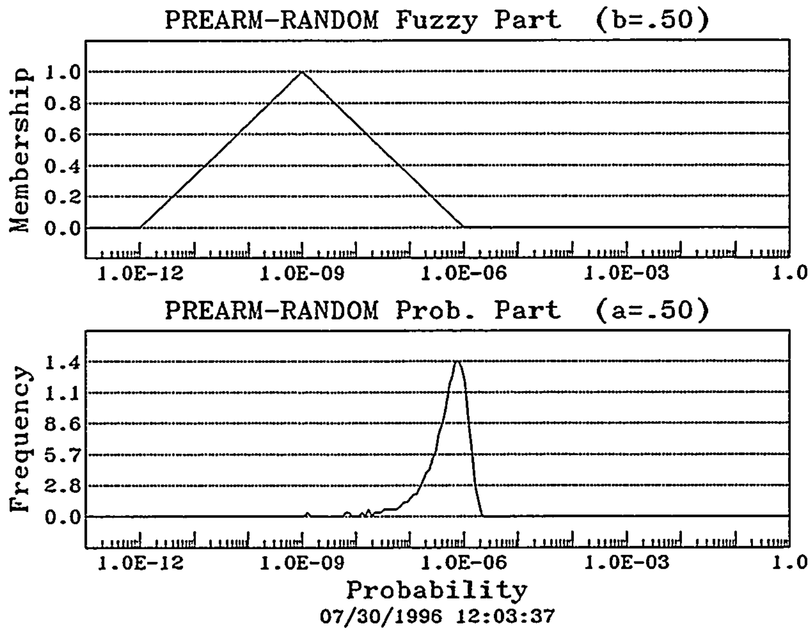


Figure 10. Event 5 Hybrid Plot for Example Analysis 3.

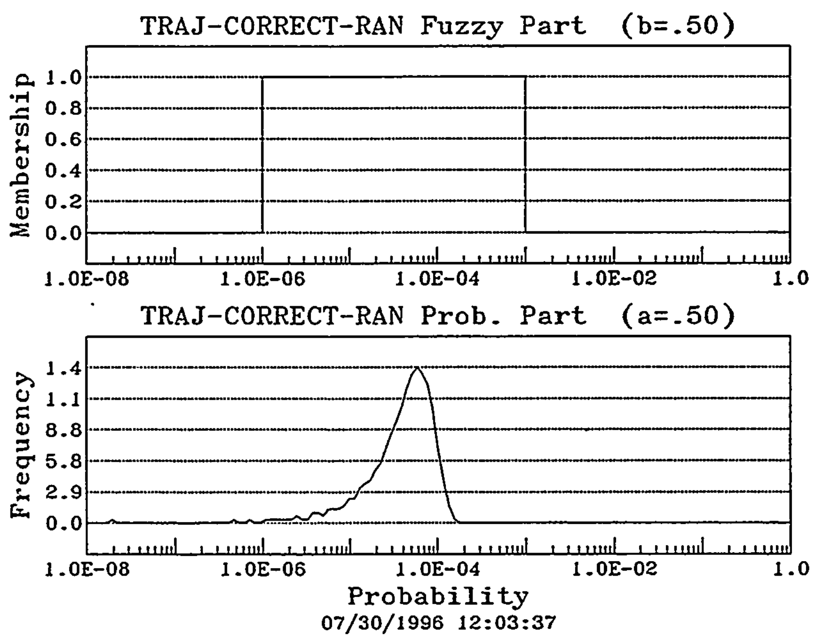


Figure 11. Event 6 Hybrid Plot for Example Analysis 3.

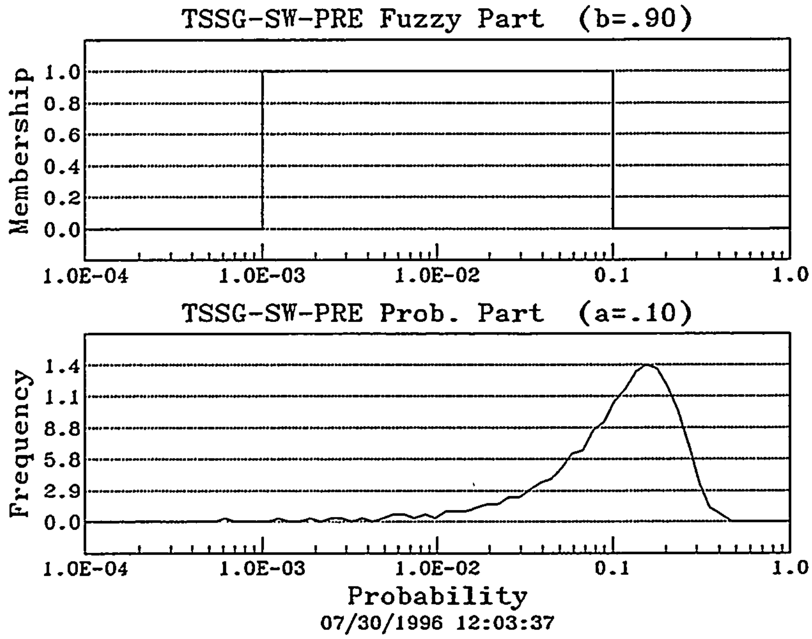


Figure 12. Event 7 Hybrid Plot for Example Analysis 3.

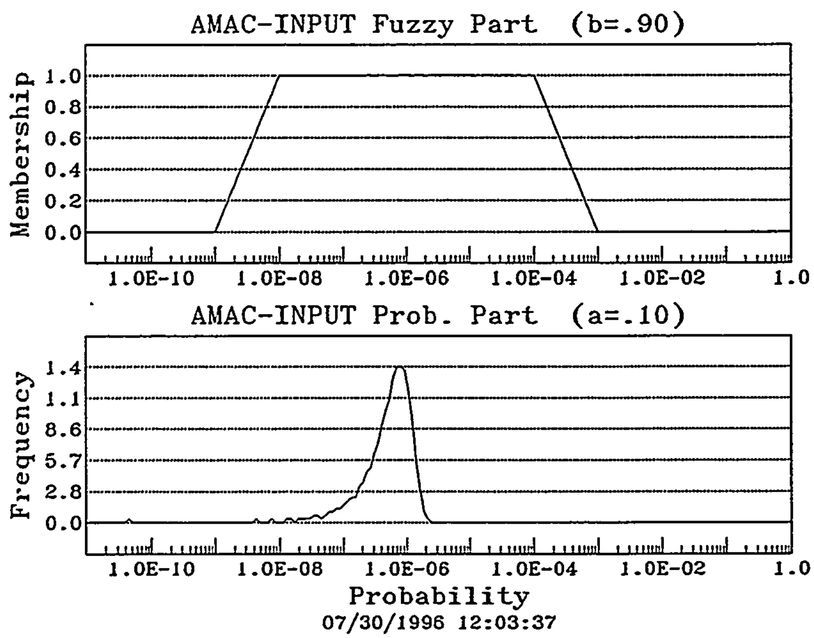


Figure 13. Event 8 Hybrid Plot for Example Analysis 3.

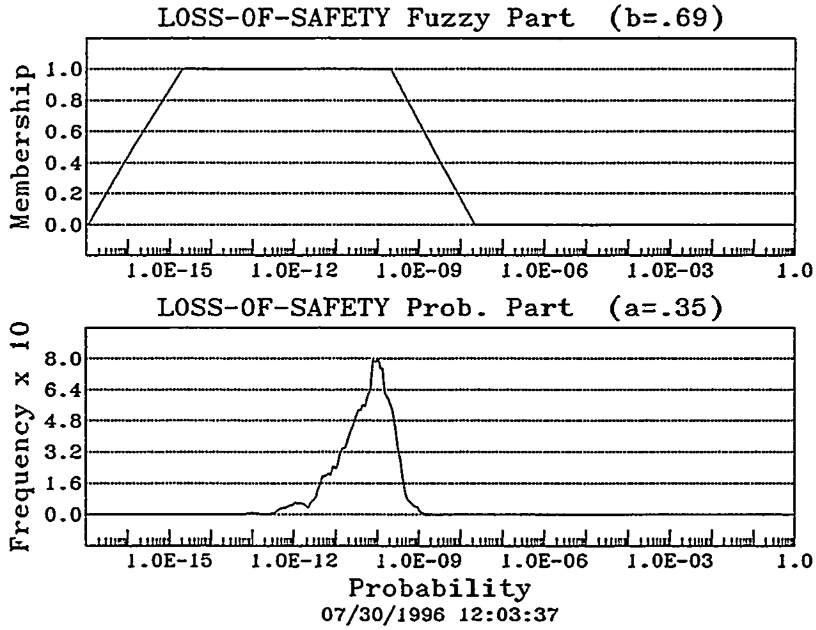


Figure 14. Top Event Hybrid Plot for Example Analysis 3.

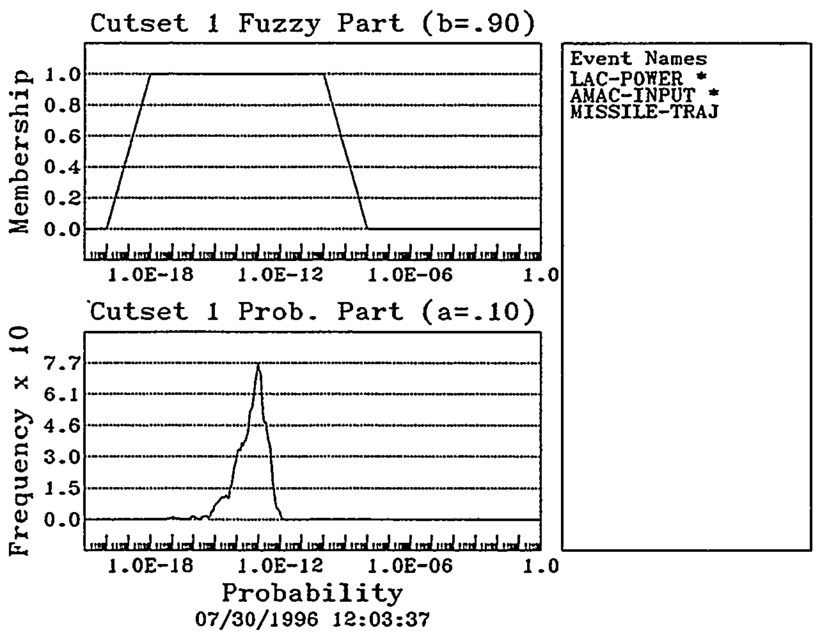


Figure 15. Cutset 1 Hybrid Plot for Example Analysis 3.

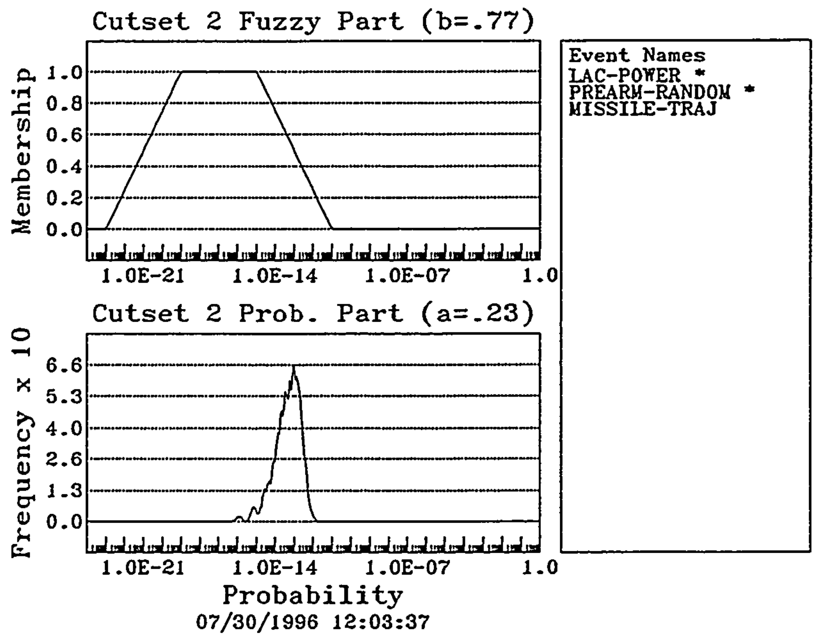


Figure 16. Cutset 2 Hybrid Plot for Example Analysis 3.

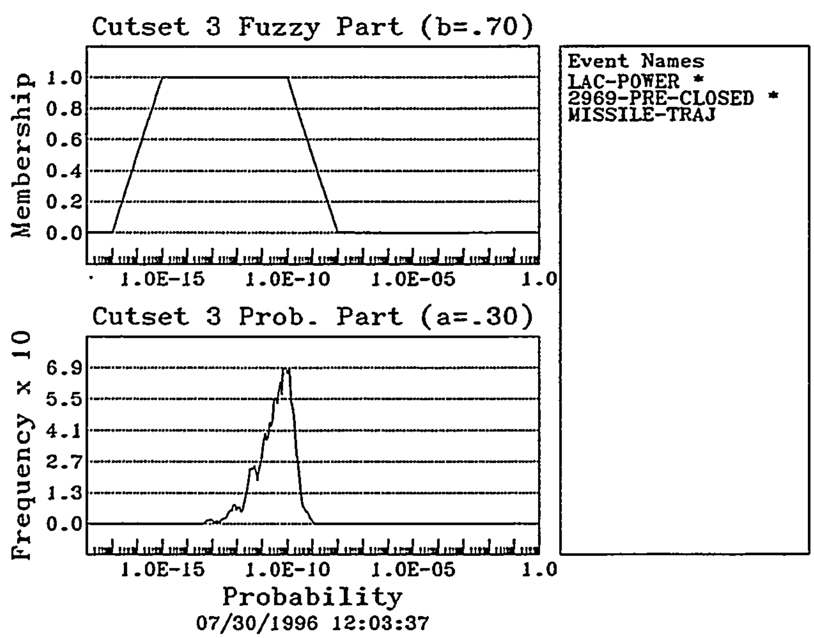


Figure 17. Cutset 3 Hybrid Plot for Example Analysis 3.

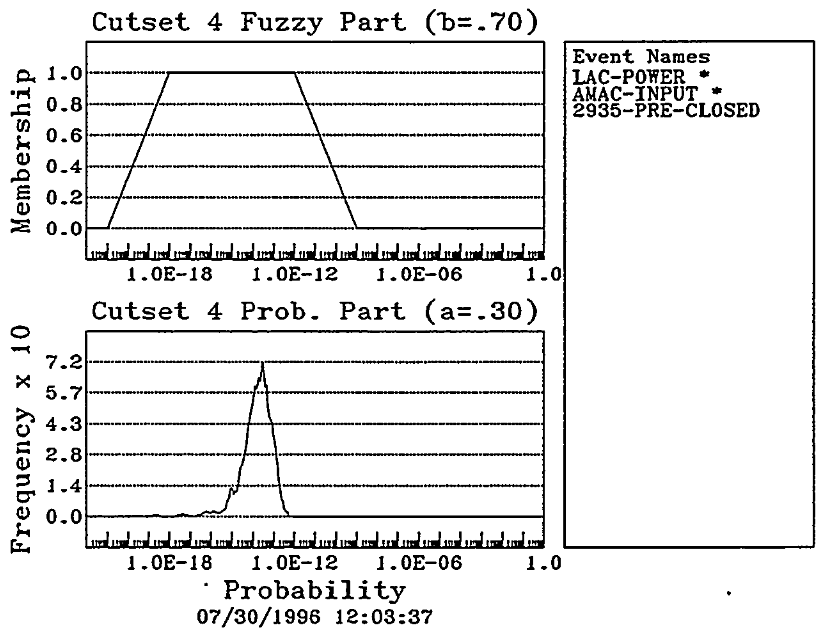


Figure 18. Cutset 4 Hybrid Plot for Example Analysis 3.

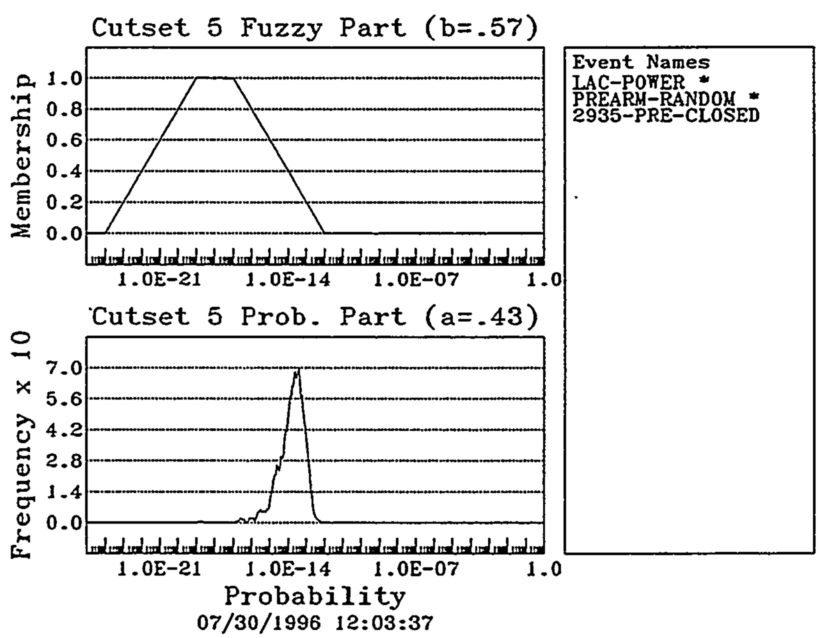


Figure 19. Cutset 5 Hybrid Plot for Example Analysis 3.

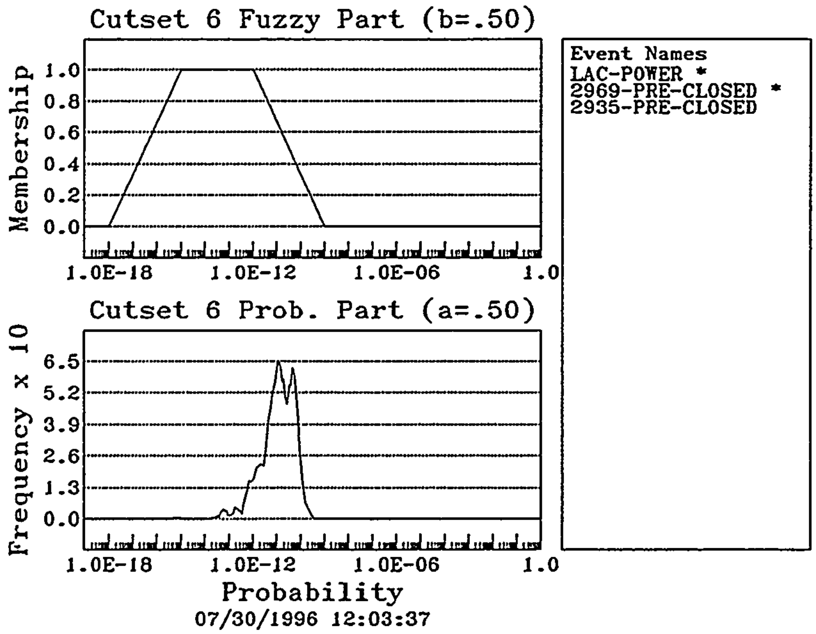


Figure 20. Cutset 6 Hybrid Plot for Example Analysis 3.

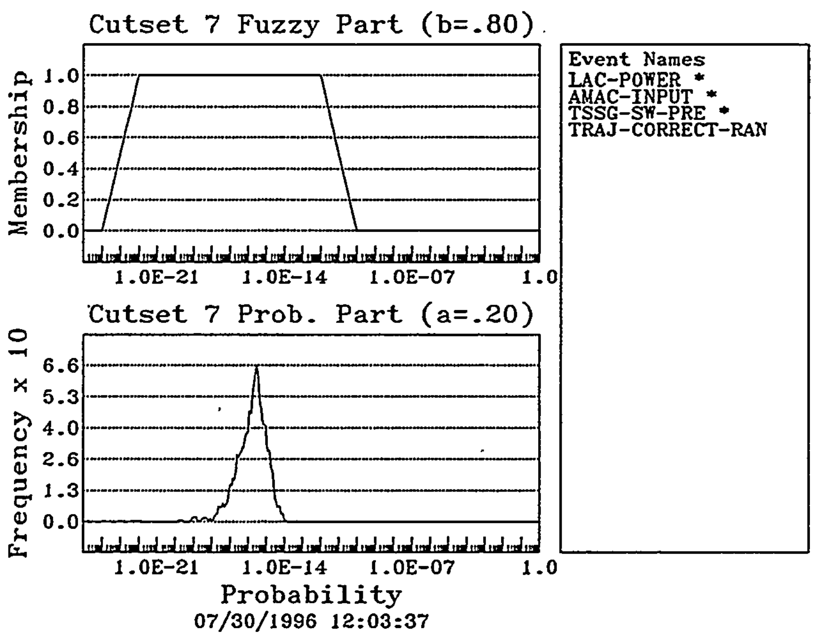


Figure 21. Cutset 7 Hybrid Plot for Example Analysis 3.

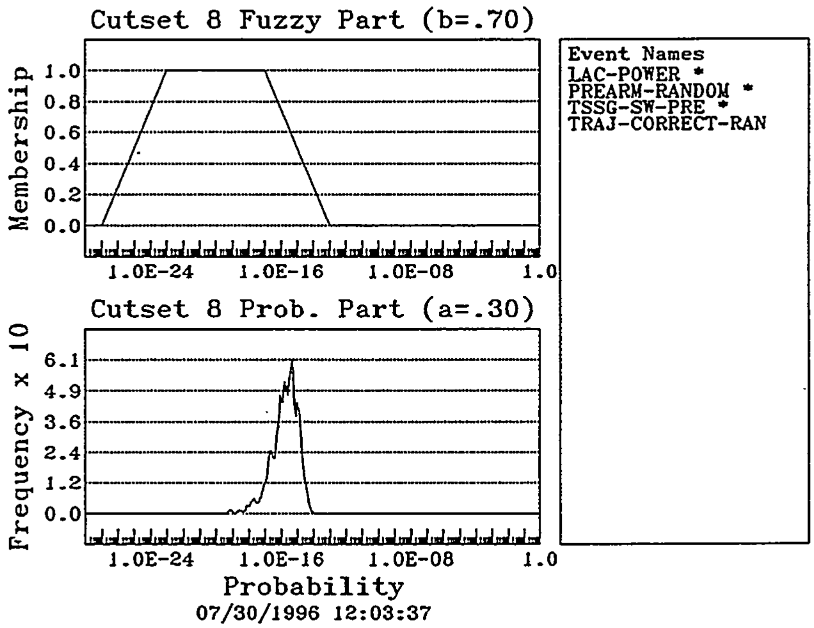


Figure 22. Cutset 8 Hybrid Plot for Example Analysis 3.

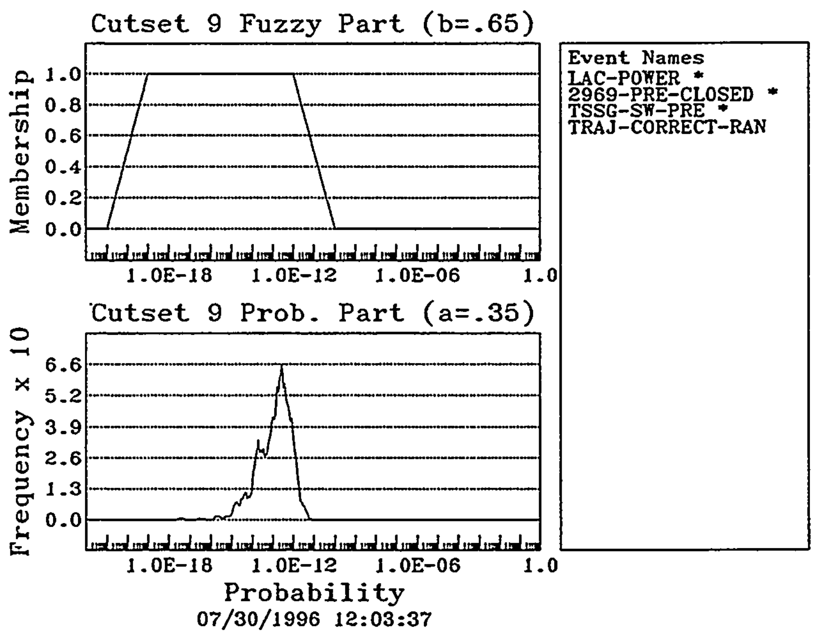


Figure 23. Cutset 9 Hybrid Plot for Example Analysis 3.

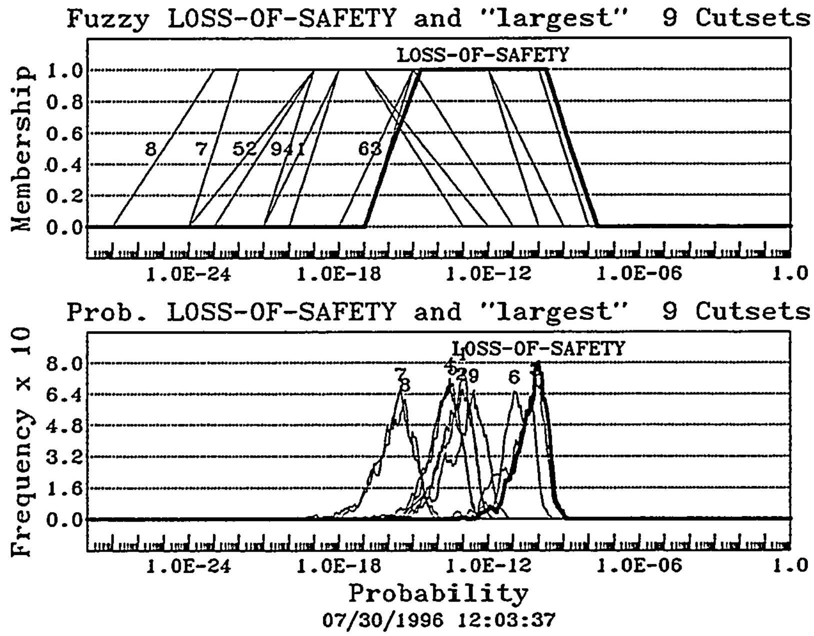


Figure 24. Composite Hybrid Plot for Example Analysis 3.

Appendix D - Example Analysis 4 - A Large Hybrid Analysis

PHASER Execution Sequence (Screen Output)

The following is a PHASER execution sequence of a rather large fault tree. Refer to Section 4.3 beginning on Page 40 for an explanation of Computer Screen Output. This analysis performs an "exact" Top Event quantification, but does not request the Disjoint Sets to be written to an output file. The Disjoint Set File for this fault tree would exceed 10 Megabytes in size. The structure for this fault tree requires four sheets to illustrate. The first sheet of this graphical illustration is on Page 83. A Top Event Plot and a Composite Plot are both requested in this analysis.

```
+-----------------------------------+
|      PHASER    VERSION  2.10      |
|           07/26/1996              |
|-----------------------------------|
|          <<< AUTHORS >>>          |
|   Bob Roginski        Org. 12333  |
|   J. Arlin Cooper     Org. 12331  |
+-----------------------------------+

  Run date & time = 07/30/1996 15:56:45
  Compiler Used   = MS Pwr Sta V1.0a

  BASIC EVENT FILE  IS  BIG-VER.DAT
  QA / ERROR FILE   IS  BIG-VER.QAF

       Reading File  BIG-VER.DAT
       Reading LHS Sampling Files
       Reading File  BIG-V-CS.DAT

       Generating Disjoint Sets

       Defining Substitute Events
       Cumulative CPU time =       .0 seconds

       Performing Problem Subdivision
       Cumulative CPU time =      1.3 seconds

       This problem is subdivided on
       the following 10 events:
       G                 (Referenced in  66 Cutsets)
       F                 (Referenced in  48 Cutsets)
       U                 (Referenced in  33 Cutsets)
       V                 (Referenced in  33 Cutsets)
       R                 (Referenced in  24 Cutsets)
       H                 (Referenced in  12 Cutsets)
       I                 (Referenced in  12 Cutsets)
       J                 (Referenced in  12 Cutsets)
       K                 (Referenced in  12 Cutsets)
       L                 (Referenced in  12 Cutsets)

       Solving 1024 Subproblems for  200 Observations

       Solving Subproblem 1024 of 1024
       Cumulative CPU time =    932.3 seconds
```

```
INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft

Copying Plot   1 to HPGL file RESULT.HGL


INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft

Copying Plot   2 to HPGL file COMPOSIT.HGL

                 Writing File  BIG-VER.QAF

                 No Errors Detected

Stop - Program terminated.
```

Keyword/Quantification Input File Listing

The following is a listing of the Keyword/Quantification Input File BIG-VER.DAT used in this example of a hybrid analysis.

```
$  This is an example Fuzzy Logic Data Input FIle.
$
$  The format is column-independent and supports the use of comments and
$  continuation lines.  Certain keywords have special meaning to the
$  program and must NOT be used as a basic event name.  The next several
$  lines are examples of recognized keywords.

CUTSETFILE     =  BIG-V-CS.DAT     $ Associated Cutset File (SABLE Output)
NLINES         =  2                $ No. of Calculation Value Lines
DEBUGINFO      =  No               $ Add Debugging Info. to QA File
PLOTEVENTS     =  No
PLOTTOPEVENT   =  Yes
PLOTCUTSETS    =  No
PLOTCOMPOSITE  =  Yes
OUTPUTDEVICE   =  CRT  HPGL        $ CRT, HPLJ or HPGL are Valid Devices
DELAY          =  10               $ Hold Plots on CRT for this long
SAMMOD         =  LHS              $ Can be USER, LHS or USEROVERRIDE
ECHOCUTSETFILE =  Yes              $ Turn off Echo if file is large
SMOOTHFACTOR   =  Auto             $ Smoothing Factor for PDF Plots
CUTSETLIMIT    =  10               $ Maximum No. Cutsets to be plotted
MAXDECIMALS    =   3               $ Maximum Decimal Places on Plots
PRECISERESULT  =  Yes              $ Precise Top Event requested

$  Some of the following keywords are read by FLOG, but all are required
$  if LHS is to be invoked (i.e., the fault tree is at least partially
$  probabilistic).  Note the '=' (equal sign) must NOT follow the key-
$  word because LHS will not accept this syntax.

LHSOBS            200              $ No. of Observations in LHS Sample
LHSOUT            LHS-69CS.DAT     $ Name of LHS Output File
LHSMSG            LHS-69CS.MSG     $ Name of LHS Message File
LHSSEED           1                $ Start of LHS Random Number Generator

$  These are the Basic Event Definitions.  Hybrid events are those having
$  a non-zero "A factor" value specified, along with an associated dis-
$  tribution definition (i.e., DATA:... etc.) that is acceptable to the
$  LHS code.  An event definition is TOTALLY fuzzy if the "A factor" value
$  is missing (defaults to zero) or specified as zero.  A distribution
$  MUST be specified if the "A factor" value is non-zero.

A          =  1.0E-4   1.0E-2           A=0.1   $ Region 3 Puncture
    DATA: A          BOUNDED NORMAL  1.0E-2  0.01     1.0E-18   0.99999
B          =  1.0E-7   1.0E-2           A=0.3   $ Inadvertant AC IUQS
```

```
    DATA: B        BOUNDED NORMAL   1.0E-7   1.0E-7   1.0E-18   0.99999
C          =  1.0E-7   1.0E-5                   $ TSL breaks
D          =  1.0E-7   1.0E-5                   $ ISL breaks
E          =  1.0E-4   1.0E-2           A=0.1   $ Exclusion reg. bypass
    DATA: E        BOUNDED NORMAL   1.0E-2   0.01     1.0E-18   0.99999
F          =  0.1      0.5      0.9             $ External power
G          =  1.0E-4   1.0E-3   1.0E-2          $ Weak link OK
H          =  1.0E-7   1.0E-2           A=0.3   $ Inadvertant AC IUQS
    DATA: H        BOUNDED NORMAL   1.0E-7   1.0E-7   1.0E-18   0.99999
I          =  1.0E-8   1.0E-6           A=0.3   $ Internal UQS
    DATA: I        BOUNDED NORMAL   1.0E-7   1.0E-7   1.0E-18   0.99999
J          =  1.0E-8   1.0E-6           A=0.3   $ External UQS
    DATA: J        BOUNDED NORMAL   1.0E-7   1.0E-7   1.0E-18   0.99999
K          =  0.5      0.8      0.9             $ Battery power
L          =  0.1      0.5      0.9             $ External power
M          =  1.0E-4   1.0E-3   1.0E-2          $ Rolamite stuck closed
N          =  1.0E-4   1.0E-3   1.0E-2          $ Inadvertant rol. drive
O          =  1.0E-8   1.0E-6           A=0.3   $ Internal UQS
    DATA: O        BOUNDED NORMAL   1.0E-7   1.0E-7   1.0E-18   0.99999
P          =  1.0E-8   1.0E-6           A=0.3   $ External TUQS
    DATA: P        BOUNDED NORMAL   1.0E-7   1.0E-7   1.0E-18   0.99999
Q          =  1.0E-6   1.0E-2           A=0.3   $ Inadvertant TUQS
    DATA: Q        BOUNDED NORMAL   1.0E-7   1.0E-7   1.0E-18   0.99999
R          =  0.1      0.5      0.9             $ Microproc. working
S          =  1.0E-8   1.0E-6           A=0.3   $ Inadvertant IUQS
    DATA: S        BOUNDED NORMAL   1.0E-7   1.0E-7   1.0E-18   0.99999
T          =  0.5      0.8      0.9             $ Battery power
U          =  0.1      0.5      0.9             $ External trigger
V          =  0.05     0.3      0.8             $ Commanded trigger
W          =  1.0E-4   1.0E-2           A=0.1   $ Region 2 breach
    DATA: W        BOUNDED NORMAL   1.0E-2   1.0E-2   1.0E-18   0.99999
X          =  0.1      0.5      0.9             $ External low voltage
Y          =  1.0E-7   1.0E-5                   $ ISL breaks
Z          =  1.0E-3   1.0E-2   1.0E-1  A=0.1   $ Region 1 breach
    DATA: Z        BOUNDED NORMAL   1.0E-2   1.0E-2   1.0E-18   0.99999
LB         =  1.0E-3   1.0E-2                   $ Shock
LE         =  1.0E-2   1.0E-1                   $ SL exposed to shock
LF         =  1.0E-3   1.0E-2                   $ SL fails in shock
UDELTA     =  1.0E-8   1.0E-6   1.0E-2          $ Lightning to weapon
LDELTA     =  1.0E-4   1.0E-2   1.0E-1          $ Power through LAC
THETA      =  1.0E-4   1.0E-2           A=0.1   $ Barrier compromised
    DATA: THETA    BOUNDED NORMAL   1.0E-2   1.0E-2   1.0E-18   0.99999
UOMEGA     =  1.0E-3   1.0E-1           A=0.1   $ Midcase compromise
    DATA: UOMEGA   BOUNDED NORMAL   1.0E-1   1.0E-1   1.0E-18   0.99999
USIGMA     =  1.0E-4   1.0E-2           A=0.1   $ Exclusion reg. breach
    DATA: USIGMA   BOUNDED NORMAL   1.0E-2   1.0E-2   1.0E-18   0.99999
LSIGMA     =  0.1      0.3      0.5             $ HV shorts to dets
ALPHA      =  1.0E-7   1.0E-5                   $ SL breaks in shock
BETA       =  1.0E-7   1.0E-5                   $ SL punctured
GAMMA      =  1.0E-7   1.0E-5                   $ Stronglink fails thermal
PHI        =  1.0E-8   1.0E-7   1.0E-6  A=0.1   $ LAC arc fails
    DATA: PHI      BOUNDED NORMAL   1.0E-7   1.0E-7   1.0E-18   0.99999
MU         =  0.1      0.3      0.5             $ Barrier bypass
```

Cutset Input File Listing

The following is a listing of the Cutset Input File BIG-V-CS.DAT used in this example hybrid analysis. This file was generated by a previous execution of the SABLE code.

```
SAFETY-MALFUNC =
UOMEGA * UDELTA * THETA +
UOMEGA * UDELTA * USIGMA +
G * F * V * Q +
G * F * V * B +
```

```
G * F * V * A +
G * F * U * Q +
G * F * U * B +
G * F * U * A +
LDELTA * PHI * LSIGMA * MU +
G * F * H * V * P +
G * F * I * V * P +
G * F * J * V * P +
G * F * H * V * O +
G * F * I * V * O +
G * F * J * V * O +
G * F * H * U * P +
G * F * I * U * P +
G * F * J * U * P +
G * F * H * U * O +
G * F * I * U * O +
G * F * J * U * O +
G * V * GAMMA * X * W +
G * V * BETA * X * W +
G * V * ALPHA * X * W +
G * U * GAMMA * X * W +
G * U * BETA * X * W +
G * U * ALPHA * X * W +
G * V * GAMMA * S * T +
G * V * BETA * S * T +
G * V * ALPHA * S * T +
G * U * GAMMA * S * T +
G * U * BETA * S * T +
G * U * ALPHA * S * T +
G * F * V * C * D * E +
G * F * U * C * D * E +
G * V * GAMMA * X * Y * Z +
G * V * BETA * X * Y * Z +
G * V * ALPHA * X * Y * Z +
G * U * GAMMA * X * Y * Z +
G * U * BETA * X * Y * Z +
G * U * ALPHA * X * Y * Z +
G * F * H * V * R * N * L +
G * F * I * V * R * N * L +
G * F * J * V * R * N * L +
G * F * H * U * R * N * L +
G * F * I * U * R * N * L +
G * F * J * U * R * N * L +
G * F * H * V * R * M * L +
G * F * I * V * R * M * L +
G * F * J * V * R * M * L +
G * F * H * U * R * M * L +
G * F * I * U * R * M * L +
G * F * J * U * R * M * L +
G * F * H * V * R * N * K +
G * F * I * V * R * N * K +
G * F * J * V * R * N * K +
G * F * H * U * R * N * K +
G * F * I * U * R * N * K +
G * F * J * U * R * N * K +
G * F * H * V * R * M * K +
G * F * I * V * R * M * K +
G * F * J * V * R * M * K +
G * F * H * U * R * M * K +
G * F * I * U * R * M * K +
G * F * J * U * R * M * K +
G * F * V * P * LB * LE * LF +
G * F * V * O * LB * LE * LF +
G * F * U * P * LB * LE * LF +
G * F * U * O * LB * LE * LF .
```

QA Output File Listing

The following is a listing of the QA Output File BIG-VER.QAF generated by this hybrid analysis. This listing illustrates the details regarding the QA Output File. These details are described in Section 4.1.1 starting on Page 34.

```
+-----------------------------------+
|        PHASER    VERSION  2.10    |
|              07/26/1996           |
|-----------------------------------|
|           <<< AUTHORS >>>         |
|    Bob Roginski        Org. 12333 |
|    J. Arlin Cooper     Org. 12331 |
+-----------------------------------+

      Run date & time = 07/30/1996 15:56:45
      Compiler Used   = MS Pwr Sta V1.0a

      BASIC EVENT FILE  IS  BIG-VER.DAT
      QA / ERROR FILE   IS  BIG-VER.QAF


                <<< Part 1>>>
   Echo of Basic Event File BIG-VER.DAT with Diagnostics

$  This is an example Fuzzy Logic Data Input FIle.
$
$  The format is column-independent and supports the use of comments and
$  continuation lines.  Certain keywords have special meaning to the
$  program and must NOT be used as a basic event name.  The next several
$  lines are examples of recognized keywords.

CUTSETFILE     =  BIG-V-CS.DAT    $ Associated Cutset File (SABLE Output)
NLINES         =  2               $ No. of Calculation Value Lines
DEBUGINFO      =  No              $ Add Debugging Info. to QA File
PLOTEVENTS     =  No
PLOTTOPEVENT   =  Yes
PLOTCUTSETS    =  No
PLOTCOMPOSITE  =  Yes
OUTPUTDEVICE   =  CRT  HPGL       $ CRT, HPLJ or HPGL are Valid Devices
DELAY          =  10              $ Hold Plots on CRT for this long
SAMMOD         =  LHS             $ Can be USER, LHS or USEROVERRIDE
ECHOCUTSETFILE =  Yes             $ Turn off Echo if file is large
SMOOTHFACTOR   =  Auto            $ Smoothing Factor for PDF Plots
CUTSETLIMIT    =  10              $ Maximum No. Cutsets to be plotted
MAXDECIMALS    =   3              $ Maximum Decimal Places on Plots
PRECISERESULT  =  Yes             $ Precise Top Event requested

$  Some of the following keywords are read by FLOG, but all are required
$  if LHS is to be invoked (i.e., the fault tree is at least partially
$  probabilistic).  Note the '=' (equal sign) must NOT follow the key-
$  word because LHS will not accept this syntax.

LHSOBS            200             $ No. of Observations in LHS Sample
LHSOUT            LHS-69CS.DAT    $ Name of LHS Output File
LHSMSG            LHS-69CS.MSG    $ Name of LHS Message File
LHSSEED           1               $ Start of LHS Random Number Generator

$  These are the Basic Event Definitions.  Hybrid events are those having
$  a non-zero "A factor" value specified, along with an associated dis-
$  tribution definition (i.e., DATA:... etc.) that is acceptable to the
$  LHS code.  An event definition is TOTALLY fuzzy if the "A factor" value
$  is missing (defaults to zero) or specified as zero.  A distribution
$  MUST be specified if the "A factor" value is non-zero.
```

```
A          = 1.0E-4   1.0E-2            A=0.1   $ Region 3 Puncture
    DATA: A        BOUNDED NORMAL   1.0E-2   0.01     1.0E-18   0.99999
B          = 1.0E-7   1.0E-2            A=0.3   $ Inadvertant AC IUQS
    DATA: B        BOUNDED NORMAL   1.0E-7   1.0E-7   1.0E-18   0.99999
C          = 1.0E-7   1.0E-5                    $ TSL breaks
D          = 1.0E-7   1.0E-5                    $ ISL breaks
E          = 1.0E-4   1.0E-2            A=0.1   $ Exclusion reg. bypass
    DATA: E        BOUNDED NORMAL   1.0E-2   0.01     1.0E-18   0.99999
F          = 0.1      0.5      0.9              $ External power
G          = 1.0E-4   1.0E-3   1.0E-2           $ Weak link OK
H          = 1.0E-7   1.0E-2            A=0.3   $ Inadvertant AC IUQS
    DATA: H        BOUNDED NORMAL   1.0E-7   1.0E-7   1.0E-18   0.99999
I          = 1.0E-8   1.0E-6            A=0.3   $ Internal UQS
    DATA: I        BOUNDED NORMAL   1.0E-7   1.0E-7   1.0E-18   0.99999
J          = 1.0E-8   1.0E-6            A=0.3   $ External UQS
    DATA: J        BOUNDED NORMAL   1.0E-7   1.0E-7   1.0E-18   0.99999
K          = 0.5      0.8      0.9              $ Battery power
L          = 0.1      0.5      0.9              $ External power
M          = 1.0E-4   1.0E-3   1.0E-2           $ Rolamite stuck closed
N          = 1.0E-4   1.0E-3   1.0E-2           $ Inadvertant rol. drive
O          = 1.0E-8   1.0E-6            A=0.3   $ Internal UQS
    DATA: O        BOUNDED NORMAL   1.0E-7   1.0E-7   1.0E-18   0.99999
P          = 1.0E-8   1.0E-6            A=0.3   $ External TUQS
    DATA: P        BOUNDED NORMAL   1.0E-7   1.0E-7   1.0E-18   0.99999
Q          = 1.0E-6   1.0E-2            A=0.3   $ Inadvertant TUQS
    DATA: Q        BOUNDED NORMAL   1.0E-7   1.0E-7   1.0E-18   0.99999
R          = 0.1      0.5      0.9              $ Microproc. working
S          = 1.0E-8   1.0E-6            A=0.3   $ Inadvertant IUQS
    DATA: S        BOUNDED NORMAL   1.0E-7   1.0E-7   1.0E-18   0.99999
T          = 0.5      0.8      0.9              $ Battery power
U          = 0.1      0.5      0.9              $ External trigger
V          = 0.05     0.3      0.8              $ Commanded trigger
W          = 1.0E-4   1.0E-2            A=0.1   $ Region 2 breach
    DATA: W        BOUNDED NORMAL   1.0E-2   1.0E-2   1.0E-18   0.99999
X          = 0.1      0.5      0.9              $ External low voltage
Y          = 1.0E-7   1.0E-5                    $ ISL breaks
Z          = 1.0E-3   1.0E-2   1.0E-1   A=0.1   $ Region 1 breach
    DATA: Z        BOUNDED NORMAL   1.0E-2   1.0E-2   1.0E-18   0.99999
LB         = 1.0E-3   1.0E-2                    $ Shock
LE         = 1.0E-2   1.0E-1                    $ SL exposed to shock
LF         = 1.0E-3   1.0E-2                    $ SL fails in shock
UDELTA     = 1.0E-8   1.0E-6   1.0E-2           $ Lightning to weapon
LDELTA     = 1.0E-4   1.0E-2   1.0E-1           $ Power through LAC
THETA      = 1.0E-4   1.0E-2            A=0.1   $ Barrier compromised
    DATA: THETA    BOUNDED NORMAL   1.0E-2   1.0E-2   1.0E-18   0.99999
UOMEGA     = 1.0E-3   1.0E-1            A=0.1   $ Midcase compromise
    DATA: UOMEGA   BOUNDED NORMAL   1.0E-1   1.0E-1   1.0E-18   0.99999
USIGMA     = 1.0E-4   1.0E-2            A=0.1   $ Exclusion reg. breach
    DATA: USIGMA   BOUNDED NORMAL   1.0E-2   1.0E-2   1.0E-18   0.99999
LSIGMA     = 0.1      0.3      0.5              $ HV shorts to dets
ALPHA      = 1.0E-7   1.0E-5                    $ SL breaks in shock
BETA       = 1.0E-7   1.0E-5                    $ SL punctured
GAMMA      = 1.0E-7   1.0E-5                    $ Stronglink fails thermal
PHI        = 1.0E-8   1.0E-7   1.0E-6   A=0.1   $ LAC arc fails
    DATA: PHI      BOUNDED NORMAL   1.0E-7   1.0E-7   1.0E-18   0.99999
MU         = 0.1      0.3      0.5              $ Barrier bypass
```

<<< Part 2>>>

Echo of Cutset File BIG-V-CS.DAT with Diagnostics

```
SAFETY-MALFUNC =
UOMEGA * UDELTA * THETA +
UOMEGA * UDELTA * USIGMA +
G * F * V * Q +
G * F * V * B +
G * F * V * A +
G * F * U * Q +
G * F * U * B +
G * F * U * A +
```

```
LDELTA * PHI * LSIGMA * MU +
G * F * H * V * P +
G * F * I * V * P +
G * F * J * V * P +
G * F * H * V * O +
G * F * I * V * O +
G * F * J * V * O +
G * F * H * U * P +
G * F * I * U * P +
G * F * J * U * P +
G * F * H * U * O +
G * F * I * U * O +
G * F * J * U * O +
G * V * GAMMA * X * W +
G * V * BETA * X * W +
G * V * ALPHA * X * W +
G * U * GAMMA * X * W +
G * U * BETA * X * W +
G * U * ALPHA * X * W +
G * V * GAMMA * S * T +
G * V * BETA * S * T +
G * V * ALPHA * S * T +
G * U * GAMMA * S * T +
G * U * BETA * S * T +
G * U * ALPHA * S * T +
G * F * V * C * D * E +
G * F * U * C * D * E +
G * V * GAMMA * X * Y * Z +
G * V * BETA * X * Y * Z +
G * V * ALPHA * X * Y * Z +
G * U * GAMMA * X * Y * Z +
G * U * BETA * X * Y * Z +
G * U * ALPHA * X * Y * Z +
G * F * H * V * R * N * L +
G * F * I * V * R * N * L +
G * F * J * V * R * N * L +
G * F * H * U * R * N * L +
G * F * I * U * R * N * L +
G * F * J * U * R * N * L +
G * F * H * V * R * M * L +
G * F * I * V * R * M * L +
G * F * J * V * R * M * L +
G * F * H * U * R * M * L +
G * F * I * U * R * M * L +
G * F * J * U * R * M * L +
G * F * H * V * R * N * K +
G * F * I * V * R * N * K +
G * F * J * V * R * N * K +
G * F * H * U * R * N * K +
G * F * I * U * R * N * K +
G * F * J * U * R * N * K +
G * F * H * V * R * M * K +
G * F * I * V * R * M * K +
G * F * J * V * R * M * K +
G * F * H * U * R * M * K +
G * F * I * U * R * M * K +
G * F * J * U * R * M * K +
G * F * V * P * LB * LE * LF +
G * F * V * O * LB * LE * LF +
G * F * U * P * LB * LE * LF +
G * F * U * O * LB * LE * LF .
```

<u>Sampling Information File</u>

This example requires sampling to be performed by the LHS code because probabilistic event definitions have been specified in the Keyword/Quantification Input File. The following is an abbreviated listing of the file LHS-69CS.DAT that was generated by a preceding execution of the LHS code for this fault tree.

```
$ LHS File Format Version 1.00
$
$ This LHS run was executed on 06/12/96 at 12:52:18.44
$ with LHS Version: 2.00 Release 1, Compiled 01/28/1994
$ The run title was:
$
$
$ Message output file for this run: LHS-69CS.MSG
$
$ Input file(s) for this run: BIG-VER.DAT
$ and BIG-VER.DAT
$
$
$ Point Values for the distributions follow:
$
$ All point values represent mean values that
$ were calculated from the actual LHS sample.
$
   A                    1.2880415E-02
   B                    1.2866739E-07
   E                    1.2872501E-02
   H                    1.2861743E-07
   I                    1.2882897E-07
   J                    1.2850315E-07
   O                    1.2868205E-07
   P                    1.2869154E-07
   Q                    1.2875063E-07
   S                    1.2860924E-07
   W                    1.2869860E-02
   Z                    1.2870150E-02
   THETA                1.2875633E-02
   UOMEGA               1.2871648E-01
   USIGMA               1.2874324E-02
   PHI                  1.2941156E-07
$
@UNCERTAINTY
  @OBSERVATIONS    200
  @VARIABLES      16
   A:
   B:
   E:
   H:
   I:
   J:
   O:
   P:
   Q:
   S:
   W:
   Z:
   THETA:
   UOMEGA:
   USIGMA:
   PHI:
@SAMPLEDATA
          1         16   0.121659E-01   0.212889E-06   0.145461E-01
  0.255892E-06   0.179217E-06   0.682798E-07   0.700427E-07   0.910739E-07
  0.122395E-06   0.980634E-07   0.129066E-01   0.131587E-01   0.121845E-01
```

```
0.171342       0.920964E-02  0.151364E-06
       2             16   0.117785E-04   0.263605E-07   0.256189E-01
0.297947E-07   0.194802E-06   0.109497E-06   0.967390E-07   0.638378E-07
0.198721E-06   0.159748E-06   0.136949E-01   0.261446E-01   0.103663E-01
0.384807       0.271837E-02   0.944353E-07
       3             16   0.123921E-01   0.867074E-07   0.913661E-02
0.166596E-06   0.115069E-06   0.899587E-07   0.219848E-06   0.196684E-06
0.977242E-07   0.547003E-07   0.236057E-01   0.200172E-01   0.178946E-01
0.107574       0.252882E-01   0.338110E-06
       4             16   0.190569E-01   0.471563E-07   0.175025E-01
0.975877E-07   0.952208E-07   0.306692E-06   0.963504E-07   0.215104E-06
0.486250E-07   0.117361E-06   0.118854E-01   0.106835E-01   0.186967E-02
0.819353E-01   0.127389E-01   0.128211E-06
       5             16   0.128567E-01   0.129008E-06   0.879117E-02
0.111886E-06   0.659667E-08   0.110794E-06   0.202208E-06   0.179327E-06
0.184709E-07   0.178223E-06   0.553798E-02   0.170265E-01   0.378511E-02
0.202604       0.214888E-01   0.958950E-07
       6             16   0.132668E-01   0.200971E-06   0.130528E-01
0.961141E-07   0.103867E-06   0.197293E-07   0.148837E-06   0.221849E-07
0.164175E-06   0.129088E-06   0.517144E-02   0.142406E-01   0.266126E-01
0.143548       0.134725E-01   0.124336E-06
       7             16   0.157439E-01   0.779223E-08   0.337896E-02
0.114880E-06   0.475799E-07   0.823938E-07   0.372317E-06   0.516241E-07
0.132338E-06   0.102145E-06   0.946096E-02   0.932052E-02   0.107917E-01
0.226232       0.587573E-02   0.121998E-06
       8             16   0.504122E-02   0.519449E-07   0.180774E-01
0.198441E-06   0.258905E-07   0.236321E-06   0.270676E-06   0.165574E-06
0.113567E-06   0.874955E-07   0.626162E-02   0.174958E-01   0.273465E-01
0.322753E-01   0.131447E-01   0.156626E-06

                        (File Cut Here)

     193             16   0.233166E-01   0.380226E-06   0.832454E-02
0.338806E-07   0.141999E-06   0.168159E-06   0.383361E-07   0.209192E-06
0.227298E-07   0.126683E-06   0.264753E-02   0.111467E-01   0.169574E-01
0.883346E-01   0.518322E-04   0.141304E-06
     194             16   0.226012E-01   0.175846E-06   0.371154E-02
0.669678E-07   0.106254E-06   0.153816E-07   0.189339E-06   0.149649E-06
0.115991E-06   0.193535E-06   0.660970E-02   0.166509E-01   0.247927E-01
0.102709       0.149669E-01   0.345581E-06
     195             16   0.133967E-01   0.136255E-06   0.333980E-01
0.342697E-07   0.132103E-06   0.840634E-08   0.127187E-06   0.125240E-06
0.228057E-06   0.237244E-06   0.671272E-02   0.214057E-01   0.156171E-01
0.629461E-01   0.172917E-01   0.252240E-07
     196             16   0.187725E-01   0.720417E-07   0.229365E-01
0.128952E-06   0.365662E-07   0.131370E-06   0.117747E-06   0.679741E-07
0.158174E-06   0.748253E-07   0.929743E-02   0.267510E-01   0.104760E-01
0.639321E-01   0.162074E-01   0.514343E-07
     197             16   0.211035E-01   0.492313E-07   0.151337E-01
0.479301E-07   0.249029E-06   0.217440E-06   0.116415E-06   0.113340E-06
0.468874E-08   0.361576E-07   0.858506E-02   0.100329E-01   0.254785E-02
0.182135       0.548346E-02   0.223298E-07
     198             16   0.297533E-01   0.152659E-06   0.235870E-02
0.186812E-06   0.128413E-06   0.889685E-07   0.532864E-07   0.998682E-07
0.106559E-06   0.175434E-06   0.301106E-02   0.643097E-02   0.232492E-01
0.199650       0.626217E-02   0.125676E-06
     199             16   0.248221E-01   0.258932E-06   0.910710E-03
0.223882E-06   0.120620E-06   0.115703E-06   0.198647E-06   0.169955E-06
0.404668E-07   0.250416E-06   0.224720E-01   0.421633E-02   0.819455E-02
0.100908       0.140922E-01   0.173395E-06
     200             16   0.405735E-02   0.103342E-06   0.436905E-02
0.497025E-07   0.172079E-10   0.126809E-06   0.109265E-06   0.332558E-07
0.289734E-07   0.569832E-07   0.206603E-01   0.439849E-02   0.129970E-01
0.185856       0.132459E-01   0.366696E-07
```

The Sampling Information File is described in Section 3.3 beginning on Page 32. The complete definition of this file format can be found in Appendix G.

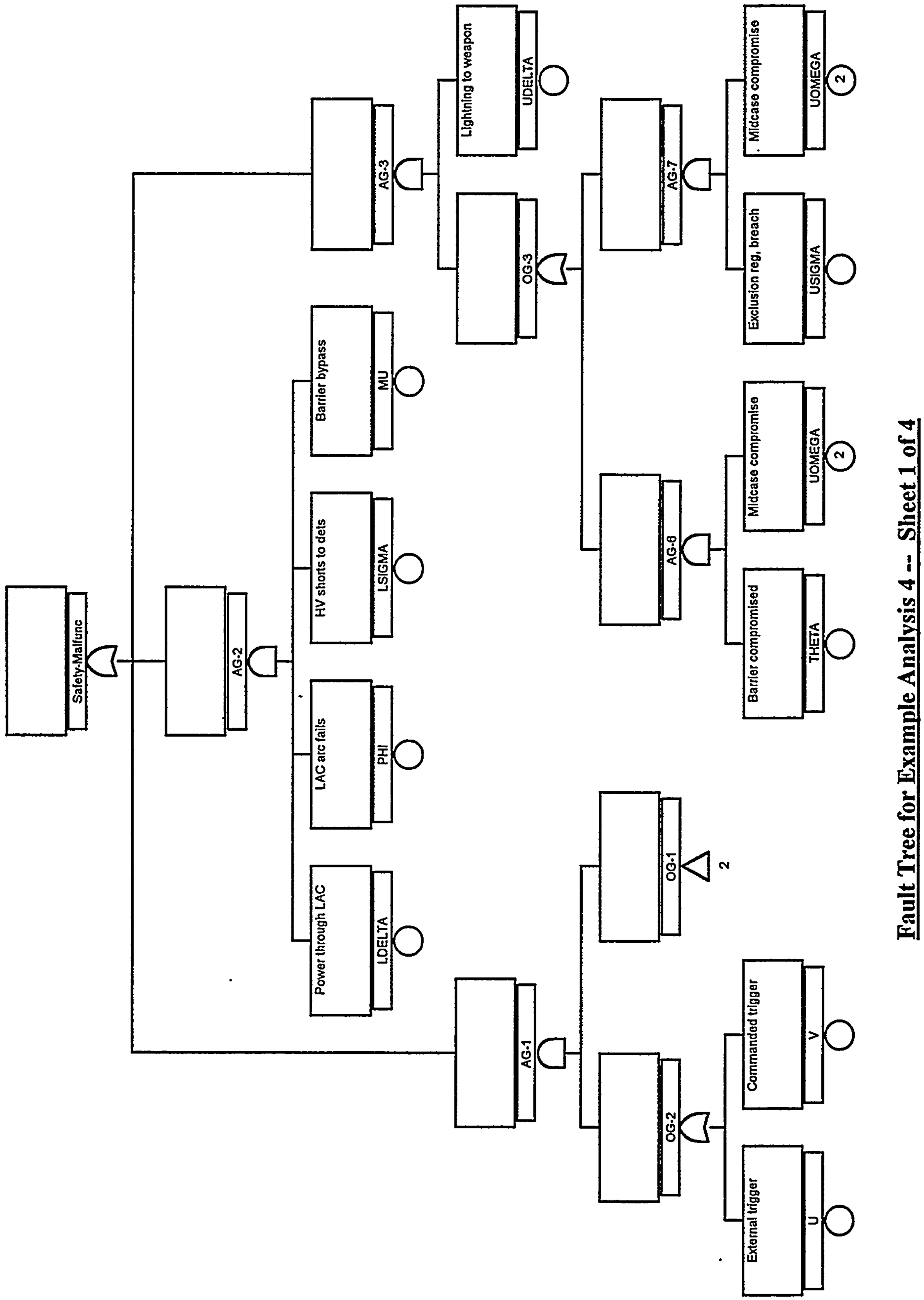


Figure 25. Fault Tree for Example Analysis 4 - Sheet 1 of 4.

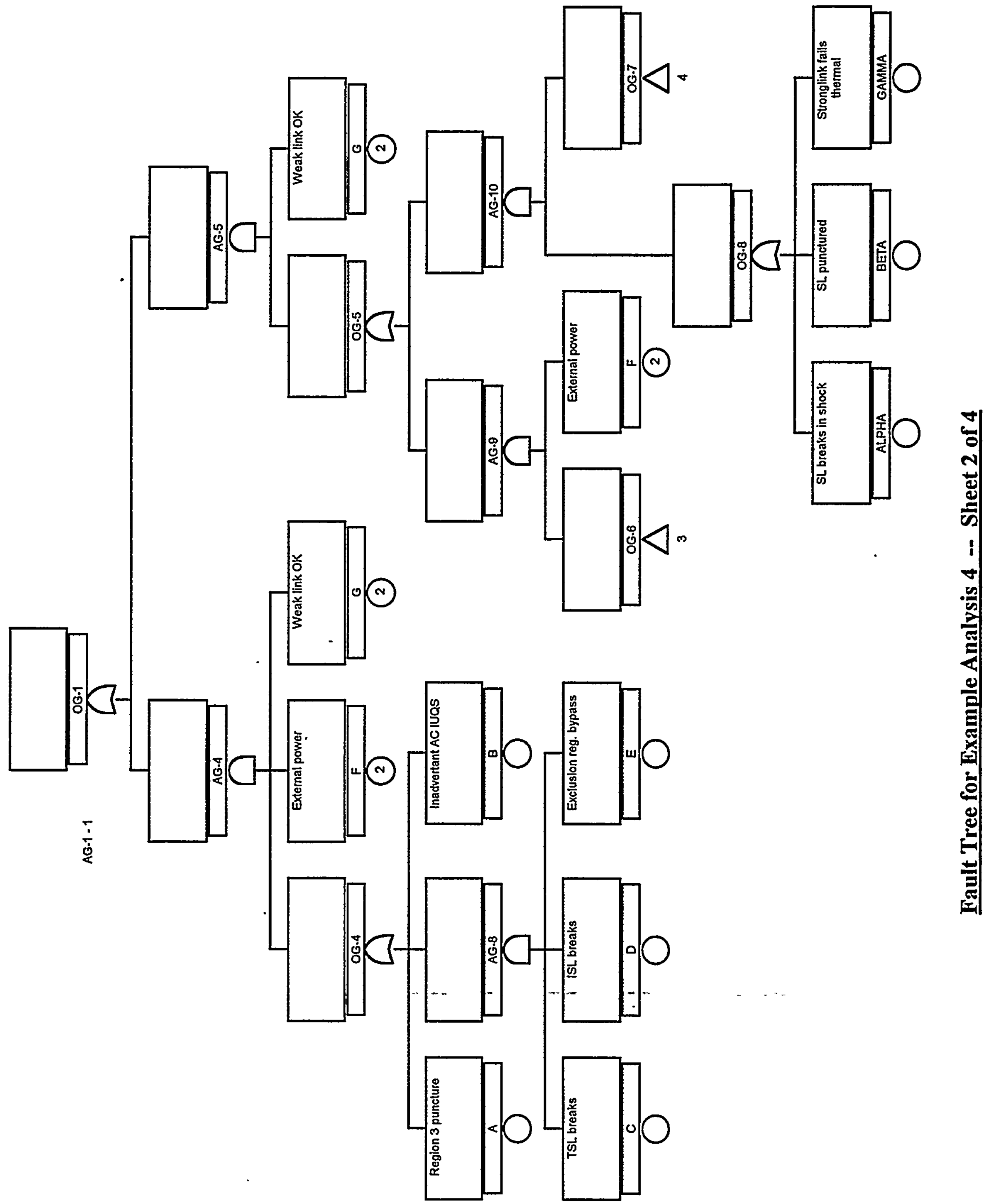


Figure 26. Fault Tree for Example Analysis 4 - Sheet 2 of 4.

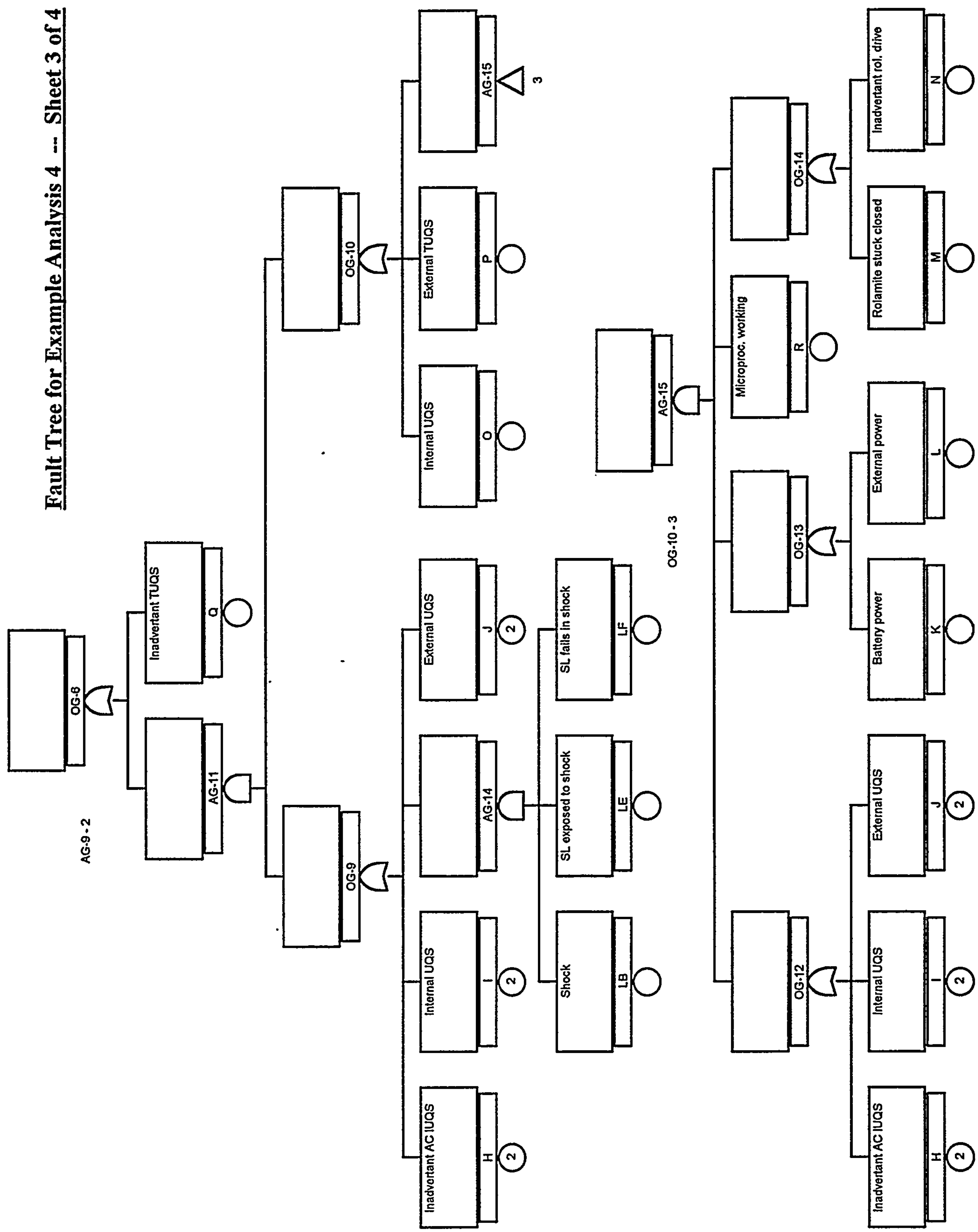
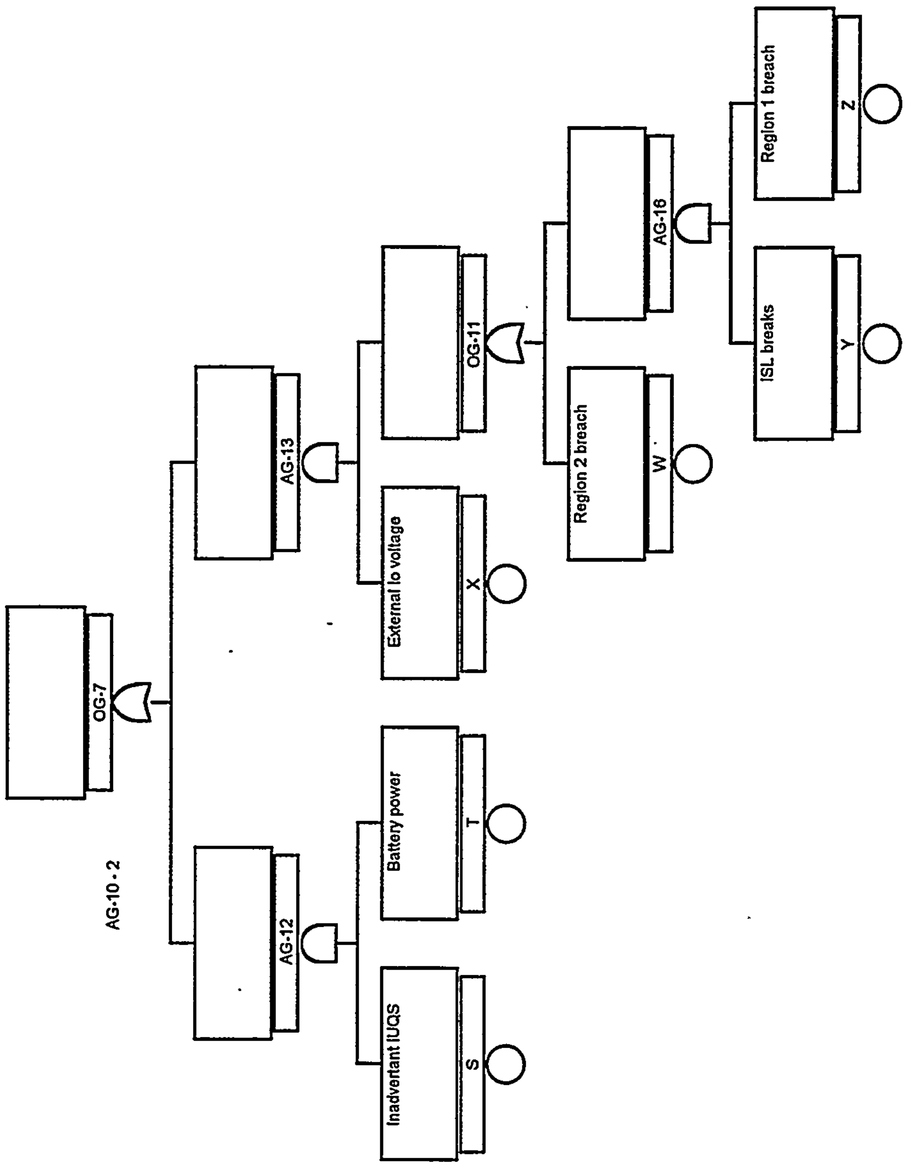


Figure 27. Fault Tree for Example Analysis 4 - Sheet 3 of 4.



Fault Tree for Example Analysis 4 -- Sheet 4 of 4

Figure 28. Fault Tree for Example Analysis 4 - Sheet 4 of 4.

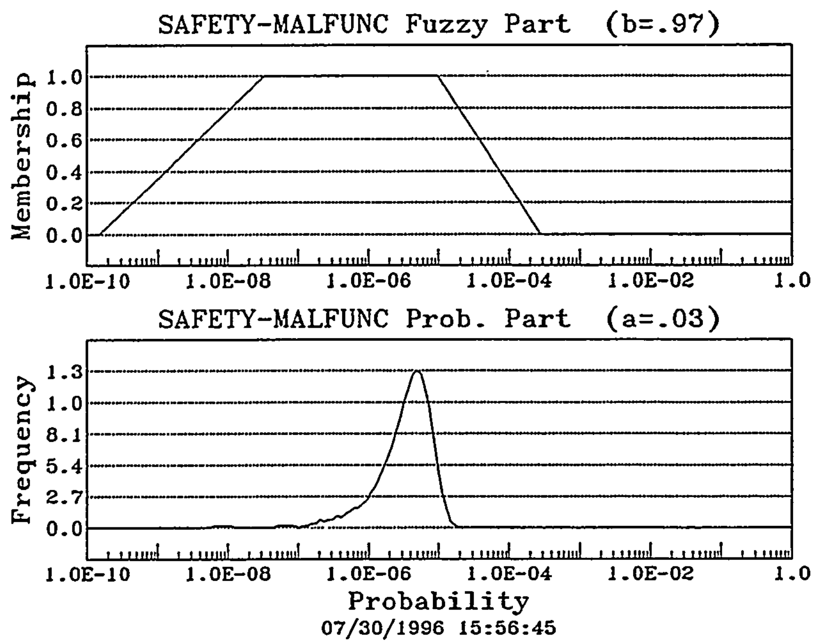


Figure 29. Top Event Hybrid Plot for Example Analysis 4.

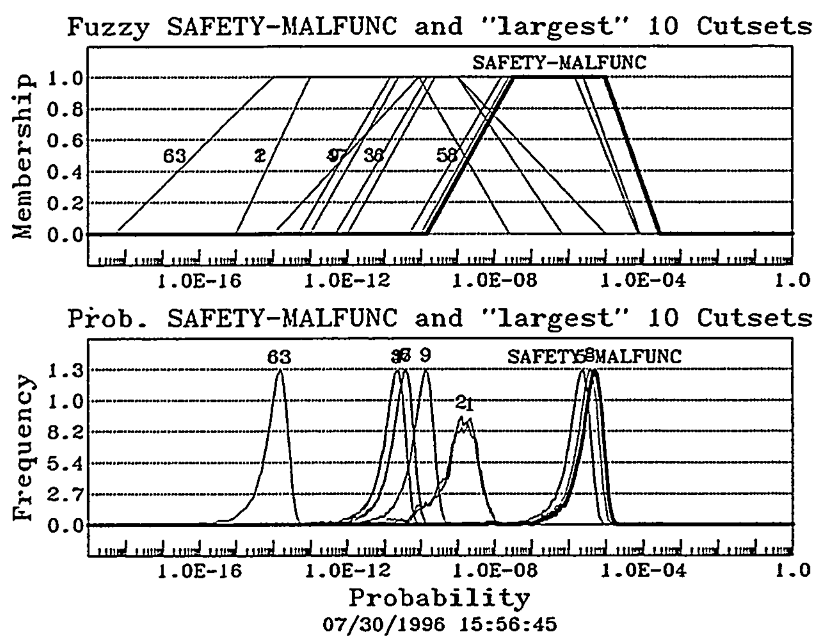


Figure 30. Composite Hybrid Plot for Example Analysis 4.

Appendix E - Example Analysis 5 - A Dependency Analysis

The following is a PHASER execution sequence of an analysis that involves event dependencies. Refer to Section 4.3 beginning on Page 40 for an explanation of Computer Screen Output. This analysis also computes and plots cutset importance and event sensitivity. Refer to Keywords PLOTIMPORTANCE and PLOTSENSITIVITY respectively defined on Pages 21 and 23. An explanation of the Dependency-Group: Definition Statement used in this example can be found in Section 3.1.3.3 beginning on Page 15.

```
          +------------------------------------+
          |       PHASER    VERSION  2.10       |
          |            07/26/1996               |
          |-------------------------------------|
          |          <<< AUTHORS >>>            |
          |    Bob Roginski       Org. 12333    |
          |    J. Arlin Cooper    Org. 12331    |
          +------------------------------------+

            Run date & time = 08/02/1996 09:34:59
            Compiler Used   = MS Pwr Sta V1.0a

            BASIC EVENT FILE  IS  PC.DAT
            QA / ERROR FILE   IS  PC.QAF

                 Reading File  PC.DAT
                 Reading LHS Sampling Files
                 Reading File  PC-CS.DAT

                 Generating Disjoint Sets

                 Defining Substitute Events
                 Cumulative CPU time =       .0 seconds

                 Performing Problem Subdivision
                 Cumulative CPU time =       .0 seconds
                 Writing File  PC.DJS

                 No Problem subdivision is required

                 Solving    1 Subproblems for 1000 Observations


                 Solving Subproblem    1 of    1
                 Cumulative CPU time =       .2 seconds

INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft

Copying Plot   1 to HPGL file COMPOSIT.HGL


                 Calculating Cutset Importance

INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft

Copying Plot   2 to HPGL file IMP-0001.HGL


                 Calculating Event Sensitivity
```

```
INGRAF Version 7.00 - Copyright 1987-94 Sutrasoft

Copying Plot   3 to HPGL file SEN-0001.HGL

                Writing File  PC.QAF

                No Errors Detected

Stop - Program terminated.
```

Keyword/Quantification Input File Listing

The following is a listing of the Keyword/Quantification Input File PC.DAT used in this example of a dependency analysis.

```
$  This is an example Fuzzy Math Data Input FIle.
$
$  The format is column-independent and supports the use of comments and
$  continuation lines.  Certain keywords have special meaning to the
$  program and must NOT be used as a basic event name.  The next several
$  lines are examples of recognized keywords.

CUTSETFILE       =  PC-CS.DAT     $ Associated Cutset File (SABLE Output)
NLINES           =  3             $ No. of Calculation Value Lines
DEBUGINFO        =  No            $ Add Debugging Info. to QA File
PLOTEVENTS       =  No
PLOTTOPEVENT     =  No
PLOTCUTSETS      =  No
PLOTCOMPOSITE    =  Yes
PLOTIMPORTANCE   =  Yes
PLOTSENSITIVITY  =  Yes
OUTPUTDEVICE     =  CRT  HPGL     $ CRT, HPLJ or HPGL are Valid Devices
DELAY            =  Wait          $ Hold Plots on CRT for this long
SAMMOD           =  LHS           $ Can be USER, LHS or USEROVERRIDE
ECHOCUTSETFILE   =  Yes           $ Turn off Echo if file is large
SMOOTHFACTOR     =  Auto          $ Smoothing Factor for PDF Plots
CUTSETLIMIT      =  10
PRECISERESULT    =  Yes  PC.DJS   $ Precise Top Event requested

$  Some of the following keywords are read by PHASER, but all are required
$  if LHS is to be invoked (i.e., the fault tree is at least partially
$  probabilistic).  Note the '=' (equal sign) must NOT follow the key-
$  word because LHS will not accept this syntax.

LHSOBS           1000           $ No. of Observations in LHS Sample
LHSOUT           LHS-PC.DAT     $ Name of LHS Output File
LHSMSG           LHS-PC.MSG     $ Name of LHS Message File
LHSSEED          1              $ Start of LHS Random Number Generator

$  These are the Basic Event Definitions.  This is assumed because the
$  first token in each statement is not recognized as a keyword.

A  =  0.7      0.8      0.9      A=0.9
    Data:  A  BOUNDED NORMAL  0.9  0.9  1.0E-20  0.99999
B  =  0.6      0.8               A=0.7
    Data:  B  BOUNDED NORMAL  0.6  0.6  1.0E-20  0.99999
C  =  0.2      0.4               A=0.4
    Data:  C  BOUNDED NORMAL  0.2  0.2  1.0E-20  0.99999

Dependency-Group:   A   B   C
    A   B     0.7
    A   C     0.5
    B   C     0.3
End-Group
```

```
D  =  0.2       0.7     A=0.5
    Data:  D    BOUNDED NORMAL  0.5  0.5  1.0E-20  0.99999
E  =  0.2       0.4     A=0.2
    Data:  E    BOUNDED NORMAL  0.3  0.3  1.0E-20  0.99999

Dependency-Group:   D   E
    D   E     0.2
End-Group

F  =  0.2       0.4     A=0.2
    Data:  F    BOUNDED NORMAL  0.3  0.3  1.0E-20  0.99999
```

Cutset Input File Listing

The following is a listing of the Cutset Input File PC-CS.DAT used in this example dependency analysis. Because this is a very small fault tree, the cutset file was manually prepared with a text editor, thereby eliminating the need to use the SABLE Code.

```
PC =
A * D * E * F +
A * D * B * C .
```

QA Output File Listing

The following is a listing of the QA Output File PC.QAF generated by this dependency analysis. This listing illustrates the details regarding the QA Output File. These details are described in Section 4.1.1 starting on Page 34.

```
            +-------------------------------------+
            |      PHASER     VERSION  2.10       |
            |            07/26/1996               |
            |-------------------------------------|
            |          <<< AUTHORS >>>            |
            |   Bob Roginski         Org. 12333   |
            |   J. Arlin Cooper      Org. 12331   |
            +-------------------------------------+

             Run date & time = 08/02/1996 09:34:59
             Compiler Used   = MS Pwr Sta V1.0a

             BASIC EVENT FILE   IS  PC.DAT
             QA / ERROR FILE    IS  PC.QAF

                        <<< Part 1>>>
       Echo of Basic Event File PC.DAT with Diagnostics

    1  $  This is an example Fuzzy Math Data Input FIle.
    2  $
    3  $  The format is column-independent and supports the use of comments and
```

```
$  continuation lines.  Certain keywords have special meaning to the
$  program and must NOT be used as a basic event name.  The next several
$  lines are examples of recognized keywords.

CUTSETFILE       =  PC-CS.DAT      $ Associated Cutset File (SABLE Output)
NLINES           =  3              $ No. of Calculation Value Lines
DEBUGINFO        =  No             $ Add Debugging Info. to QA File
PLOTEVENTS       =  No
PLOTTOPEVENT     =  No
PLOTCUTSETS      =  No
PLOTCOMPOSITE    =  Yes
PLOTIMPORTANCE   =  Yes
PLOTSENSITIVITY  =  Yes
OUTPUTDEVICE     =  CRT  HPGL      $ CRT, HPLJ or HPGL are Valid Devices
DELAY            =  Wait           $ Hold Plots on CRT for this long
SAMMOD           =  LHS            $ Can be USER, LHS or USEROVERRIDE
ECHOCUTSETFILE   =  Yes            $ Turn off Echo if file is large
SMOOTHFACTOR     =  Auto           $ Smoothing Factor for PDF Plots
CUTSETLIMIT      =  10
PRECISERESULT    =  Yes  PC.DJS    $ Precise Top Event requested

$  Some of the following keywords are read by PHASER, but all are required
$  if LHS is to be invoked (i.e., the fault tree is at least partially
$  probabilistic).  Note the '=' (equal sign) must NOT follow the key-
$  word because LHS will not accept this syntax.

LHSOBS              1000            $ No. of Observations in LHS Sample
LHSOUT              LHS-PC.DAT      $ Name of LHS Output File
LHSMSG              LHS-PC.MSG      $ Name of LHS Message File
LHSSEED             1               $ Start of LHS Random Number Generator

$  These are the Basic Event Definitions.  This is assumed because the
$  first token in each statement is not recognized as a keyword.

A  =  0.7      0.8       0.9      A=0.9
    Data:  A  BOUNDED NORMAL  0.9  0.9  1.0E-20  0.99999
B  =  0.6      0.8                A=0.7
    Data:  B  BOUNDED NORMAL  0.6  0.6  1.0E-20  0.99999
C  =  0.2      0.4                A=0.4
    Data:  C  BOUNDED NORMAL  0.2  0.2  1.0E-20  0.99999

Dependency-Group:    A    B    C
    A    B     0.7
    A    C     0.5
    B    C     0.3
End-Group

D  =  0.2      0.7      A=0.5
    Data:  D   BOUNDED NORMAL  0.5  0.5  1.0E-20  0.99999
E  =  0.2      0.4      A=0.2
    Data:  E   BOUNDED NORMAL  0.3  0.3  1.0E-20  0.99999

Dependency-Group:    D    E
    D    E     0.2
End-Group

F  =  0.2      0.4      A=0.2
    Data:  F   BOUNDED NORMAL  0.3  0.3  1.0E-20  0.99999
```

<<< Part 2>>>

Echo of Cutset File PC-CS.DAT with Diagnostics

```
PC =
A * D * E * F +
A * D * B * C .
```

Sampling Information File

This example requires sampling to be performed by the LHS code because probabilistic event definitions have been specified in the Keyword/Quantification Input File. The following is an abbreviated listing of the file LHS-PC.DAT that was generated by a preceding execution of the LHS code for this fault tree.

```
$ LHS File Format Version 1.00
$
$ This LHS run was executed on 02/16/96 at 10:38:10.70
$ with LHS Version: 2.00 Release 1, Compiled 01/28/1994
$ The run title was:
$
$
$ Message output file for this run: LHS-PC.MSG
$
$ Input file(s) for this run: PC.DAT
$ and PC.DAT
$
$
$ Point Values for the distributions follow:
$
$ All point values represent mean values that
$ were calculated from the actual LHS sample.
$
   A                    5.3933209E-01
   B                    5.2103412E-01
   C                    2.5748619E-01
   D                    5.0001156E-01
   E                    3.7782550E-01
   F                    3.7783918E-01
$
@UNCERTAINTY
  @OBSERVATIONS    1000
  @VARIABLES       6
   A:
   B:
   C:
   D:
   E:
   F:
@SAMPLEDATA
          1          6  0.871811       0.493059E-01     0.159819
   0.382805       0.132012        0.547212
          2          6  0.738221       0.570463         0.251989
   0.219478       0.104485        0.448723
          3          6  0.578632       0.534438         0.261339
   0.428197       0.208954        0.701722
          4          6  0.990935       0.278458E-01     0.225475
   0.141518       0.120159        0.408031
          5          6  0.720170       0.558099         0.134618
   0.103574       0.858677        0.171566
          6          6  0.398153       0.853375         0.589729
   0.607302       0.578457        0.182228
          7          6  0.655708       0.766489         0.125362
   0.212821       0.594752        0.499938
          8          6  0.998402       0.956463         0.291285
   0.720048       0.346575        0.318569
          9          6  0.468457       0.424971E-01     0.337631
   0.206453       0.418452        0.729708
         10          6  0.293917E-01   0.833709         0.343429
   0.398529       0.241662E-02    0.592708E-01
         11          6  0.268107       0.854494         0.360712
   0.820028       0.190963        0.337318
         12          6  0.539163       0.690135         0.375749
   0.203746       0.652238        0.398235E-01
         13          6  0.181089       0.556439         0.237313
```

```
0.892658        0.518107        0.652474
      14              6   0.444841       0.245342       0.185003
0.439464        0.348804        0.450114
      15              6   0.787695       0.849900       0.260573
0.707066        0.264312E-01    0.174793

                         (File Cut Here)

     989              6   0.259675       0.411479E-01   0.127690
0.229206        0.512251E-01    0.349043
     990              6   0.651427       0.920688       0.306501
0.266974        0.347772        0.535899
     991              6   0.676993       0.351213       0.303756
0.935618        0.502294E-01    0.309193
     992              6   0.692537       0.208006E-01   0.273033
0.121203        0.310889        0.339965
     993              6   0.952346       0.697734       0.163722
0.159812        0.363270        0.185457
     994              6   0.935874       0.341558       0.318013
0.658944        0.352934        0.203656
     995              6   0.762567       0.130740       0.117322
0.570198E-01    0.838222E-01    0.517213E-01
     996              6   0.762957E-01   0.650786       0.698259E-01
0.271049        0.634498        0.891177
     997              6   0.283354       0.203315       0.329617
0.255026        0.420167        0.133960
     998              6   0.838870       0.446011E-01   0.102301
0.381023        0.247157        0.673929
     999              6   0.928450       0.821720       0.824297E-01
0.189990        0.289031        0.320474
    1000              6   0.492174       0.178780       0.276815
0.117864        0.159427        0.226808
```

The Sampling Information File is described in Section 3.3 beginning on Page 32. The complete definition of this file format can be found in Appendix G.

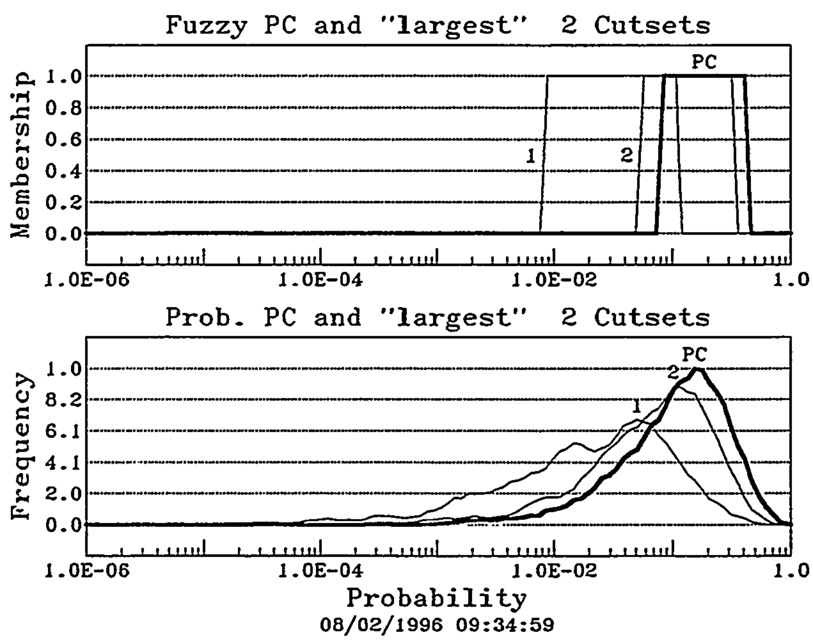


Figure 31. Composite Hybrid Plot for Example Analysis 5.

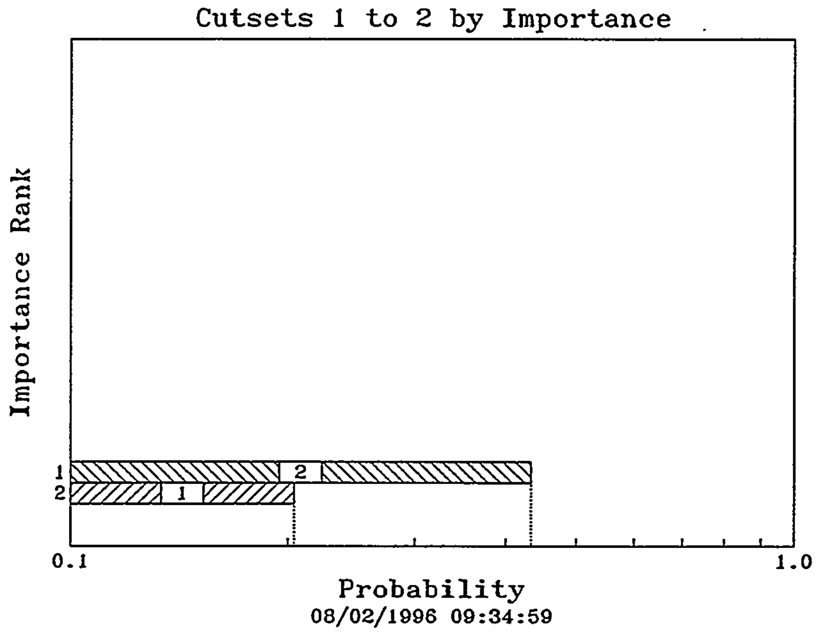


Figure 32. Cutset Importance Plot for Example Analysis 5.

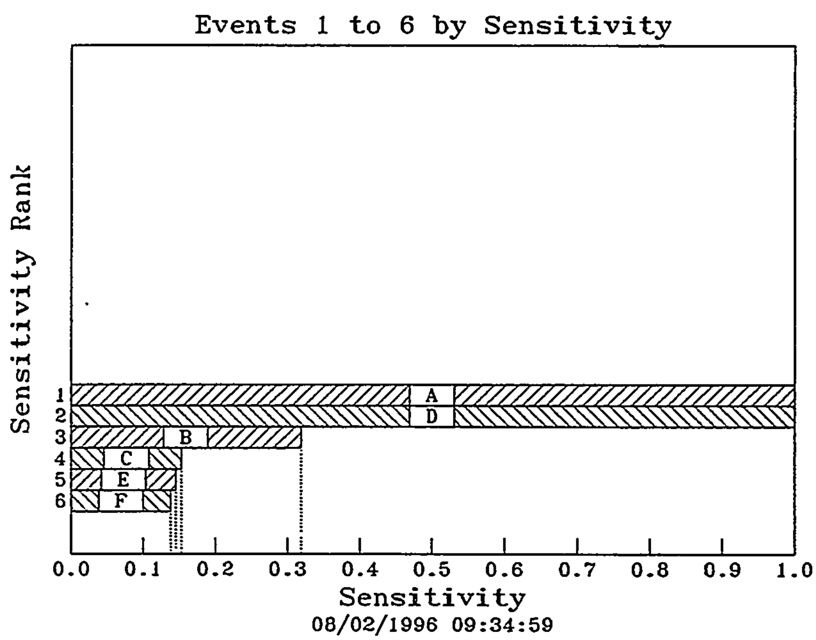


Figure 33. Event Sensitivity Plot for Example Analysis 5.

Appendix F - Code Suite Inter-relation

The following diagram describes how PHASER interfaces to other Sandia PRA analysis codes. The user must be aware that not all of these interface links are direct. For example, PHASER cannot read any of the files written by SEATREE, but is able to read the Unquantified Cutset File written by SABLE.

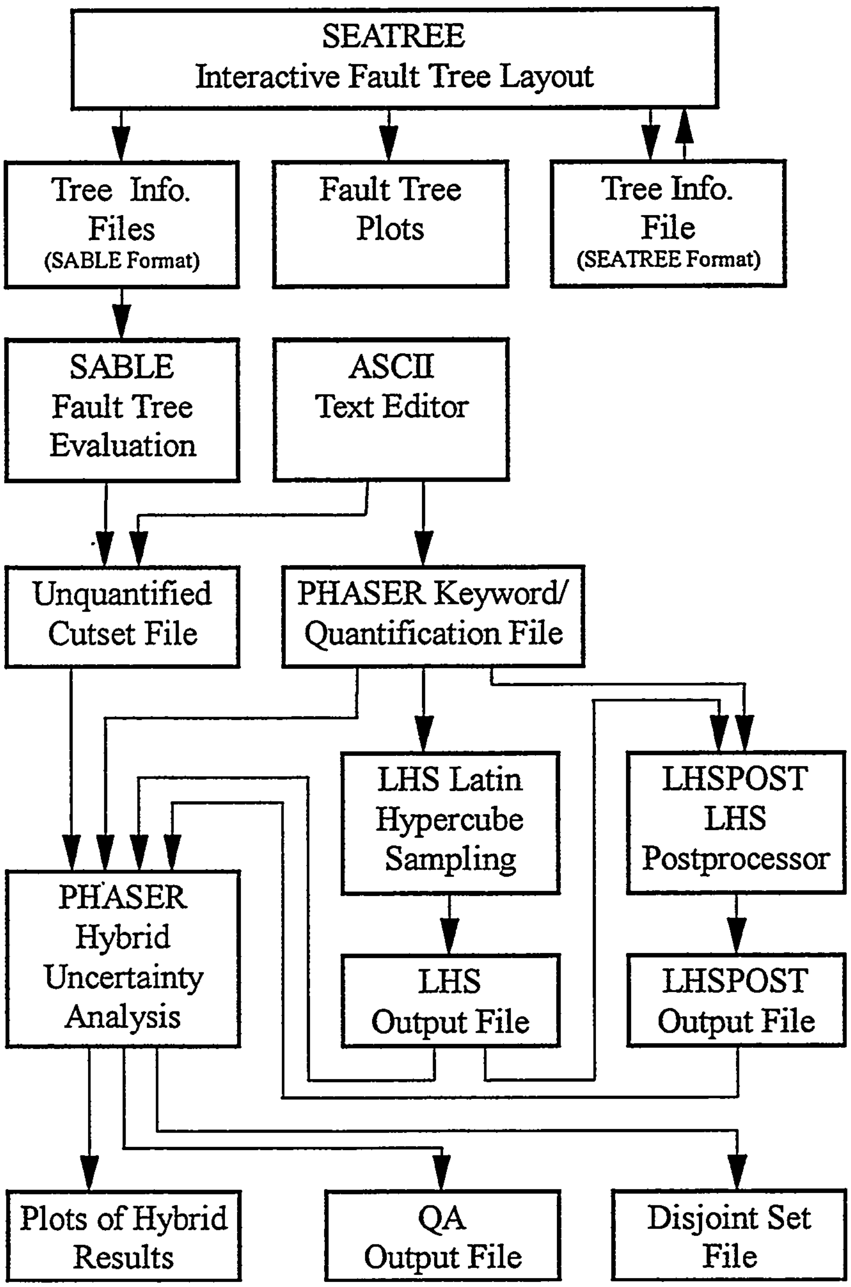


Figure 34. How PHASER Interfaces with Other PRA Codes.

Format for LHS Output and LHS-Like Files

Specification Version 1.00, June 11, 1993

1. Overview

The file format consists of three blocks: the point estimate data block, the uncertainty header block, and the uncertainty data block. All three blocks must be present in the file in the order listed above. The point estimate data block starts at the beginning of the file and proceeds until the keyword "@UNCERTAINTY" is found as the first item on the line. This marks the beginning of the uncertainty header block. This header block ends with the keyword "@SAMPLEDATA". The uncertainty data block follows this keyword and occupies the rest of the file. A copy of the top portion of an example file is attached.

2. Common Characteristics of the Point Estimate and Uncertainty Header Blocks

1) All data fields are space-delimited. All processors should treat commas and tab characters as if they were blank spaces.

2) A data record may occupy multiple lines, but each line may have no more than 80 characters. Characters that occur in columns greater than 80 are ignored. If a data record is to be continued on the following line, it must contain a continuation character (either a "#" or a "%") as the last character prior to any trailing blanks or comments (see below). The continuation character must be preceded by one or more blank spaces.

3) All text following a "$" (Dollar Sign) is considered a comment. If a Dollar Sign is the first item on a data record, the entire record is treated as a comment. A Dollar Sign and comment may also follow all data items on a record or the continuation character (trailing comment). In these cases, the Dollar Sign must be preceded by one or more blank spaces. Comments may not come between data items on a single record (except following a continuation character on a continued line).

4) Blank lines are considered comment records and are ignored. Any number of blank lines and/or comment lines may be placed between a line and its continuation or between consecutive continuation lines.

5) All names used in the file must meet the following criteria: a) each name must contain no more than 16 characters; b) the "$" (Dollar Sign), "#" (Number Sign), "%" (Percent Sign), "," (Comma), " " (Blank Space), and Tab characters are not valid within names; and c) a name must not form a valid representation of a real number for an ANSI-standard Fortran compiler. All names are to be treated as case-insensitive, so the names "FRED", "Fred", "fred" and "freD" are all equivalent. Names that are longer than 16 characters may be truncated to 16 characters at the discretion of the processor.

6) Where numbers are specified, they may be in any format recognized by an ANSI-standard Fortran compiler.

7) Each name must be unique within each section. Duplicate definitions in the same section for a single data item are not valid. However, an item may be defined once in each section. If an item is defined once in the point estimate block and once in the uncertainty header block, both definitions are effective. The reading program would have to decide whether its calculations should use the point estimate value, the distribution, or both.

8) A line and all of its continuation lines (with all trailing and intervening comments eliminated) must together consist of no more than 32767 characters.

3. Specifications for the Point Estimate Data Block

The point estimate data block must be the first section in the file. It should begin with a single comment record (starting with a Dollar Sign) that documents the version of the LHS file format being used. The record should be exactly as follows:

$ LHS File Format Version 1.00

The record need not begin in the first column. Any program wishing to read this record (in order to verify input file compatibility) may assume that only one blank character exists between each of the words, but should not make any assumptions regarding which characters will be in upper or lower case.

The version specification comment record should be followed by several additional comment records that document the pedigree of the file, such as the name and version of the program that created it, the date and time that the program was run, and the list of files accessed by the program.

A data record in the point estimate data block consists of anything that is not discarded as a comment according to the format described in Section 2 above. Only one type of data record is permissible in the point estimate data block. A data record consists of a list of one or more data item names followed by one or two real number values. The first of these values represents the point value for each of the items found in the list of named data items. The second item, which is optional, is the standard deviation associated with the point estimate value. The point estimate value that appears at the end of the line is assigned to all named data items on that line (including all active continuation lines). The list is space-delimited (see Section 2 above).

Any processor reading this data format should look for the following common errors: a) a record consisting of a list of names that is not followed by a legal value is illegal; b) a record consisting of a value without a corresponding list of names is illegal; c) names that follow the value(s) on a record are illegal.

Any processor wishing to skip this section can simply read and discard all lines until the keyword "@UNCERTAINTY" is found as the first data item on a non-comment line (@UNCERTAINTY may be preceded by leading blank spaces).

4. Specifications for the Uncertainty Header Block

The uncertainty header block contains two input sections which may occur in either possible order. The first section consists of a single line containing the keyword "@OBSERVATIONS" as its first data item, followed by a positive integer that represents the number of observations that are found in the uncertainty data block. It is critical that the value on this record accurately reflect the true number of observations present in the file. Any processor reading this data format must be sure that there are at least this number of observations present in the file. It may, however, ignore any additional observations that may be present.

The second section describes the number and names of the distributions that are found in the uncertainty data block. The section begins with a single line containing the keyword "@VARIABLES" as its first data item, followed by a positive integer that represents the number of distributions that are found in the uncertainty data block. It is critical that the value on this record accurately reflect the true number of variables present in the file. Any processor reading this data format must be sure that there are at least this number of distributions present in the file. It may, however, ignore any additional distributions that may be present.

The @VARIABLES n line must be followed by exactly n lines that provide names for the n distributions. Each of these lines begins with the primary name for the distribution, followed by a ":" (Colon Character). Following the Colon Character is an optional list of secondary names for the distribution. Thus, each of the n distributions is given exactly one primary name and an arbitrary number of secondary names. The list of names is space-delimited and may extend to one or more continuation lines as described in Section 2. Comments may be present at any point in this block as described in Section 2.

The order in which these records appear is significant. All names on the first record encountered in this section are assumed to correspond to the first distribution in the uncertainty data section of the file. The names on the second record are assumed to correspond to the second distribution, and so forth. For this reason, the number of records found in this section must correspond exactly to the number that follows the @VARIABLES keyword, and that value must exactly match the number of distributions found in the uncertainty data block. Anything else is an error condition.

The uncertainty header block is terminated by the "@SAMPLEDATA" keyword.

5. Specifications for the Uncertainty Data Block

The uncertainty data block is completely different from either of the preceding blocks. It contains only numeric data (no names). Comments lines are not supported in this block. Continuation lines exist only as described below.

This block contains one data record for each observation. The data record for a file containing n variables consists of two integers followed by n real values. The first integer value contains the observation number. The second integer value contains the number of distribution values that follow (should be n). These integers are followed by one real value that has been selected from each of the n distributions. One such record is present for each observation.

The records in this section are generally written and read using a FORTRAN list-type format in an implied "Do Loop". Thus, one record may consist of several lines without explicit continuation characters. The FORTRAN program will read additional lines as needed. The following hypothetical code example would read one entire uncertainty data block (all variables and all observations):

```
Do i=1, NObs
        Read (1,*) i, NVar, (Values(i,j), j=1, NVar)
End Do
```

The block is typically written to the file using similar code. Note that the use of the FORTRAN "*" format for reading and writing does not allow for continuation characters or comment lines. Thus, these are not allowed in this data block.

Note that this block occupies the remainder of the file. Thus, an attempt to read this file following the completion of the above loop should result in an end-of-file error condition.

Distribution:

0405	D. D. Carlson,	12333	
0405	D. E. Bennett,	12333	
0405	R. J. Breeding,	12333	
0405	M. K. Fuentes,	12333	
0405	T. R. Jones,	12333	
0405	K. J. Maloney,	12333	
0405	K. B. Sobolik,	12333	
0458	L. R. Gilliom	5133	
0490	S. D. Spray,	12331	
0490	R. Bennett,	12331	
0490	J. A. Cooper,	12331	(50)
0491	R. E. Smith,	12302	
0491	P. E. D'Antonio,	12324	
0491	M. Caldwell,	12324	
0491	J. M. Covan,	12324	
0491	P. Werner,	12324	
0491	M. A. Dvorack,	12333	
0491	S. A. Kalemba,	12333	
0491	Y. T. Lin,	12333	
0491	R. D. Pederson,	12331	
0491	R. J. Roginski,	12333	(20)
0491	J. L. Tenney,	12333	

0492	J. F. Wolcott,	12332	
0492	C. G. Shirley,	12332	
0492	D. A. Summers,	12332	
0621	V. J. Johnson,	12304	
0631	W. C. Nickell,	12300	
0633	P. N. Demmie,	12333	
0747	A. L. Camp,	6412	
0747	G. D. Wyss,	6412	
0766	D. E. Ellis,	5500	
0829	K. V. Diegert,	12323	
1146	L. F. Restrepo,	9364	
9015	Lutz Dahlke,	12324	
9018	Central Technical Files	8523-2	
0899	Technical Library	4414	(5)
0619	Review and Approval Desk for DOE/OSTI	12360	(2)