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SAFE-R and SAFE-D: Computer Codes for the Analysis of Failure Data

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Prepared by
J. K. Shultis, N. D. Eckhoff, D. E. Johnson, G. A. Milliken

Department of Nuclear Engineering
Kansas State University
Manhattan, KS 66506

Prepared for
Division of Risk Analysis
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
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Abstract

This user's manual presents a detailed description of two FORTRAN computer codes for analyzing component failure data. The first code SAFE-R is used to analyze data giving the number of observed failures in specified component operation times, while the second code SAFE-D is to be applied to failure data giving the number of failures observed in specified numbers of component demands. The theory behind the many analyses performed by these codes is summarized in a companion report NUREG/CR-2374 "Use of Non-Conjugate Prior Distributions in Compound Failure Models." A description of the overall program structure and detailed use of the many program commands is presented here. A sample input is given along with the resulting output.

Table of Contents

Acknowledgment

The size and scope of this project requires the skills and insight provided by researchers in statistics, engineering, numerical analysis, and computer science. To transform the conventions and jargon from each of these disciplines to a unified standard has been a challenging and educational experience for the entire research team. Much of the credit for orienting the direction of this research must go to Dr. W. Vesely whose many suggestions and inspirations have done much to give our work its present form. Finally, much of the computational legerdemain evolved in this project and which is only hinted at in this report arises from the efforts of our research assistants Messrs. W. Buranapan, S. Hansen, and V.A. Samaranayake.

JKS
NDE
DES
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Notes on This Edition

Since the computer codes SAFE-R and SAFE-D are available via the Internet, there is a demand to also have an electronically distributable version of the documentation. Therefore the documentation which was only available in paper form was scanned in and re-edited by

Wilfried Hennings c./o.
Forschungszentrum (Research Center) Jülich GmbH
Institute for Safety Research and Reactor Technology
D-52425 Jülich (Germany)
email: <W.Hennings@fz-juelich.de>

Please note that this edition is not an exact copy of the original:

Although the OCR was quite good, I found and corrected some OCR errors. There may be still some uncorrected. Please let me know. On the other hand, I corrected some obvious typing errors which were in the original document. Moreover, I made some additional remarks resulting from my usage of the codes. Last not least the changes from the original versions of the programs to the PC versions – which of course are not part of the original documentation – are also included in this edition.

All additions and changes as against the original report are typeset in Arial = Helvetica like the text in this section.

The document is primarily stored as Microsoft Word 7.0 for Windows95, also readable by Microsoft Word 6.0 for Windows, and also available as PostScript file. The OCR was performed by Caere OmniPage Pro 7.0 for Windows95. The flow diagrams were re-drawn manually (beware of typing errors!) in Micrografx FlowCharter 7.0 for Windows95 and inserted in the document as wmf graphics.

1. Introduction

In an earlier companion report, NUREG/CR-2374 "Use of Non-Conjugate Prior Distributions in Compound Failure Models," the theory and computational methods were described for application of a compound failure model to two types of commonly encountered attribute failure data. This report describes the computer codes which were developed from the theoretical and numerical investigation presented in the earlier report.

Two separate but similar FORTRAN computer codes have been developed for the analysis of component failure data with a compound statistical model: SAFE-D and SAFE-R. The SAFE-D code (Statistical Analysis for Failure Estimation-failure-on-Demand) analyzes data which gives the observed number of failures (failure to respond properly) in a specified number of demands for several similar components that should change their condition upon demand. The second program, SAFE-R (Statistical Analysis for Failure Estimation-failure Rate) is to be used to analyze normally-operating components for which the observed number of failures in a specified operating time is given. In both these codes the failure parameter (failure probability per demand for SAFE-D or failure rate for SAFE-R) may be assumed equal for all similar components (the homogeneous failure model) or may be assumed to be a random variable distributed among similar components according to a prior distribution (the heterogeneous or compound failure model).

For the compound model analysis, the prior distribution may be chosen as one of several distribution families (e.g. lognormal, beta, gamma, Weibull, etc.). The parameters of the selected prior distribution are estimated from the failure data by any or all of the following methods: (i) matching the data mean and variance to those of the selected prior distribution, (ii) matching the data mean and variance to those of the marginal distribution, and (iii) maximizing the likelihood function of the marginal distribution. Both a chi-square and/or a Kolmogorov-Smirnov goodness-of-fit test can be performed in order to see how well the resulting statistical models describe the given failure data. Finally an analysis of the posterior distribution estimated for each component can be requested as well as various types of confidence intervals and tolerance intervals.

Both programs are multi-run semi-free format programs designed to give the user a great amount of flexibility in specifying program options and values of program parameters. Each input command requests a particular calculation or analysis with either the homogeneous or compound model as is appropriate to the given failure data. A run consists of one or more commands which specify the particular statistical analyses desired by the user. SAFE-D and SAFE-R allow the user to build upon earlier runs or to reinitialize and start a completely separate analysis during a single load and execution of the program.

Section 2 describes the structure of the codes including input commands and options, and includes a flow diagram showing how the separate parts of the codes are used. Finally, in Section 3 an example is presented which illustrates the use of the codes.

2. Structure of Codes

2.1 Introduction

SAFE-R(D) is a multi-run semi-free-format program designed to give the user great flexibility in execution specifications and parameter entry. The input consists of a number of commands identified by specific keywords. Each command requests a particular analysis with either the homogeneous or compound failure model. A "run" consists of one or more commands that request particular analyses of interest to the user. Command cards are thus used to select program options, set parameter values, and to supply data to the program. SAFE-R(D) is a multi-run program which allows the user to build upon earlier runs or to reinitialize and start a completely separate analysis within the same loading and execution of the program.

2.1.1 Input

An input command consists of an eight character (maximum) keyword followed by a space with free-format values of the command parameters starting in column 10 of the command card. These command parameters are used to set program flags, to control the program flow, to specify program and analysis options, and to supply data. The parameters on a command card are separated (not delimited) by commas. Spaces are completely ignored, can be added for ease in distinguishing parameters, and can also be embedded in large numbers to help the user distinguish magnitude.

Most parameters have default values which are used if a parameter value is not specified. A comma followed by another comma or by an end of card symbol (semicolon), possibly with blanks in between, indicates that a value for that parameter is not specified in that command.

There are three special characters used in the syntax of command cards.

(i) The Comma (parameter separator symbol)

The comma is the separating character for parameter values. Each command card has a sequence of parameters that controls options for the command. The parameters must always be specified in the proper sequence and be separated by commas. For example, to set the sixth parameter on a command card to -1, the user would enter:

```
COMMANDX ,,,,,-1
```

Note that it is not necessary to specify parameter sequences past the parameter(s) of interest; however, the user is free to do so. Whenever a comma is followed by a comma or an end of card symbol (with optional spaces in between), it is assumed the parameter associated with that location is missing and will be assigned a previous or default value. Care should be taken in indicating missing parameters since an unintended comma makes all following parameter values be assigned to the wrong parameters.

(ii) The Semi-colon (end of command symbol)

The semi-colon is used to indicate the end of a command card. When a semi-colon is encountered, interpretation of parameters ceases for both that card and the command. The semi-colon is used primarily for

efficiency in processing a card since it will stop further scanning of a card and thus decrease data input time. Arbitrary labeling of command cards is allowed past the semi-colon since these columns are not processed.

(iii) The Asterisk (continuation card symbol)

The asterisk is the character that indicates a continuation card follows for the same command. It can be used for commands with a large number of parameters or large parameter specification sizes. The asterisk is placed after the last parameter specified on a card and causes interpretation to stop for that card and to restart in column 1 of the following card.

Individual parameter values cannot be extended across card boundaries. The continuation character is treated as a comma in determining the sequence and separation of parameters. As with the semi-colon, columns past the continuation character are not interpreted and can be used for arbitrary labeling by the user.

2.1.2 Multiple-run Program Design

The multiple-run feature allows the user to make a number of distinct analyses during a single load and execution on the computer. A single analysis or run results from a group of command cards followed by command EXECUTE. The EXECUTE command indicates that all commands previously specified are to be executed. All commands in a run are performed completely before command cards for another run are read and interpreted. The multiple-run feature of the code creates less redundancy in command specification by creating a hierarchy of command and parameter specifications.

2.1.2.1 Alteration of Commands and Their Parameters

(i) Command Specification

A hierarchy of command and parameter specifications is created by using multiple EXECUTE commands. Once a command is issued it is set to "on" state. When an EXECUTE command is encountered all commands that are "on" are performed. There are two ways to change a command from the "on" state to the "off" state.

The first and easiest way is to insert a CLEAR command card at the start of a run. This command reinitializes the program and sets to "off" all commands issued prior to it. Note that the CLEAR command re-requires all desired commands to be turned "on" again by use of subsequent command cards. This reinitialization can require a significant number of command cards even if only one or two commands are to be altered. One exception should be noted. The CLEAR command does not affect a previous DATA command by clearing the current failure data the user must explicitly replace the current data with a new data set.

The second and most selective way to change the status of a command is to use the individual "on"/"off" parameters of the command itself. The first parameter of each command is an "on"/"off" flag with a 1 designating "on" and a 0 designating "off" (COMPONTS, PARMEST, EXECUTE, and CLEAR excluded). The default value, whenever this on/off parameter is missing, is a 1 unless the command has already been previously set to the "off" state using the "on"/"off" parameter.

There are additional tradeoffs to consider for parameter specifications when choosing the 'CLEAR' or the command by command method for changing the state of a command. These are discussed below.

(ii) Parameter Specifications

Command parameters that are not specified by the user are set to default values whenever possible. Once a parameter has been given a specific numerical value by the user, it retains that value as the default value. This convention thus requires the user to specify only those command parameters he wishes to alter from the values used in previous runs. Once a parameter has been numerically specified then the previous user specifications are lost and the most recent specification will be used. If a command appears more than once in the program input stream, the parameter specifications of the command that appears latest in the run will be used. However, should a particular parameter be omitted from the latest command card, it will assume the value given in the most recent previous use of the same command (if any). This reverse search continues into previous runs until a parameter value is found, or if none is found, then SAFE-R(D) supplies a default value, if feasible .

2.1.2.2. Reinitialization

The CLEAR command sets the parameters of every command to SAFE-R(D) default values, if any. The CLEAR command allows the user to start a completely new analysis. Since all commands, except the DATA commands, are set to the "off" state and the user must re-specify each command and those to be changed from SAFE-R(D) defaults. The CLEAR command is automatically performed prior to the first run and need not be specified.

2.1.2.3. Command and Run Order

The order in which runs are interpreted and performed is sequential. However, the order of commands within a run is not important unless duplicate commands appear (refer to Section 2.1.2.1(ii)). The output from SAFE-R(D) will always appear in the same order, i.e. it is completely independent of the order of commands in a run.

2.1.3 Input Format

The column specification for a COMMAND card is as follows:

column 1-8: command keyword (eight characters)

column 9: blank

column 10-80: parameter specification (may be continued on following cards starting in column 1)

Example 1 Single Command on a Single Card

```
card column 1      8 10        ...              80
            |      | |
            COMMANDX P1,...P2,,, PN;
```

[The number and meaning of the command parameters P1, P2,..,PN vary with the command. The semi-colon is optional.]

Example 2 Single Command, Multiple Cards

```
card column 1      8 10           ...               80
            |      | |
            COMMANDX P1, P2, P3, P4* , P6  * CRD1
            P7, P8, ...          PN        * CRD2
            .                           .
            .                           .
            .                           .
            PJ, , PJ+2, ...          , PK; * CRDK
```

[The semi-colon is again optional.]

2.2 Overall Program Flow

In the figure on the next two pages, the execution flow of the programs SAFE-D(R) is presented. Although commands for various program options can be input in any order for a particular run, the order of execution and output of results is always performed in the order shown in this flow diagram.

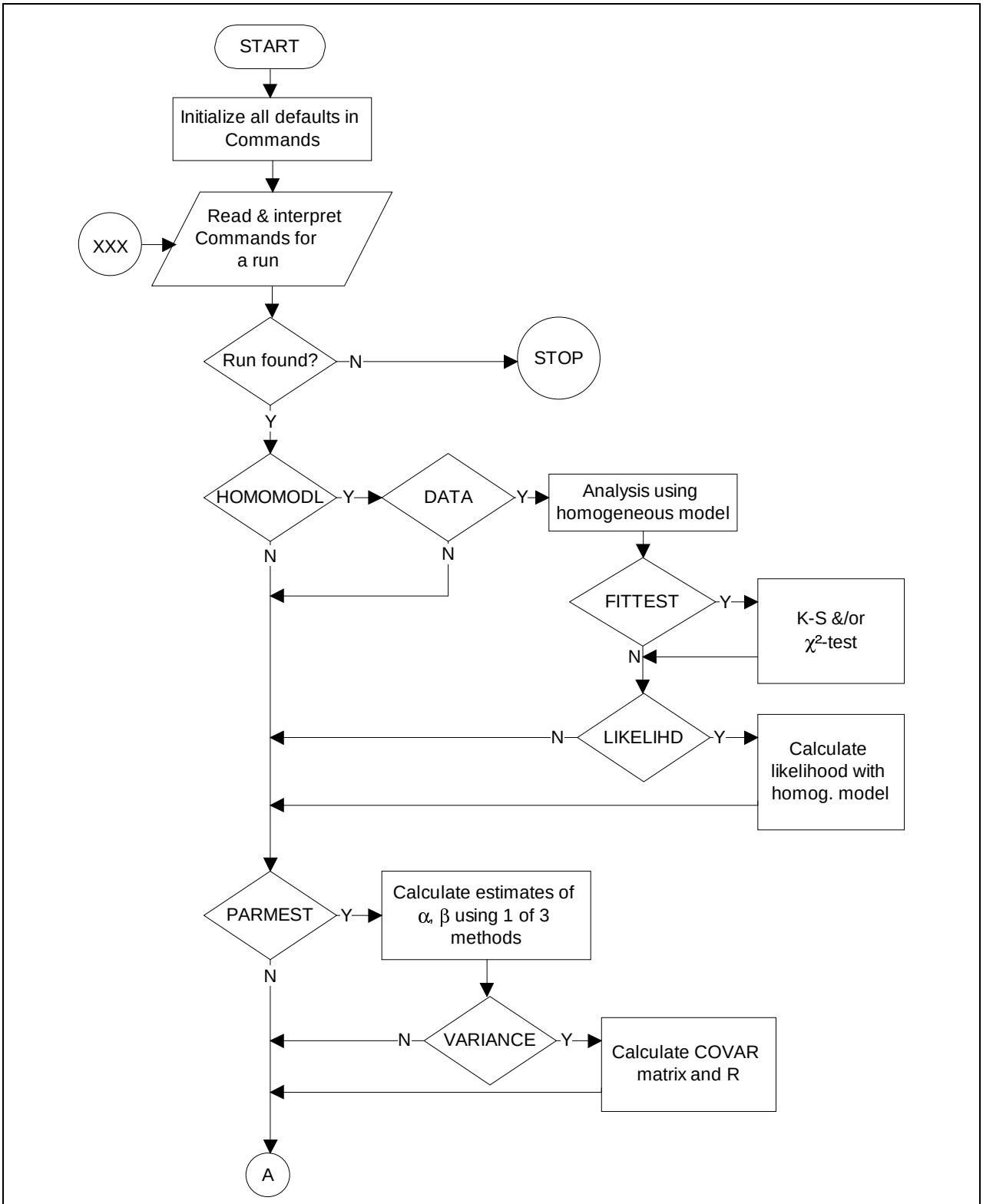

Fig. 1 Basic flow of program SAFE-D(R) showing the order in which the various program options are executed.

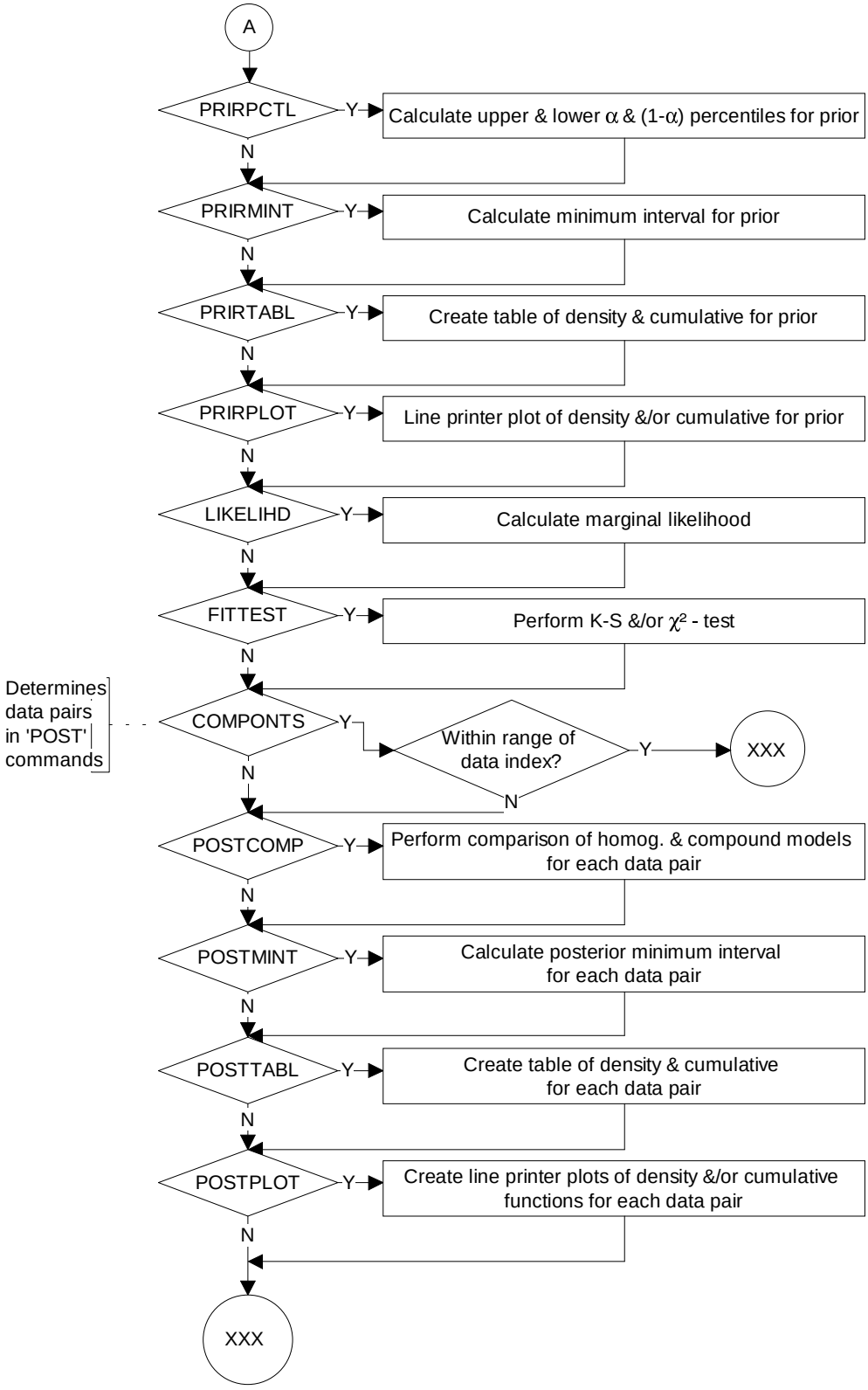

Fig. 1 (cont.) Program flow of SAFE-D(R) options.

2.3 Input Commands

CLEAR	Requests all command parameters and specifiers be set to their initial SAFE-D or SAFE-R default values. Also, all commands (except the DATA command) are set to the "off" state.
COMPONTS	Specifies which data pairs (F_i,T_i) are to be used in a posterior analysis. COMPONTS affects all commands with the prefix 'POST'... .
DATA	Specifies a data set which contains either failures (F_i) and attempts (T_i) for SAFE-D or failures (F_i) and test times (T_i) for SAFE-R.
EXECUTE	Indicates that the command requests are to be executed.
FITTEST[+]	Requests either chi-square or Kolmogorov-Smirnov goodness-of-fit test to be performed for the homogeneous model or the compound model.
HOMOMODL	Requests the analysis of the homogeneous model to be performed.
LIKELIHD[+]	Requests the sample likelihood to be calculated under either the homogeneous model or the compound model.
PARMEST	Specifies the estimation method to be used for the prior distribution parameters. Alternatively, the user may also provide his own estimates to be used in the subsequent analysis.
POSTCOMP[+]	Requests a component by component comparison of the homogeneous distribution and the posterior distribution.
POSTMINT[+]	Requests the calculation of a minimum probability interval of the posterior distributions of each of the specified data pairs.
POSTMOMS	Requests the calculation of the first four central moments and moments about zero for the posterior distribution of each pair. Skewness and kurtosis are also calculated.
POSTPLOT[+]	Requests line printer plots of the posterior density and for cumulative distributions for each specified data pair.
POSTTABL[+]	Requests a table of the posterior distributions for each of the specified data pairs.
PRIRMINT	Requests the calculation of a minimum probability interval for the estimated prior distribution.
PRIRMOMS	Requests the first four central moments and the moments about zero for the estimated prior distribution. Skewness and kurtosis are also calculated.

[+] Indicates commands which require extensive computer time to perform. For FITTEST and LIKELIHD, only the compound model analysis is exorbitant. Also the "POST" commands can be made to use less computer time by limiting the number of data pairs for which a posterior analysis is to be performed via the COMPONTS command.

PRIRPCTL	Requests the a and 1-a percentiles be calculated for the estimated prior distribution.
PRIRPLOT	Requests a line printer plot of the estimated prior density and/or cumulative distributions
PRIRTABL	Requests a tabulation of the estimated prior distribution.
VARIANCE	Requests the variance and covariance of prior parameter estimators.

2.4 Command Parameter Explanation

It should be noted that the default values indicated below for any command parameter are in effect at the start of the program execution. If numerical values are used to change the parameter from the initial default values, the new value becomes the value substituted for missing parameters in a later call of the same command. The user defined parameter value remains as the default value until a CLEAR command is issued thereby resetting all parameters back to their initial default values.

Listed below are the commands available in SAFE-R(D) and the parameters associated with each command.

CLEAR

no parameters

The CLEAR command sets all prior commands, except the DATA command, to the "off" state. The CLEAR command also resets all appropriate parameters to their SAFE-R(D) initial default values. With the exception of the DATA command and other command parameters for which SAFE-R(D) cannot supply values but have been specified by the user, the program is in the same state as that of the initial computer execution.

EXECUTE

no parameters

The EXECUTE command is used to signal that a complete set of commands and their parameters (known as a "run") has been inputted and that the computations requested by the commands are to be performed. SAFE-R(D) then stops reading input and performs the requested analyses. After this execution, SAFE-R(D) attempts to read another set of commands which must be terminated by an EXECUTE command. If no run is found, execution ends.

DATA

1 parameter

The DATA command is used to enter the data pairs of either failures and time for SAFE-R or failures and attempts for SAFE-D. Use of the DATA command requires several cards. The first card begins with the command DATA and a single parameter specifying the number of data pairs (F_iT_i) to be read. This DATA command card is followed by a data format card which gives the format for reading the failure data from columns 10-80 of the subsequent data cards. SAFE-R requires either a F or D format for the failure data, while SAFE-D expects integer data and thus requires an I format. Following the format cards is a data set identifier card containing any alphanumeric label in columns 1-80 to identify the particular set of failure data to be read in. Finally, the data cards, one card per component, complete the DATA command. Each data card is assumed to contain an alphanumeric label in columns 1-8 to identify each component, a blank in column 9, and the values of F_i and T_i for that component in columns 10-80 formatted according to the data format card.

Parameter Explanation

1 Number of data pairs (or components) to be read.

Example:

```
card column 1      8 10      ...            80
            |      | |
            DATA 5,                              command card
            F5.1,2X,F6.1                         format card
            DATA SET EXAMPLE FOR 5 COMPONENTS    identifier card
            comp 1   2.0   1250.0          ⎫
            comp 2   1.0   1020.0          ⎪
            comp 3   0.0   1637.0          ⎬   data cards
            comp 4   2.0   1112.0          ⎪
            comp 5   3.0   2028.1          ⎭
```

HOMOMODL

2 parameters

The HOMOMODL command requests analysis of the failure data using the homogeneous failure model. This analysis computes the estimated failure probability with SAFE-D or the estimated failure rate with SAFE-R. Both programs also calculate the estimated standard deviation and variance along with the confidence bounds for the failure parameter assuming the homogeneous model.

Parameters Explanation

1 State flag for the HOMOMODL command. (default = 1)

0 sets HOMOMODL to the "off" state.

1 sets HOMOMODL to the "on" state.

2 Level of significance between 0 and 1 for the confidence bounds on the estimated failure probability or failure rate.
(default = 0.05)

FITTEST

7 parameters

The FITTEST command requests the Kolmogorov-Smirnov and/or chi-square goodness-of-fit tests be performed for either the homogeneous failure model and/or the marginal of the compound failure model.

Parameter Explanation

1 State flag for the FITTEST Command. (default = 1)

0 sets the command to the "off" state.

1 sets the command to the "on" state.

2 Distribution request flag. (default = 1)

1 indicates only the goodness-of-fit tests for the homogeneous failure model is to be performed.

2 indicates only goodness-of-fit tests for the marginal distribution of the compound failure model is to be performed.

3 indicates goodness-of-fit tests for both the homogeneous and compound failure models are to be performed.

3 Test type request flag. (default = 1)

1 indicates only Kolmogorov-Smirnov goodness-of-fit test is to be used.

2 indicates only chi-square goodness-of-fit test is to be used.

3 indicates both Kolmogorov-Smirnov and chi-square goodness-of-fit tests are to be used.

4 Intermediate print flag. (default = 0)

0 indicates no intermediate printing for the goodness-of-fit tests.

1 indicates intermediate printing is to be done for the goodness-of-fit tests.

5 Number of degrees of freedom to be used in the chi-square test.
(default = 1)

6 Minimum expected value for each class or bin in the chi-square test.
(default = 3)

7 Maximum number of groups or bins in the chi-square test.
(default = 16)

LIKELIHD

2 parameters

The LIKELIHD command requests the calculation of the sample likelihood using either the homogeneous model or the marginal distribution of the compound model.

Parameters Explanation

1 State flag for the LIKELIHD command. (default = 1)

0 sets the command state to "off". 1 sets the command state to "on".

2 Distribution request flag. (default = 1)

0 indicates the sample likelihood is to be calculated using the homogeneous model only.

1 indicates the sample likelihood is to be calculated only using the marginal distribution of the compound model.

PARMEST

6 parameters plus method parameters

The PARMEST comment requests estimation of the parameters of the prior distribution. Estimation methods are matching moments to the prior distribution (PMM), matching moments to the marginal distribution (MMM), and marginal maximum likelihood method (MML). Alternatively, the user may specify the parameter estimates directly without any estimation by the program. The first 5 parameters are the same no matter which method is used, but the following parameters have different meanings depending on the value of parameter 6. The parameter default values usually will suffice in giving accurate estimators. However, some adjustments may be required for certain cases.

Parameter Explanation

1 Prior distribution request flag. (no default)

1 gamma	for SAFE-R
2 log normal	"
3 Weibull	"
4 log beta	"

1 beta	for SAFE-D
2 log beta	"
3 log normal-1	"
4 log normal-2	"
5 log gamma-1	"
6 log gamma-2	"

In SAFER for lognormal distribution the original code allows for a non-zero shift parameter "THETA". Because in nearly all risk analyses UNshifted lognormal distributions are used, W.Hennings inserted line 6625 in the SAFER source file which forces THETA=0 which is documented in the printout header by source line 797. If you need a lognormal with THETA not zero, comment-out lines 797 and 6625 and recompile the program.

2 Initial estimate of α. (no default)

suggested value for SAFE-R (log normal): $+\ln(\lambda_{50})$ e.g. if expected $\lambda_{50} \approx 10^{-3}$/h then parameter2≈–7

suggested value for SAFE-D (log normal-2): $-\ln(p_{50})$ e.g. if expected $p_{50} \approx 10^{-3}$/h then parameter2≈7

3 Initial estimate of β (no default)

suggested value for SAFE-R (log normal): $\sigma \approx 2$

suggested value for SAFE-D (log normal-2): $\sigma \approx 2$

4 Minimum value of λ for SAFE-R or p for SAFE-D. (no default)

suggested value: 0 for SAFE-R, 10^{-60} for SAFE-D

5 Maximum value of λ for SAFE-R or p for SAFE-D. (no default)
For SAFE-R a value of –1 for maximum λ will indicate that there is no upper limit and infinity will be used.

suggested value: –1 for SAFE-R, 1.0 for SAFE-D

6 Indicator to select method for estimating the prior parameters.

0 the initial estimates of a and ß (parameters 2 and 3, respectively) are to be used directly as the prior parameters.

1 matching moments to the prior distribution (PMM) will be performed to estimate α and β. Parameters 2 and 3 will be used as starting points in the optimization subroutines if needed.

2 marginal matching moments (MMM) method will be used to estimate α and β of the prior distribution. Starting values are provided from values of parameters 1 and 2.

3 maximum likelihood method (MMM) will be performed to estimate α and β. Parameters 2 and 3 will be used as starting points in the optimization subroutines.

<u>For Matching Moments Method</u>: parameter 6 = 1 or 2

Parameter Explanation

7 Maximum number of integrations used in both the Simplex method and the Mueller's iteration method. (default = 500)

8 Accuracy desired in the integration subroutine.
(default = 10^{-10})

9 Relative accuracy of solution in Simplex method.
(default = 10^{-7})

10 Relative accuracy of solution to Mueller's iteration method. (default = 10^{-10})

11 Step size used for a search in either Simplex or Mueller's iteration method. (default = 5% of initial estimate of α, i.e. 5% of parameter 2)

12 Step size used for β in either Simplex or Mueller's iteration method. (defaults to 5% of initial estimate of β [parameter 3])

13 Scaler indicating range of α and β. α and β are expected to be within $\pm$ the scaler times the initial estimates (parameters 2 and 3) of α and β (default = 20)

14 Intermediate print flag. (default = 0)

0 indicates no intermediate printing.

1 indicates intermediate printing is desired.

<u>For Maximum Likelihood Method</u>: parameter 6 = 3

Parameters Explanation

7 Maximum number of iterations allowed in the Simplex method subroutine. (default = 500)

8 Relative accuracy desired in the Simplex method solution or for maximum likelihood convergence. (default = 10^{-4})

9 Relative accuracy desired in integration to determine marginal probability. (default = 10^{-6})

10 Intermediate print flag. (default = 0)

0 indicates no intermediate printing.

1 indicates intermediate printing is desired.

11 Step size method indicator.

0 indicates parameter 12 is to be used for the step size of α in the simplex method, and that parameter 13 is to be used for the step size of β in the simplex method.

1 indicates that 10% of initial estimates of α and β (parameters 2 and 3) is to be used for the step size in the simplex method.

2 indicates that parameter 12 contains the fraction of the initial estimates of α and β (parameters 2 and 3) which is to be used as the step size for the simplex method. Parameter 12 must be between 0 and 1.

12,13 Refer to parameters 12 and 13 of the previous matching moments section for explanation.

VARIANCE

2 parameters

The VARIANCE command requests that estimates of the variance and covariance of the prior parameter estimators are to be calculated. The variance and covariance lower bounds of the maximum likelihood estimators can be calculated using the exact method or an approximation method. The exact method is computationally more difficult and requires a great deal more execution time. The exact method is generally cost prohibitive but available if needed by the user.

Parameters Explanation

1 State flag for the VARIANCE command. (default = 1)
0 sets the command state to "off".
1 sets the command state to "on".

2 Calculation method for maximum likelihood request flag. (default = 1)
0 indicates exact method is to be used.
1 indicates the approximation method is to be used.

PRIRMOMS

1 parameter

The PRIRMOMS command requests the calculation of the first four central moments, the first four moments about zero, and the skewness and kurtosis for the estimated prior distribution.

Parameter Explanation

1 State flag for the PRIPMOMS command. (default = 1)
0 sets the command to the "off" state
1 sets the command to the "on" state

PRIRTABL

3 parameters plus specifiers

The PRIRTABL command requests a table of the estimated prior and cumulative prior distributions to be printed. There are 5 possible methods by which the table format may be defined. The specifiers are entered by the user and their meaning is dependent upon the table format requested.

Parameters Explanation

1 State flag for the PRIRTABL command. (default = 1)

0 sets the command state to "off".

1 sets the command state to "on".

2 Format method request flag. (default = 3)

1 user supplies specific values of λ or p at which the prior density and cumulative distributions are to be calculated. Parameter 3 must equal the total number of λ or p values specified. (no default; specifiers must follow parameter 3).

2 the prior density and cumulative distributions are to be tabulated at equidistant λ or p values between upper and lower limits given by specifiers 1 and 2 respectively following parameter 3. Parameter 3 equals the number of equidistant λ or p values (included upper and lower limits) at which the prior distribution is to be tabulated. (no default and two specifiers must follow parameter 3).

3 the prior density and cumulative distributions are to be tabulated at equidistant λ or p values between specified upper and lower percentile values given by specifiers 1 and 2, respectively. Parameter 3 equals the number of equidistant λ or p values (including endpoints) at which the prior distribution is to be tabulated. (no default, and two specifiers must follow parameter 3)

4 user specifies percentile levels at which the corresponding λ or p values and the prior distribution are to be computed and tabulated. Parameter 3 equals total number of defined percentiles. (default=5; specifiers equal to 0.05, 0.1, 0.5, 0.9 and 0.95)

5 user gives specific lower and upper percentiles specifiers 1 and 2, respectively) between which the prior distribution is to be tabulated at equidistant percentiles. Parameter 3 equals the number of equidistant percentiles, including endpoints, to be used for the tabulation. (no default and two specifiers follow parameter 3)

3 Number of points in the table. (default = 10)

Specifiers of p and λ or percentiles, separated by commas, would follow the third command parameters.

PRIRPLOT

3 parameters

The PRIRPLOT requests line printer plots of either the estimated prior density, or cumulative distribution, or both. The range for the plots is generated by using a percentile value as the lower end-point and 1 minus that percentile value as the upper end-point for the plotted values.

Parameter Explanation

1 State flag for the PRIRPLOT command. (default = 1)
- 0 sets the command state to "off".
- 1 sets the comment state of "on".

2 Distribution request flag. (default = 1)
- 1 plot only the estimated prior distribution.
- 2 plot only the estimated prior cumulative distribution.
- 3 plot both the estimated prior and cumulative distributions.

3 Percentile from which lower and upper bound of plots are determined. (default 0.05)

PRIRMINT

2 parameters

The PRIRMINT command requests the calculation of the minimum probability interval of the estimated prior distribution such that the sum of the area outside the interval is equal to a specified value and the values of the density function at the interval endpoints are also equal.

Parameters Explanation

1 State flag for the PRIRMINT command (default = 1)
- 0 sets the command state to "off".
- 1 sets the command state to "on".

2 Total probability desired outside the minimum interval.
(default = 0.05)

PRIRPCTL

2 parameters

The PRIRPCTL command requests that the percentiles for the estimated prior density function be calculated. This command is less informative than the PRIRTABL command but can be used to get a feel for the significant range of p or λ.

Parameters Explanation

1 State flag for the PRIRPCTL command (default = 1)
- 0 sets the command state to "off".
- 1 sets the command state to "on".

2 percentile used for determining p or λ. Percentile value and 1 minus this percentile value are used to determine corresponding p or λ values. (defaults = 0.05)

POSTMOMS

1 parameter

The POSTMOMS command requests the calculation of the first four central moments and the moments about zero for the estimated posterior distribution of each of the components specified by the COMPONTS command. Skewness and kurtosis are also calculated for each specified component.

Parameters Explanation

1 State flag for the POSTMOMS command. (default = 1)
- 0 sets the command state to "off".
- 1 sets the command state to "on".

POSTCOMP

2 parameters

The POSTCOMP command requests a comparative analysis between the homogeneous model and the posterior distribution of the compound model for each component. The subroutine produces a table giving the mean, median, variance, skewness, and upper and lower percentiles of the posterior distribution as well as the estimated failure rate or probability and its confidence interval for the homogeneous model.

Parameter Explanation

1 State flag for the POSTCOMP command. (default = 1)
- 0 sets the command state to "off".
- 1 sets the command state to "on".

2 Percentile used in determining confidence intervals. The percentile value is the significance level of the confidence interval. (default = 0.05)

POSTTABL

3 parameters plus specifiers

The POSTTABL command requests a table of the estimated posterior and cumulative posterior distributions to be printed of each component specified by the COMPONTS command. There are 5 possible methods by which the table format may be defined. The specifiers are entered by the user and their meaning is dependent upon the format method used.

Parameters Explanation

1 State flag for the POSTTABL command. (default = 1)

- 0 sets the command state to "off".
- 1 sets the command state to "on".

2 Format method request flag. (default = 3)

- 1 user supplies specific values of λ or p at which the posterior density and cumulative distribution are to be calculated. Parameter 3 must equal the total number of or p values specified. (no default; specifiers must follow parameter 3).
- 2 the posterior density and cumulative distributions are to be tabulated at equidistant λ or p values between upper and lower limits given by specifiers 1 and 2 respectively following parameter 3. Parameter 3 equals the number of equidistant λ or p values (included upper and lower limits) at which the posterior distribution is to be tabulated. (no default,and two specifiers must follow parameter 3).
- 3 the posterior density and cumulative distributions are to be tabulated at equidistant λ or p values between specified upper and lower percentile values given by specifiers 1 and 2, respectively. Parameter 3 equals the number of equidistant λ or p values (including endpoints) at which the posterior distribution is to be tabulated. (no default, ant two specifiers must follow parameter 3).
- 4 user specifies percentile levels at which the corresponding λ or p values and the posterior distribution are to be computed and tabulated. Parameter 3 equals total number of defined percentiles. (default –5 specifies equal to 0.05, 0.], 0.5, 0.9 and 0.95)
- 5 user gives specific lower and upper percentiles (specifiers 1 and 2, respectively) between which the posterior distribution is to be tabulated at equidistant percentiles. Parameter 3 equals the number of equidistant percentiles, including endpoints, to be used for the tabulation. (no default and two specifiers follow parameter 3).

3 Number of points in the table. (default = 10)

Specifiers of p or λ or percentiles would follow the third parameter and must also be separated by commas.

POSTPLOT

3 parameters

The POSTPLOT command requests line printer plots of either the estimated posterior density, or cumulative, or both for each of the components specified in the COMPONTS command. The plots are generated using a percentile value as the lower endpoint and one minus the percentile as the upper endpoint for the plotted distributions.

Parameters Explanation

1 State flag for the POSTPLOT command. (default =1)
- 0 sets the command state to "off".
- 1 sets the command state to "on".

2 Distribution request flag. (default = 1)
- 1 plot only the estimated posterior distribution.
- 2 plot only the estimated posterior cumulative distribution.
- 3 plot both the estimated posterior density and cumulative distributions.

3 Percentile from which lower and upper bound of plots are determined. (default = 0.05)

POSTMINT

2 parameters

The POSTMINT command requests the calculation of the minimum interval of the estimated posterior distribution such that the sum of the area outside the interval is equal to a given value and the values of the density function at the interval endpoints are also equal. The POSTMINT command determines the minimum interval for each of the components specified in the COMPONTS command.

Parameters Explanation

1 State flag for the POSTMINT command. (default = 1)
- 0 sets the command state to "off".
- 1 sets the command state to "on".

2 Total probability desired outside the minimum interval.
Default = 0.05.

COMPONTS

Component Indexes are parameters

The COMPONTS command specifies the components of interest for the posterior analysis commands POSTMOMS, POSTCOMP, POSTTABL, POSTPLOT, and POSTMINT. The parameters are index values which correspond to the order in which the data pairs were read in. For example, if the components of interest were the first, fifth, ant sixth data pairs read, then the parameters would be 1,5,6 . To run a single component, its index must be followed by a comma otherwise all components following this designate, component will also be analyzed. A COMPONTS command followed without any parameters following indicates that all components are to be used for posterior analysis. The COMPONTS command should be used to limit unnecessary posterior analyses since they are generally very costly in computer execution time. (default = all)

2.5 /CMD/ Common Blocks Cross-Reference

The /CMD/ common blocks are used to store the parameter values for each command. The single /CMD/ block at the top of the common blocks store the on/off states of the commands. Each command has an index number associated with it which appears after the letters CMD for its common block. This number is also the location of the on/off element in the ICMD array. The command indexes are as follows:

Command	Index
CLEAR	1
COMPONTS	22
DATA	6
EXECUTE	2
FITTEST	9
HOMOMODL	8
LIKELIHD	10
PARMEST	7
POSTCOMP	18
POSTMINT	21
POSTMOMS	17
POSTPLOT	20
POSTTABL	19
PRIRMINT	15
PRIRMOMS	12
PRIRPCTL	16
PRIRPLOT	14
PRIRTABL	13
VARIANCE	11

PARMEST has a 7A for matching moment specifiers and a 7B for maximum likelihood specifiers.

The /CMD/ common block parameter cross-reference to parameters and specifiers is as follows:

/CMD/	ICMD(25) contains the on/off state indicators for each command.
/CMD6/	TITLE contains the 80 character label for the data set. COMPID contains the 8 character identifications for the component data. FL contains the number of failures for each component. TM contains the time and attempts for each component. I6P1 parameter 1.
/CMD7/	R7P(4) contains parameters 2,3,4, and 5 in that order. I7P1 parameter 1 I7P6 parameter 6
/CMD7A/	R7AP(8) contains specifiers 1 through 8 in that order for the matching moments methods.

/CMD7B/	R7BP(7) contains specifiers 1 through 7 in that order for the maximum likelihood method.
/CMD8/	R8P2 parameter 2
/CMD9/	R9P(6) contains parameters 1 through 6 in that order.
/CMD10/	I10P2 parameter 2
/CMD11/	I11P2 parameter 2
/CMD13/	R13PA(40) contains user defined specifiers for methods 1 and 4. R13PB(2) contains user defined specifiers for methods 2,3, and 5. I13P2 parameter 2 I13PA3 parameter 3 for methods 1 and 4 I13PB3 parameter 3 for methods 2,3, and 5.
/CMD14/	R14P3 parameter 3 I14P2 parameter 2
tCMD15/	R15P2 parameter 2.
/CMD16/	R16P2 parameter 2.
/CMD18/	R18P2 parameter 2.
/CMD19/	R19PA(40) contains user defined specifiers for methods 1 and 4. R19PB(2) contains user defined specifiers for methods 2,3, and 5. I19P2 parameter 2. I19PA3 parameter 3 for methods 1 and 4. I19PB3 parameter 3 for methods 2, 3, and 5.
/CMD20/	R20P3 parameter 3. I20P2 parameter 2.
/CMD21/	R21P2 parameter 2.
/CMD22/	I22P(100) contains component index values I22PN number of index values in I22P(100) array.

3. Sample Input and Output

3.1 Sample Input

Listed below is a printout of example input for the code SAFE-R.

The sample input is omitted in this edition because it is available as file SAFRTEST.IN.

3.2 Sample Output

On the following pages, the output produced by SAFE-R for the above input is shown. For reasons of economy of space, some of the output pages have been combined in the following example output.

The sample output is omitted in this edition because it is available as file SAFRTEST.OUT.

The sample output is different from the one shown in the original report because of the following changes in the program code:

The banner page showing the program name in big letters was deleted.
The program name is instead printed in normal letters.
Additionally the date and time of the program start and end are printed.
(Currently the date is in German format dd.mm.yyyy but this is easily changeable.)

In the original the data which are input by the DATA keyword are listed in the output at the beginning of each execution. This was changed so that the data are only listed ONCE (after completion of the DATA routine).

"G" output formats were changed into "1PG" (instead of 0.iiiEii now i.iiiEii is printed).