Living PRAs Made Easier With IRRAS*

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Abstract

The Integrated Reliability and Risk Analysis System (IRRAS) is an integrated PRA software tool that gives the user the ability to create and analyze fault trees and accident sequences using an IBM-compatible microcomputer. This program provides functions that range from graphical fault tree and event tree construction to cut set generation and quantification.

IRRAS contains all the capabilities and functions required to create, modify, reduce, and analyze event tree and fault tree models used in the analysis of complex systems and processes. IRRAS uses advanced graphic and analytical techniques to achieve the greatest possible realization of the potential of the microcomputer. When the needs of the user exceed this potential, IRRAS can call upon the power of the mainframe computer.

The role of the Idaho National Engineering Laboratory in the IRRAS program is that of software developer and interface to the user community. Version 1.0 of the IRRAS program was released in February 1987 to prove the concept of performing this kind of analysis on microcomputers. This version contained many of the basic features needed for fault tree analysis and was received very well by the PRA community. Since the release of Version 1.0, many user comments and enhancements have been incorporated into the program providing a much more powerful and user-friendly system. This version is designated "IRRAS 2.0". Version 3.0 will contain all of the features required for efficient event tree and fault tree construction and analysis.

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1. Introduction

The Integrated Reliability and Risk Analysis System (IRRAS) is a software tool which gives the user the ability to create and analyze fault trees using an IBM-PC. This program provides the functionality required for probabilistic risk analysis (PRA) functions ranging from graphical fault tree construction to cut set generation and quantification.

At the center of the PRA analysis is the fault tree model. This model, along with the component reliability data such as failure rates and probability of failure on demand, provides the basic elements for a PRA. Prior to the development of IRRAS, an analyst would generate models using an alphanumeric text editor. The information would be input in a format compatible with the particular PRA software used to process the information. When changes to the model were required, the analyst would return to the text file and modify the card images to reflect the changes. This process is prone to errors and is difficult for the analyst to visualize. IRRAS helps eliminate these problems.

IRRAS automates the model creation, manipulation, modification, and quantification processes. Designed for the IBM-PC, IRRAS is readily accessible and portable. Taking advantage of the state-of-the-art in computer graphics and analysis algorithms, IRRAS is powerful and efficient. However, it is recognized that there are limitations to a PC-based program, so IRRAS has been designed to communicate with a mainframe computer for extremely large and complex models.

IRRAS simplifies the analysis process and automates the preparation of input to the analysis software. The analyst can graphically construct and modify fault trees. It provides the user with an excellent tool to construct and maintain the fault tree models. All of the basic symbols involved in fault tree analysis are supported, including the ability to input tables of events, similar to the TAB-OR gate. Once the tree is constructed, the program will automatically generate the input for the analysis software. The graphical output from IRRAS can also be printed on a laser printer for report quality documentation of the work.

After constructing the PRA models, the analyst can store these models in an integrated relational data base. IRRAS then manages this data for the user during the analysis process. Included in the data management routines is the detection of changes to the model information and automatic recalculation of associated data. This powerful feature can greatly reduce the time required to track and propagate model changes throughout a complex system.

IRRAS version 2.0 also includes the ability to link fault trees according to analyst-determined logic to create accident sequence cut sets. These sequence cut sets can then be analyzed using the same powerful tools provided for fault tree cut sets. IRRAS 3.0 contains the event tree graphics module and automatically generates the event sequence logic for event sequence cut set generation.

Many of the features of mainframe programs have also been incorporated into IRRAS. Improved fault tree reduction techniques such as the identification of independent subtrees and modules and coalescing gates have demonstrated significant performance improvements over IRRAS 1.0. Many more error checking routines have been provided to aid the user in debugging and checking the completed fault trees.

The addition of a module to automatically generate fault trees on the PC directly from the alphanumeric input used by mainframe codes such as SETS lets the analyst quickly load existing models and data from prior studies into IRRAS for modification and re-analysis.

Section 2 of this paper contains a brief history of the IRRAS project. The features of IRRAS 1.0, 2.0 and 3.0 are described in Sections 3, 4, and 5, respectively. Section 6 contains a summary of the applications of IRRAS by version. Section 7 contains a brief summary and conclusion of the project.

2. A Brief History of IRRAS Development

For many years the PRA codes available were mainframe or mini-computer based. These codes were very complex and hard to use. Thus the U. S. Nulcear Regulatory Commission (USNRC) staff relied upon contractors to make computer runs for them. This process was slow, and often the answers arrived at the NRC weeks after the crisis was over.

In 1985 the USNRC began the development of a new set of PRA computer codes that would be easy to use. At about the same time, the personal computer began to be more powerful and gained capabilities that would allow some of the data preparation tasks to be done on it. However, the power of the PC increased rapidly and new capabilities were introduced by the PC manufacturers. Thus, it was possible to do almost all of the PRA tasks and calculations on the PC and rely only on the mainframe computer for large and complicated system fault trees. The decision was made to develop PC-based tools that would allow as many of the PRA tasks as possible to be done on the PC.

The initial phase of the USNRC PRA software development project was to develop an overall plan for the software project. The next task of the project was to provide a software package which could demonstrate the feasibility of using the microcomputer as a workstation for performing PRA analyses. This package did not necessarily need to perform all of the functions required. However, it did need to provide certain essential functions such as fault tree construction, failure data input, cut set generation, and cut set quantification. The result of this software development project was IRRAS 1.0. This version of the software was released in February 1987 and contained only the essential concepts mentioned above.

IRRAS 1.0 was an immediate success and clearly demonstrated not only the feasibility, but also the tremendous need of performing this work on a microcomputer. As a result of this success, IRRAS 2.0 development was begun. This package was designed to be a comprehensive PRA analysis package and include all the functions necessary for a PRA analyst to perform his work. The areas which were not treated in version 1.0 were addressed and a fully integrated package was developed.

Since IRRAS 2.0 was a complete rewrite from version 1.0, a thorough test plan was necessary. The major features of IRRAS 2.0 along with an Alpha test was completed in early March 1988. Following the Alpha test and corrections to the software, approximately 15 sites were selected from among the sites currently using IRRAS 1.0. These sites were sent a Beta test version of IRRAS 2.0. In May 1988 we completed the Beta test. We began work on fixing the bugs found and adding new features identified during the Beta test which could be reasonably incorporated into version 2.0. IRRAS 2.0 is now ready for distribution.

IRRAS 3.0 is the final phase of this software development effort. It includes addition of the event tree graphics portion of the software and the related data base features needed to support this part of the analysis. The cut set generation algorithms are also being improved. IRRAS 3.0 is scheduled for completion in early 1990.

3. IRRAS 1.0 Features

The main menu of IRRAS 1.0 is shown in Figure 1. The first two options will be discussed below. The others are used to define the computer configuration and output the fault tree for a report.

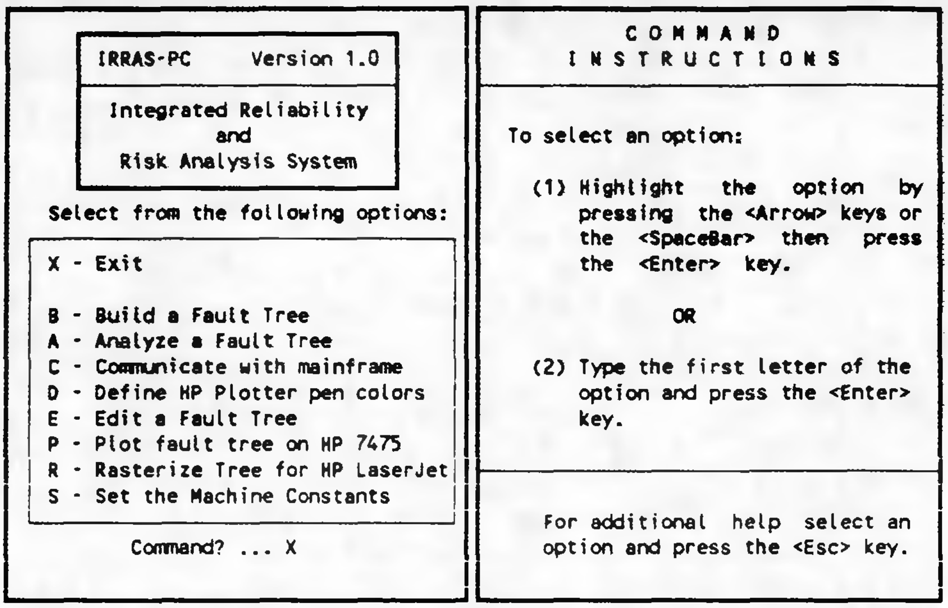

Figure 1. The IRRAS 1.0 Main Menu.

Fault Tree Build Option

The Build module is used to build a graphical fault tree model. A three button mouse is used to place the pop-up menus on the screen and select the various options that are desired. The Build module contains:

(1) Predefined shapes for constructing fault tree diagrams.

(2) Edit functions for moving, copying, and deleting shapes, lines, and text.

(3) Edit functions for changing attributes such as colors and line types.

(4) Assignment of names and probability values to the basic events.

(5) Ability to add descriptive text to the fault tree.

(6) A file system for storing and retrieving diagrams and paging between drawings.

(7) Ability to zoom in/out on a portion of the drawing and to pan while in the zoom mode.

(8) Output to the Hewlett Packard Laser Jet+, Hewlett Packard pen plotter, or Epson printer/plotter.

(9) Construction of tabular relational data from the graphical diagrams.

Figure 2 is an example of the menus in the Build module. Figure 3 shows the fault tree icons that are supported in IRRAS 1.0.

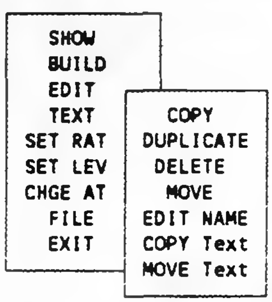

Figure 2. Example IRRAS 1.0 Build Menus.

The philosophy taken in IRRAS is to develop the fault tree by pages. Each page is an 8.5 by 11 inch page. Thus, it is best not to have to large a fault tree on a page or it cannot be easily read when it is printed. This philosophy differs from that of other codes where a large sheet is used to draw the fault tree and then it is broken up for printing.

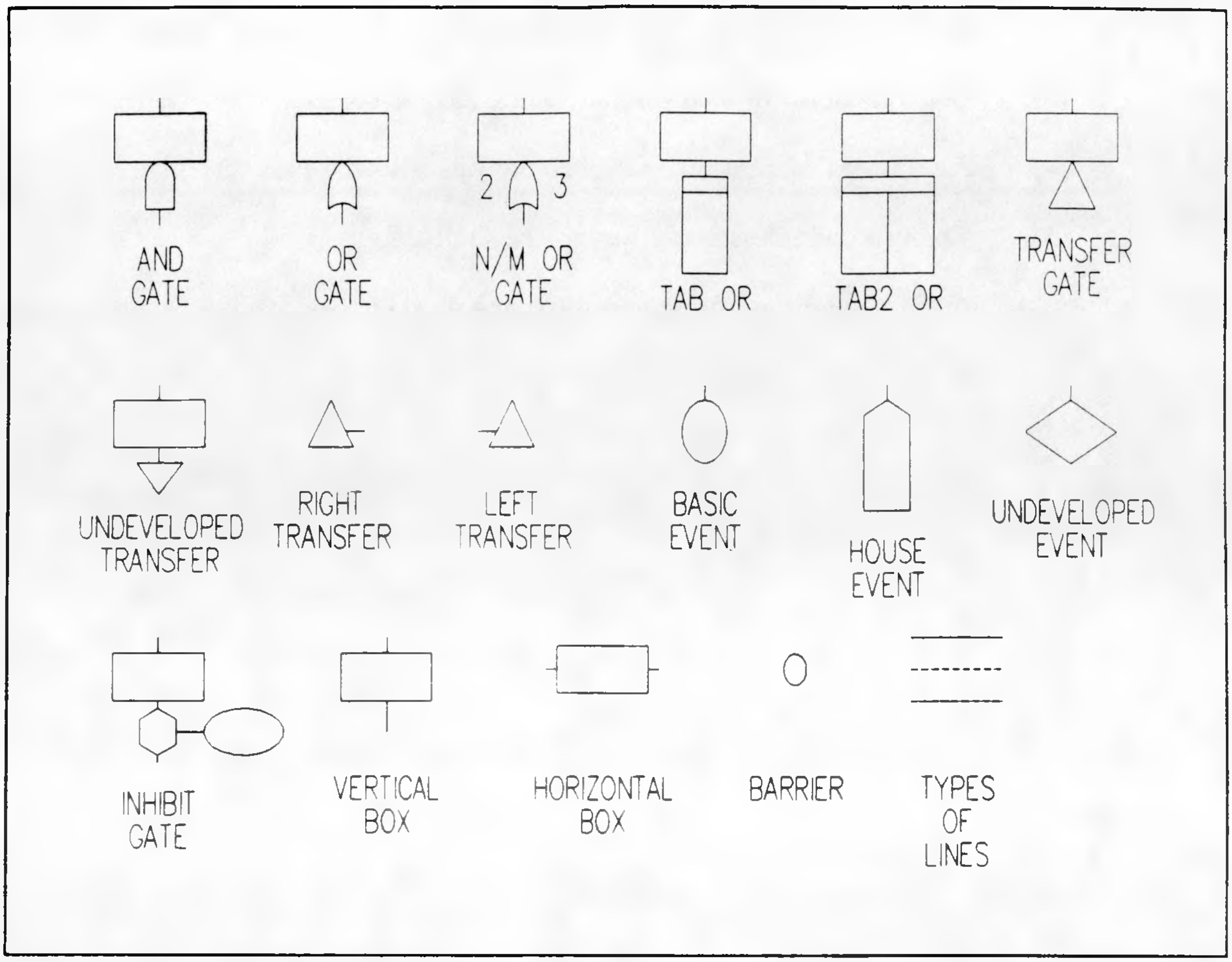

Figure 3. IRRAS 1.0 Fault Tree Icons.

When a fault tree file is saved, an input file containing the gate names, gate types, and gate inputs is automatically prepared and saved on disk. This file has the extension .TRE and is referred to as the TREE file. The basic event failure data are also stored in a file with the extension .RAT. This file is called the RATE file.

<u>Analyze a Fault Tree Option</u>

Figure 4 contains the Fault Tree Analysis Menu. This menu contains the options to load a fault tree to be analyzed, to load the failure data, the RATE file, and then to generate the cut sets, quantify the cut sets, calculate importance measures for the basic events, and print the results of the analyses. It also has the option of performing an uncertainty analysis using only the lognormal distribution.

I R R A S - P C
Fault Tree Analysis System

Select	X	To Execute ...
X	X----->	Exit
L	L----->	Load Fault Tree Data
R	R----->	Read BINARY Data
E	E----->	Edit Loaded Tree
C	C----->	Generate Cutsets
Q	Q----->	Quantify Fault Tree
I	I----->	Importance Measures
U	U----->	Uncertainty Analysis
P	P----->	Print Fault Tree Data
W	W----->	Write BINARY Data

Figure 4. IRRAS 1.0 Fault Tree Analysis Menu.

The cut set algorithm in IRRAS 1.0 is a very simple top-down approach. No effort was taken to optimize it. Thus, no independent subtrees or modules are identified, no restructuring of the fault tree occurs, no external storage is used to store intermediate results, etc. In fact, COMCAN III was used to restructure some fault trees for test purposes. The results showed that much time can be saved by coalescing the gates and restructuring the fault tree for processing.

IRRAS 1.0 was finished in February 1987. Since that time over 300 copies have been distributed to many different groups in the U. S. These include the NRC, national laboratories, utilities, the Armed Forces, NASA, other government agencies, and the chemical, aerospace, and automotive industries.

4. IRRAS 2.0 Features

The success of IRRAS 1.0 demonstrated the great need for easily accessible and useful PRA tools. Even the basic tools provided in IRRAS 1.0 were received with much enthusiasm. With these concepts in mind, IRRAS 2.0 was designed. This system is a major rewrite from the software contained in Version 1.0. It contains many features which significantly improve the usefulness and flexibility of the system. The Beta test of IRRAS provided positive feedback on the user interface and capabilities of IRRAS 2.0. As a result, IRRAS 2.0 features combine to provide a fault tree analysis tool that is powerful enough to solve the complex problems associated with fault tree analysis, yet is simple enough to be convenient and easy to use.

Relational Data Base Facility

IRRAS 1.0 used a very simple flat file system for the storage and retrieval of the PRA data. This system lacked the necessary features to allow the user to manage very complex data structures. IRRAS 2.0 includes a relational data base for managing this data. This data base allows IRRAS to automatically maintain the PRA data and track changes to the data. These changes can then be propagated throughout the system during the update phase of the analysis. The structure of the data base is shown in Figure 5.

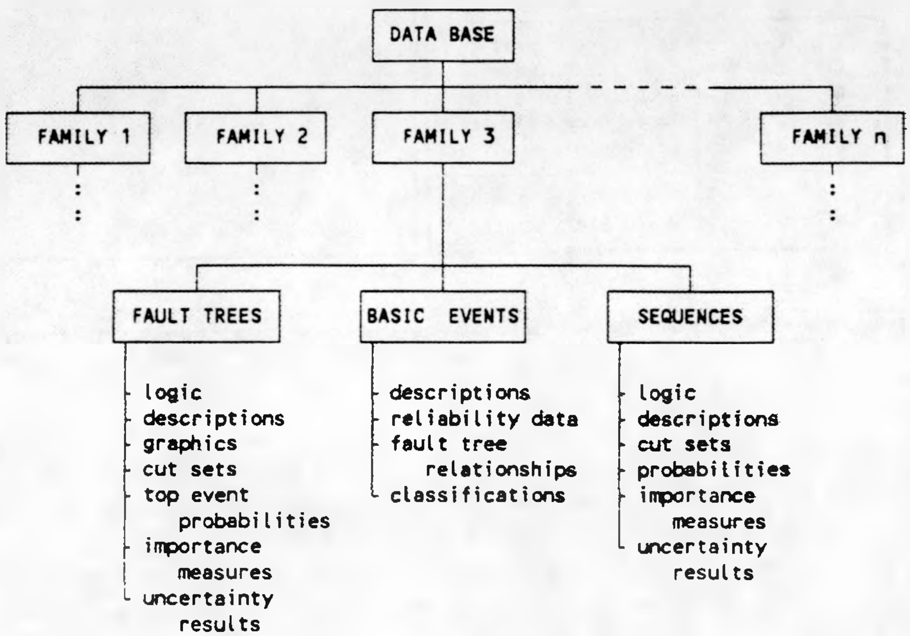

Figure 5. IRRAS 2.0 Data Base Structure.

The design of the data base allows the user to store multiple "families" in each data base. A "family" usually represents the data for one power plant or group of related models. In each family, a list is maintained of all basic events in the system. This list includes a description of the basic event, failure rate information, uncertainty data, and various attributes associated with each event. Space is also provided for the storage of an alternate name for associating the PRA name to the plant-specific name. The user may specify that the primary or the alternate name be used anywhere events are displayed. Any changes the user makes to the event data are automatically maintained and propagated throughout the system.

Each "family" also contains many fault tree records. Each fault tree record usually represents a single page of a fault tree. The system allows the user to assign a level to each fault tree. This level can be used in the analysis to determine which trees are "zero" level pages and which are "sub pages" to be included in other fault trees. Only "zero" level fault trees can be analyzed independently. "Zero" level fault trees also have cut sets and quantification information associated with them.

Each "family" may also contain event tree and accident sequence information. The user defines sequences by representing failure or success of system fault trees in the same "family". IRRAS can then calculate and store cut sets and quantification information for each sequence in the "family".

The relational data base provides an environment for the maintenance of all the information associated with a PRA. The design of the data base allows for easy modification and inclusion of data as needs change. The result is a very flexible data base that meets current needs and can be easily expanded to meet future needs. As needs change, the data base can be easily modified and populated data bases can be easily restructured to include the new data element.

Options and Menus

The most striking change to IRRAS 2.0 has been the redesign of the menus. This redesign was done to provide a more user-friendly interface and to incorporate many new features. All of the menus use a hierarchical structure with state-of-the-art windows and online help features. The main IRRAS menu is shown in Figure 6. This menu displays the options currently available in Version 2.0 of IRRAS.

```
                    I R R A S
  Integrated Reliability and Risk Analysis System
                   Version 2.0

          EXIT      IRRAS 2.0

          BUILD     Fault Trees
          FAULT     Tree Analysis

          CREATE    Event Trees
          SEQUENCE  Analysis

          MODIFY    Data Base
          REPORT    on Data Base

          UTILITY   Options

     Option... EXIT      ...Selected
```

Figure 6. IRRAS 2.0 Main Menu.

BUILD Fault Trees Option

The "BUILD Fault Trees" option allows the user to perform the graphical fault tree-related functions including extracting from the data base, editing, plotting, and alphanumeric-to-graphics conversions. The IRRAS Build menu is shown in Figure 7.

Perhaps the most well-received feature of IRRAS is the graphical fault tree construction facility. This module is basically the same as Version 1.0; however, many cosmetic changes have been included. These changes resulted primarily from user comments and include the following:

```
I R R A S - P C
Fault Tree Graphics System

Currently Selected Family ──> NO FAMILY

E - Exit

S - Select Family

X - eXtract Fault Trees

B - Build Graphics Trees

P - Plot Tree (plotter)
R - Rasterize Tree
D - Define plotter pens
A - Alpha to Graphics

Option... E
```

Figure 7. The IRRAS 2.0 Build Menu.

(1) enhanced plotter output capabilities,

(2) the elimination of unused and redundant graphical symbols,

(3) the addition of a table of events, "TBL", symbol,

(4) the inclusion of "NAND" and "NOR" gates,

(5) the elimination of the "Level" feature,

(6) the elimination of the failure rate definition facility (a more powerful capability is provided in the data base),

(7) the inclusion of support for all 2 and 3 button mice, and

(8) the inclusion of more friendly menus and pick options.

A major new feature of the graphical editor is the ability to generate the graphical fault tree representation from an alphanumeric input format. This feature allows any fault tree generated for other codes to be easily converted to the IRRAS graphical format. This feature also allows the analyst to make changes to the alphanumeric representation of the fault tree and have these changes easily added to the graphical representation. An example of the fault tree generated from the alphanumeric representation shown in Figure 8 is displayed in Figure 9. These changes significantly improve the usefulness and power of the graphical fault tree editor in IRRAS.

```
TOPGATE AND GATE1 GATE2 GATE3
GATE1 OR EVENT1 GATE4
GATE2 OR EVENT1 EVENT2 GATE5
GATE3 OR EVENT1 EVENT2 EVENT3
GATE4 2/3 EVENT8 EVENT9 EVENT10
GATE5 AND EVENT1 EVENT2
```

Figure 8. An Example Alphanumeric Fault Tree Representation.

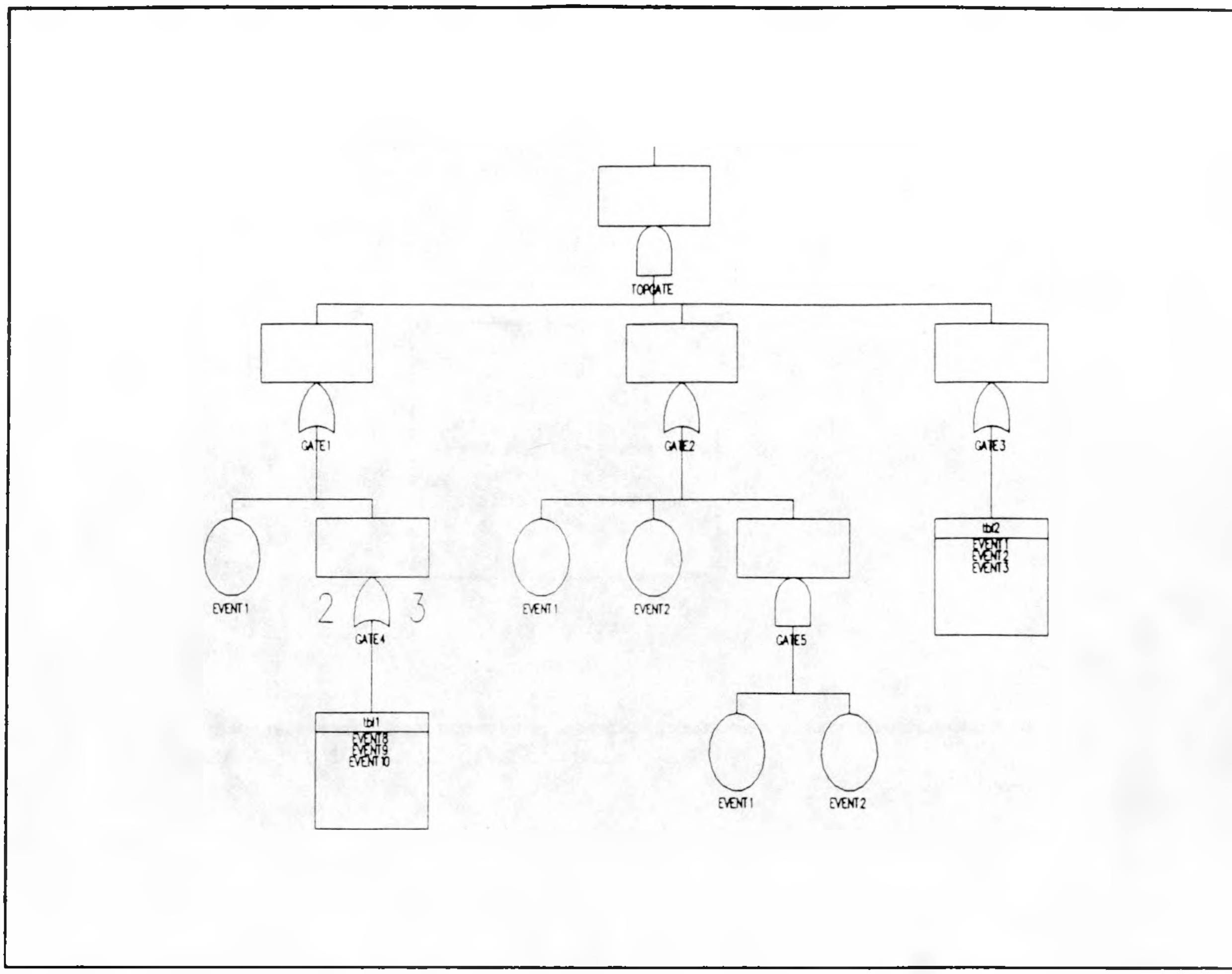

Figure 9. Fault tree Graphics for the Logic Shown in Figure 8.

Fault Tree Analysis Option

The "FAULT Tree Analysis" option allows the user to perform the fault tree analysis functions including basic event modifications, cut set generation, quantification, uncertainty calculations, and modification and display of the results. The Fault tree analysis menu is shown in Figure 10.

Modify Event Data Option

One of the most important features of a good risk analysis system is the ability to define and maintain the event failure and uncertainty data. IRRAS 2.0 provides the user with a very powerful method of performing this function. IRRAS 2.0 maintains a "base case" and a "current" failure and uncertainty data table. These tables allow the user to maintain data which is considered to be the "operating" values as well as a set of data considered to be "temporary". With this arrangement, the user can perform sensitivity analysis on the data while still maintaining the base case or "operating" values associated with plant specific design, operation, maintenance, and

```
I R R A S - P C
Fault Tree Analysis System

Currently Selected Family ——> NO FAMILY

E - Exit

S - Select Family
M - Modify Event Data
A - Analyze Fault Trees
C - Cut Set Editor
F - Fault Tree Editor
D - Display Fault Trees

Option... E
```

Figure 10. The IRRAS 2.0 Fault Tree Analysis Menu.

technical specifications.

IRRAS 2.0 also provides the user with the ability to change single event probabilities or to make "bulk" or "class" changes to a group of events. The user input screen that provides this function is shown in Figure 11. In this screen, the user may select any of the fields displayed to limit or define the class to which the uncertainty and failure data changes are to apply. The limiting fields may also be further segmented by using "don't care" and "wild card" characters in the specific fields. This feature thus allows the user to make changes to classes of events such as, all pumps or all valves in a feedwater system. Multiple class modifications are accumulated until the user "clears" them back to the default "base case".

The user may select from eleven different methods of defining the failure data for IRRAS. The various options are displayed in Figure 12. As shown, all of the standard methods for defining failure data are provided. The user may also specify that the current data be modified by a percent or fixed amount, as well as define any event to be a house event. These options provide the user with a very powerful method of performing sensitivity analysis.

The user may select from six different uncertainty distributions for each basic event. The various distributions are displayed in Figure 13. The user can also specify the input parameters to the selected distribution and a correlation class to assign a basic event to. This class of events will then be treated as if they were 100% correlated when the uncertainty analysis is performed.

```
E v e n t   C l a s s   C h a n g e s

Currently Selected Family ——> DEMO FAMILY

                              Event-Attributes
   Event Name     Fail Mode  Component Type  System Type  Component ID

                             1  2  3  4  5  6  7  8  9  10 11 12 13 14 15 16
 Location     Class Attributes

 Note:  Enter the attributes of the events to be changed.  Fields which are
        left blank are  not used.  The ? may  be used for positional "don't
        care"  characters.  The * may be  used for non-positional  variable
        length "don't care" strings.
        e.g.  AB?CD*  matches  ABXCD  through  ABXCDXXXXXXXXXXX

        Uncertainty-Data                      Failure-Data
 Distribution Type ————————> L        Calculation Type ————————> 1
 (press Esc for list of types)        (press Esc for list of types)
 Value ——————————> ------E----        Prob    ——————————> ------E----
 Correlation Class—> ----             Lamda   ——————————> ------E----
                                      Tau     ——————————> ------E----
```

Figure 11. The Basic Event Class Change Menu.

Failure Data Calculation Types	
Type	Calculation Method
1	Probability
2	Lamda * Mission Time
3	1 - Exp(-Lamda * Mission Time)
4	Lamda * Min(Mission Time, Tau)
5	Operating Component with Repair (Full Eq)
6	Lamda * Tau / 2.0
7	1 + (EXP(-Lamda*Tau)-1.0) / (Lamda * Tau)
8	Base Probability + Probability
9	Base Probability * Probability
T	Set to House Event (Failed, Prob=1.0)
F	Set to House Event (Successful, Prob=0.0)
Calculation Type ——>1	

Figure 12. The IRRAS 2.0 Calculation Types.

Uncertainty Distribution Types	
Type	Distribution Values
L	Log Normal, Error Factor
N	Normal, Standard Dev.
B	Beta, b of Beta(a,b)
G	Gamma, a of Gamma(a)
E	Exponential, none
U	Uniform, Upper End Pt.
	Distribution Type---->L

Figure 13. The IRRAS 2.0 Distribution Types.

Analyze Fault Trees Option

This option allows the analyst to perform the cut set generation, quantification, and uncertainty analysis on fault trees. The cut set generation algorithm has been completely rewritten for Version 2.0. The rewrite of the algorithm was necessary to include more comprehensive fault tree reduction techniques. Some of the features added to the new algorithm are:

(1) coalescing like gates in the fault tree,

(2) automatic optimization of independent subtrees,

(3) complimented event and gate processing,

(4) error detection for "Loops", multiple top events and other common errors,

(5) full implementation of paged fault trees, and

(6) the ability to handle larger fault trees.

These features provide a much more powerful fault tree reduction algorithm with significant performance improvements. Cut set generation using a sample fault tree from an existing plant showed a performance improvement from 2-1/2 hours to 20 seconds. These performance improvements were achieved because the new algorithm was able to take advantage of a large amount of independence in the tree. Most fault trees reductions will not improve this much; however, all should detect some improvement.

Fault Tree and Cut Set Editors

Two new editors have been provided in IRRAS 2.0. These editors allow the user to edit the alphanumeric logic of the fault tree and the generated cut set lists. Examples of the screens for the fault tree and cut set editors are shown in Figure 14 and 15 respectively. These two tools provide the analyst with an integrated method of creating or modifying the logic associated with a fault tree without needing to use the graphical editor and allow the analyst to edit cut sets to apply recovery. Both of these editors use a very simple to use full screen editing concept with single keystroke functions and are a powerful addition to IRRAS 2.0.

FAULT TREE EDITOR

Exit / Add / Modify / Delete / Locate / Next / Previous
Insert / Replace / Search / Options / Undo Delete / Esc for more help

Gate Name	Type	Inputs		
C-MOV-1-FAILS	OR	C-MOV-1	DG-B	
CCS-SUPPLY	OR	C-MOV-1-FAILS	TANK	
CCS-TOP	OR	CCS-SUPPLY	CCS-TRAINS	
CCS-TRAIN-A	OR	C-CV-A	C-MOV-A	DG-A
		C-PUMP-A		
CCS-TRAIN-B	OR	C-CV-B	C-MOV-B	C-PUMP-B
		DG-B		
CCS-TRAINS	AND	CCS-TRAIN-A	CCS-TRAIN-B	

Figure 14. The IRRAS 2.0 Fault Tree Editor.

Cut Set Display and Partition Options

The user is provided with a very versatile screen display of the cut sets for a fault tree or sequence in IRRAS 2.0. This module allows the user to page through the cut sets and display various attributes of the basic events included in the cut sets. The user may also choose to display basic event importance measures or cut set uncertainty information.

C U T   S E T   E D I T O R

Exit / Add / Modify / Delete / Locate / Next / Previous
Insert / Replace / Search / Options / Undo Delete / Esc for more help

Set #	Event Names			
1	DG-B			
2	TANK			
3	C-MOV-1			
4	C-MOV-A	C-MOV-B		
5	C-MOV-A	C-CV-B		
6	C-MOV-A	C-PUMP-B		
7	DG-A	C-MOV-B		
8	DG-A	C-CV-B		
9	DG-A	C-PUMP-B		
10	C-PUMP-A	C-MOV-B		
11	C-PUMP-A	C-CV-B		
12	C-PUMP-A	C-PUMP-B		
13	C-CV-A	C-MOV-B		
14	C-CV-A	C-CV-B		
15	C-CV-A	C-PUMP-B		

Figure 15. The IRRAS 2.0 Cut Set Editor.

This facility takes full advantage of hierarchical menus and windows to display the cut set data, thus providing an integrated method for the user to display the results of a fault tree analysis without leaving the IRRAS system. This feature significantly reduces the time required to perform sensitivity analysis, whereby the user makes changes to fault trees or component reliability information and desire to see the resulting effect of the changes before making further modifications.

Also provided in IRRAS 2.0 is an option to allow the analyst to perform some additional analysis on the cutsets by using the partition option. An example of the "Partition" option is shown in Figure 16. This option allows the analyst to partition the cutsets by selecting only those cutsets which contain a "Qualified" event.

Events can be qualified in groups by "Including" or "eXcluding" them or individually by selecting the "View Events" option. In this example we selected to include all events which contained the string "MOV" somewhere in the name. Figure 16 also shows the result of this operation.

The analyst can also specify other attributes to further qualify an event or use "eXclude" to remove some of the qualified events from the list. The View Events" options allows us to display the basic events in this family. The screen in Figure 17 gives an example of this option.

```
                    Partition Cut Sets

          Currently Selected Family ──> DEMO FAMILY
          Total Family Events ────────>   18
          Total Qualified Events ─────>    6

  Option |I|  Exit / Include / eXclude / Compliment / Reset / View Events

──────────────────────────Event Attributes──────────────────────────────
   Event Name     Fail Mode  Component Type  System Type  Component ID
 *MOV*
                             1  2  3  4  5  6  7  8  9  10 11 12 13 14 15 16
Location     Class Attributes

Note:  Enter the attributes of the events to be included. Fields which are
       left blank are not used.  The ? may be used for positional "don't
       care" characters.  The * may be used for non-positional variable
       length "don't care" strings.
       e.g.  AB?CD*  matches  ABXCD  through  ABXCDXXXXXXXXXXX
```

Figure 16. The Partition Cut Sets Menu.

```
                      View Events

          Option |I| Exit  / Include event  <= choose Event

──Event Name──────Event Description──────────────────────────────────
   C-CV-A           CCS Train A pump discharge check valve
   C-CV-B           CCS Train B pump discharge check valve
 + C-MOV-1          CCS suction isolation valve
 + C-MOV-A          CCS Train A pump discharge isolation valve
 + C-MOV-B          CCS Train B pump discharge isolation valve
   C-PUMP-A         CCS Train A motor-driven pump
   C-PUMP-B         CCS Train B motor-driven pump
   DG-A             Emergency diesel generator A
   DG-B             Emergency diesel generator B
   E-CV-A           ECS Train A pump discharge check valve
   E-CV-B           ECS Train B pump discharge check valve
 + E-MOV-1          ECS suction isolation valve

Note: Use <PgUp> or <PgDn> to display more Events.  Included events are
      indicated by "+".
```

Figure 17. The View Events Menu.

The currently qualified events are displayed with a "+" in front of the name. These events can be individually toggled from qualified to not qualified by highlighting the event and pressing the enter key. Once we exit the "Partition" menu and get back to the Cut Set display menu, the screen in Figure 18 is displayed.

```
                    F A U L T   T R E E   C U T   S E T S
          Family Name DEMO FAMILY        Fault Tree Name CCS
 Min Cut  2.120E-002  Num   15     Part. ==>  1.156E-003    5.45%  Num    7

Option |P|  Exit / Partition / Report / Basic Events    <- choose a cut set below

Num | %    | Frequency |              E v e n t   N a m e s
  1   4.72   1.000E-003  C-MOV-1
  2   0.47   1.000E-004  DG-A               C-MOV-B
  3   0.12   2.500E-005  C-MOV-A            C-MOV-B
  4   0.07   1.500E-005  C-PUMP-A           C-MOV-B
  5   0.07   1.500E-005  C-MOV-A            C-PUMP-B
  6   0.00   5.000E-007  C-MOV-A            C-CV-B
  7   0.00   5.000E-007  C-CV-A             C-MOV-B

               Use <PgUp> or <PgDn> to display more Cut Sets
```

Figure 18. Partitioning Completed.

Notice that only those cut sets including an event whose name contains the string "MOV" are displayed. Also note that the top of the display now contains different values for the current partition contributions.

To get a hard copy report of the partitioned cut sets, the analyst can select the "Report" option. This option generated the report shown in Figure 19.

Thus, the analyst can perform some very powerful partitioning of the cut sets to determine the contribution of systems, component types or other categories needed to gain insights into the data generated by IRRAS. This feature goes far beyond most systems in aiding the analyst to understand the large amounts of information generated in a PRA.

Partition Cut Set Report

Family Name ->DEMO FAMILY   Fault Tree Name ->CCS
Mincut Upper Bound 2.120E-002   This Partition   1.156E-003

Cut No.	% Total	% Cut Set	Freq.	Cut Sets
1	4.7	4.7	1.0E-003	C-MOV-1
2	5.2	.5	1.0E-004	DG-A, C-MOV-B
3	5.3	.1	2.5E-005	C-MOV-A, C-MOV-B
4	5.4	.1	1.5E-005	C-PUMP-A, C-MOV-B
5	5.4	.1	1.5E-005	C-MOV-A, C-PUMP-B
6	5.4	.0	5.0E-007	C-MOV-A, C-CV-B
7	5.5	.0	5.0E-007	C-CV-A, C-MOV-B
8	5.5	.0	9.0E-006	C-PUMP-A, C-PUMP-B
9	5.5	.0	2.0E-006	DG-A, C-CV-B
10	5.5	.0	5.0E-007	C-CV-A, C-MOV-B
11	5.5	.0	5.0E-007	C-MOV-A, C-CV-B
12	5.5	.0	3.0E-007	C-CV-A, C-PUMP-B
13	5.5	.0	3.0E-007	C-PUMP-A, C-CV-B
14	5.5	.0	1.0E-007	TANK
15	5.5	.0	1.0E-008	C-CV-A, C-CV-B

Figure 19. Report of Partitioned Cut Sets.

CREATE Event Tree Option

The "CREATE Event Tree" option was not implemented in version 2.0 of IRRAS. This option was reserved for Version 3.0. It will provide the user with a tool to graphically construct event trees and link them similar to the way the fault trees are currently constructed in IRRAS 2.0.

SEQUENCE Analysis Option

The "SEQUENCE Analysis" option provides the same functions for sequences that is provided for fault trees in the "FAULT Tree Analysis" option. IRRAS 2.0 provides a sequence analysis module which generates the cut sets for an accident sequence and quantifies the sequence. Cut set generation is accomplished by combining the cut sets for the fault trees that make up the sequence. Comparisons are made among the cut set lists for successful and failed systems to eliminate impossible failure combinations. Once the sequence cut sets are generated, the sequence may be quantified, importance measures may be calculated, and uncertainty analysis may be performed. The results can be displayed on the screen, sent to a printer, or written to a file for later use.

MODIFY Data Base Option

The "MODIFY Data Base" option provides access to the data base maintenance facilities in IRRAS. With this option, the user can make changes to the data stored in the relational data base. This feature allows access to all of the data generated by a PRA in an organized fashion. Simple state-of-the-art menus are utilized to make the process even easier.

REPORT on Data Base Option

The "REPORT on Data Base" option provides access to the report generation facility. This facility is a comprehensive report generation facility that allows the user to generate a report of any information contained in the data base. The user is allowed to specify the title for the report and the output device. The user may choose to output the report to the console, the line printer, or to a file for later modification or printing. The following list represents the reports available in IRRAS 2.0:

(1) Data Base Families report,

(2) Basic Event - Summary, Probabilities, and Uncertainty Values,

(3) Fault Tree - Logic, Expanded Logic, Modified Logic, Importance Measures, Cut Sets, Summary, and Uncertainty Values,

(4) Sequence - Logic, Importance Measures, Cut Sets, Summary, and Uncertainty Values reports.

UTILITY Options

The "UTILITY Options" function contains a number of utilities including data conversion, mainframe communications, and data recovery.

The conversion utilities have been added to IRRAS 2.0 to allow the analyst to convert between various formats. These formats include IRRAS 1.0, SETS, and MAR-D. Both of these conversion utilities allow conversion to and from the specified formats and include fault tree logic, failure rate data, and both sequence and fault tree cutsets. These utilities make it easy for the analyst to interface with these programs and still be able to use the power of IRRAS 2.0.

5. IRRAS 3.0 Features

IRRAS 2.0 was developed with the knowledge that it's features and capabilities would be expanded and enhanced in a follow-on version. IRRAS 3.0 carries on where version 2.0 left off. This version is designed to provide the capabilities necessary to conduct all the steps in fault tree and event tree analysis. Future efforts in these areas will most likely be limited to maintenance of the software and documentation.

The major areas of capabilities and features reserved for IRRAS 3.0 were large-scale event tree model creation and analysis, improvement of the cut set generation algorithms, and the ability to handle larger fault tree models and fault trees that generate a large number (over a million) of cut sets. Also left for IRRAS 3.0 were improvements in the fault tree graphics, cross-referencing within the data base, and enhanced versatility in the interface with other NRC-sponsored PRA software. Each area is explored in the following sections.

Event Tree Model Creation and Analysis

The main menu for Version 3.0 is identical to that for Version 2.0. However, in Version 3.0 the "CREATE Event Trees" option has been implemented to allow graphical creation of event trees, linking fault trees to the branch points in the event trees, and analysis of accident sequences.

```
                     I R R A S
           Event Tree Graphics System

Currently Selected Family ——> DEMO FAMILY

        E - Exit

        S - Select Family

        X - eXtract Event Trees
        C - Create Event Trees

        L - Link Event Trees

        P - Plot Tree (HP)
        R - Rasterize Event Tree
        D - Define plotter pens

              Option... E
```

Figure 20. The IRRAS 3.0 Event Tree Graphics System Menu.

To draw an event tree, the "CREATE Event Trees" option is selected. This brings up the "IRRAS Event Tree Graphics System" menu shown in Figure 20. This menu contains the options that allow the creation of graphical event tree models and the linking of fault trees to the branch points in the event trees. Other options provide interaction with the data base for model information and set up for hardcopy output of the event trees.

The graphical event tree editor is accessed via the "Create Event Trees" option. This brings up the graphics drawing board and the editor main menu shown in Figure 21. The user may create a new event tree from scratch or from an existing event tree file. Existing event tree models may be called up for revision.

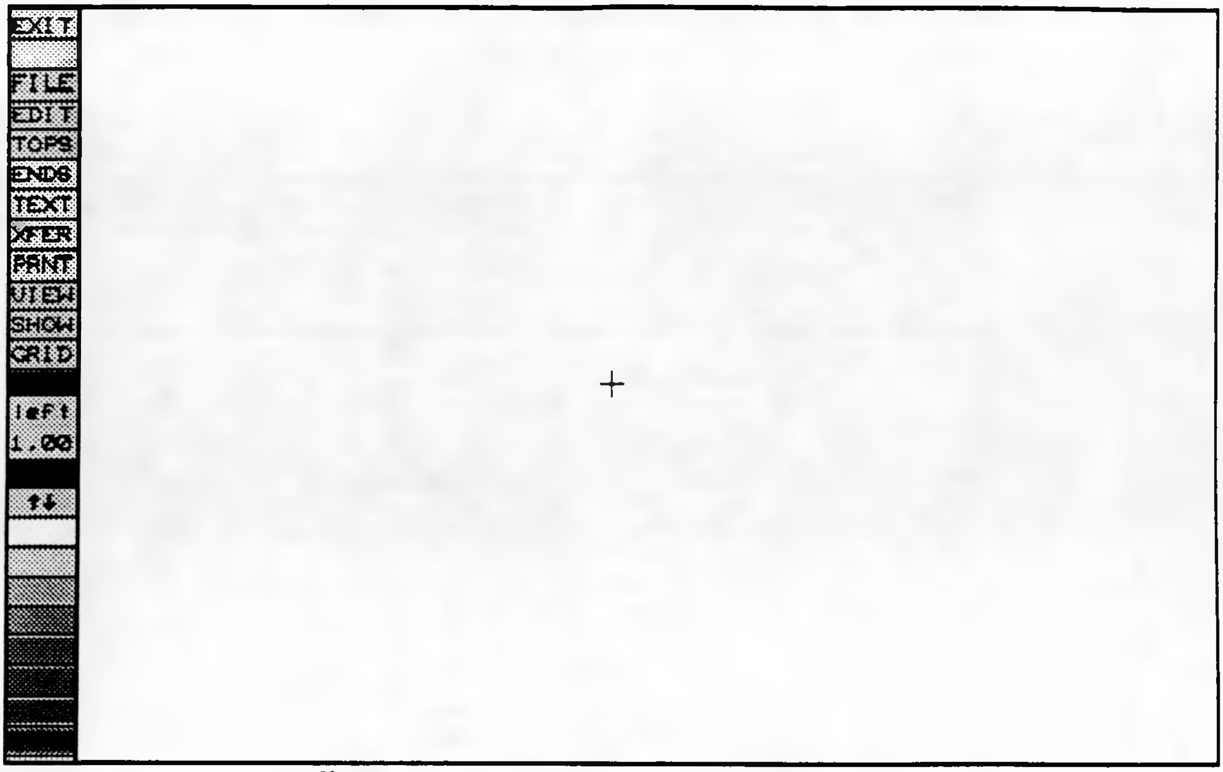

Figure 21. Event Tree Graphics Main Menu.

When a new event tree is to be created, the user is prompted for the initiating event and the event tree top events in the order they are to appear in the tree. The initiating event and event tree top event names may be up to 16 characters long, however, only the first 5 characters will appear on the drawing. With this information, IRRAS will draw a starter tree consisting of the initiating event and two sequences with the branch point at the first top event (see Figure 22). The user may then add branches to the event tree as needed. The editor provides the capability to delete unwanted branches from the tree, to copy logic patterns from one part of the tree to another, to insert new top events within the tree, to delete top events from the tree, and to create transfers between event trees.

Five columns of information are available for display at the ends of the event tree sequences. The first column is the sequnce number. IRRAS automatically assigns sequence numbers in order from the top down. Modifications to the event tree cause the sequence numbers to automatically update. Sequence numbers are always displayed.

The next four columns can be turned on and off and can be placed in any order at the user's discretion. The titles for these columns are given default names by IRRAS but they can be edited to suit the user. The sequence name and endstate name columns tie these attributes to the sequences and automatically sends this information to the IRRAS relational data base upon exiting

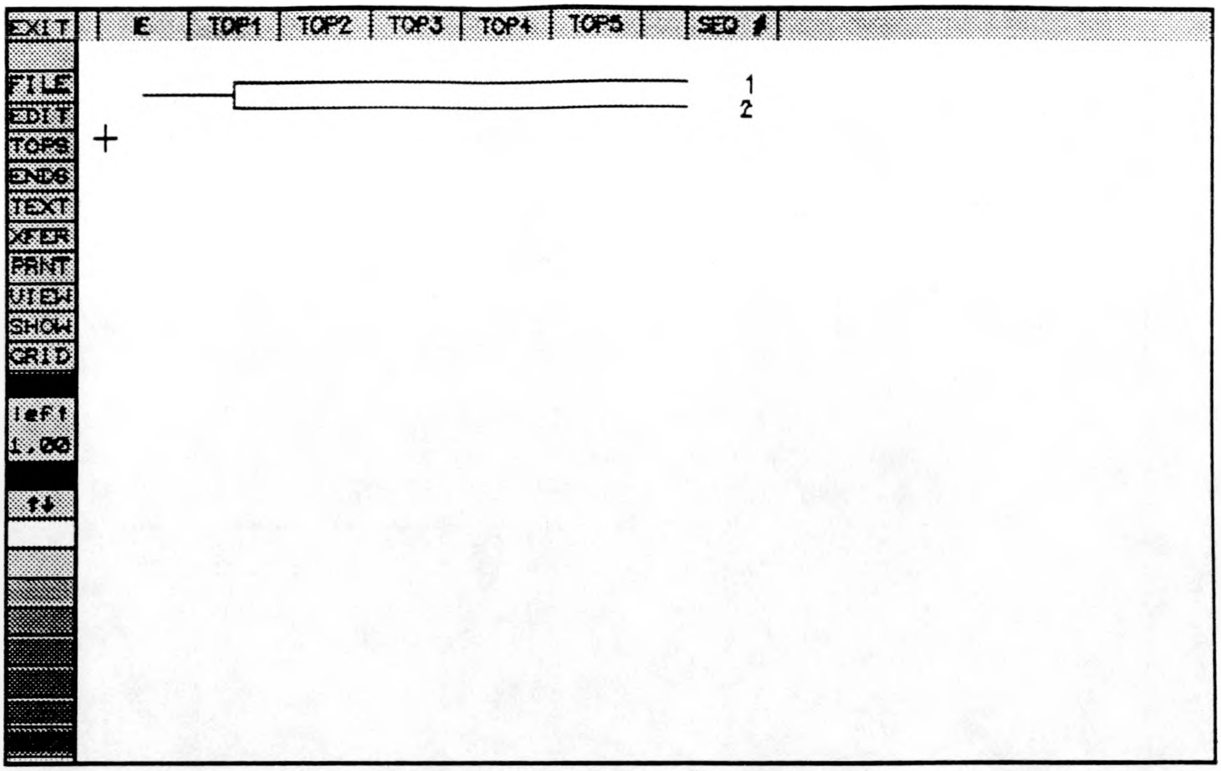

Figure 22. Event Tree Starter Tree.

the graphical editor. The titles for these two columns and the order in which they appear on the drawing (if they appear at all) may be changed, but the information will be sent to the data base as the sequence names and endstate names. IRRAS will assign a unique default sequence name to each sequence but will leave the endstate names blank. Sequence and endstate names may be up to 16 characters long.

The final two columns are called "EXTRA #1" and "EXTRA #2." These columns may be titled with any name up to 16 character in length. The information put in these columns is stored in the relational data base as attributes of the graphics, but do not influence any aspect of the event tree analysis. These columns are handy for adding comments to the drawing that need to be tied to the individual sequences, such as the sequence frequency or transfer comments.

Text may be placed anywhere on the drawing. Text may be used to add a title, to place page numbers on the drawing, or to add comments. The user has complete control of the text size, color, placement, and content. Text editing features provide the capabilities to copy, move, and erase existing text. The user has control of whether existing text is displayed or not with the push of a button.

Figure 23 shows a completed event tree model developed for the NUREG-1150 Zion front-end analysis using IRRAS 3.0.

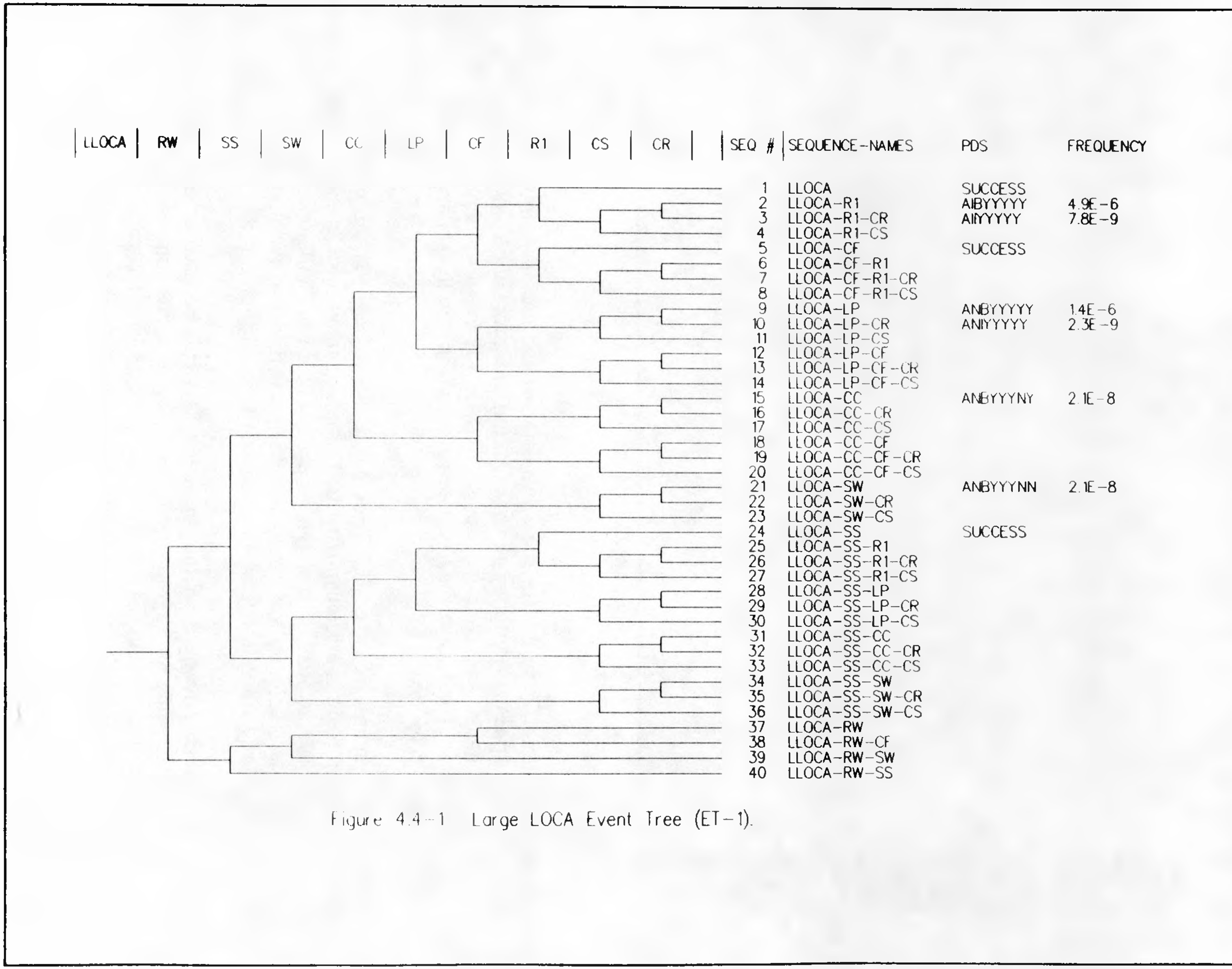

Figure 23. Example event tree using IRRAS 3.0.

When an event tree drawing is completed and the graphical editor is exited, the data base is updated with several items of new information. The graphics are stored for later uses such as printing out hardcopies and model revision. The newly-created event tree name is placed in the data base for use in accessing the associated sequences. The sequences and their attributes are added to the data base and are available for further analysis.

With the event tree model created and added to the data base, the next logical step is to generate the sequence cut sets and quantify the sequences. To generate the sequence cut sets, IRRAS must be told which fault trees are to be used at each of the branch points in the event tree. This is done through the "Link Event Trees" option on the IRRAS Event Tree Graphics System menu.

IRRAS uses logic rules to assign the fault trees to the event tree branch points, rather than explicitly stating which fault tree to use at each individual branch point. These logic rules determine a default fault tree for each top event and express the exceptions to the defaults. An example is used to demonstrate how this works.

In general, for the Large LOCA event tree shown in Figure 23, the fault trees needed have the same names as their top events (i.e., the fault tree for top event SS is also called SS). An exception is top event LP. This top event models the low pressure injection system with automatic actuation given a large break LOCA, except when the safety injection actuation signal (modeled by top event SS) is failed. In these cases, top event LP also includes operator action to actuate the injection system. The automatic actuation fault tree is called LP-LL and the manual actuation fault tree is called LP-LL-M.

IRRAS 3.0 looks for a fault tree with the same name as the event tree top event. If such a fault tree exists, IRRAS uses it for the default assignment to each of the branch points under that top event. Therefore, we need only to create and apply logic rules to deal with top event LP.

Figure 24 shows the Linkage Editor used to create the IF-THEN logic rules used by IRRAS. To assign fault tree LP-LL as the default for top event LP, the following rule must be created:

> If top event LP is failed, then use fault tree LP-LL.

This is rule 1 in Figure 25. Rule 2 shows the exception to this default, namely:

> If top event SS is failed, then use fault tree LP-LL-M for top event LP.

This set of rules results in the automatic assignment of the proper fault trees to the event tree branch points (and therefore, to the sequences). IRRAS 3.0 will allow any combination of success and failed top events in the stipulation of the conditional portion of the rules. IRRAS will automatically apply the converse of the assigned fault tree (1.0 - fault tree) for success branches. The creation of the event tree added the sequences to the data base with their attributes of sequence name, endstate name, and initiating event. The assignment of fault trees to the event tree branch points established the sequence logic in terms of an initiating event and a succession

```
                    L I N K   E V E N T   T R E E

           Currently Selected Family ---> DEMO FAMILY

      Option |E| Exit / Link Event Trees / Generate Sequences

--- N a m e ------------------ D e s c r i p t i o n ---------
LOSP               Loss of offsite power event tree
LLOCA              Large Loss of Coolant Accident event tree

Note:  To link or generate, enter option <L, or G>, move the cursor
       to the desired Event Tree, and press <Enter>.
```

Figure 24. The Link Event Tree Menu.

```
                         Linkage Editor

           Option:   Exit / Add / Insert / Delete / Restore

        I f           A n d             T h e n            I s

-- # --- Top Event --- Top Event ------ Top Event ---- Fault Tree --
                                                     =
   1     LP                              LP          =  LP-LL
                                                     =
                                                     =
                                                     =
                                                     =
                                                     =
                                                     =
                                                     =
                                                     =
                                                     =

Note:   Use <PgUp>, <PgDn>, < >, or < > to display more rules.
```

Figure 25. An Example Event Tree Linking Rule.

of failed and successful fault trees. Figure 26 shows the logic for the sequences in the Large LOCA event tree. The next step is the generation and quantification of the sequence cut sets based on this logic.

The IRRAS Sequence Analysis System provides the ability to generate the sequence cut sets from the fault tree cut sets and the sequence logic. The initiating event and failed fault trees' cut sets are ANDed together and reduced to minimal cut sets. These cut sets are compared against the success fault trees' cut sets and any impossible cut set combinations are eliminated from the sequence cut sets.

```
                              SEQUENCE LOGIC REPORT

                              Family:  DEMO FAMILY

Seq.
No.  Sequence Name  Event Tree  Init. Event                Logic
---- -------------- ----------  ----------- --------------------------------
   1 LLOCA          LLOCA       LLOCA       /RW /SS /SW /CC /LP-LL /CF /R1

   2 LLOCA-R1       LLOCA       LLOCA       R1 /RW /SS /SW /CC /LP-LL /CF
                                            /CS /CR

   3 LLOCA-R1-CR    LLOCA       LLOCA       R1 CR /RW /SS /SW /CC /LP-LL
                                            /CF /CS

   4 LLOCA-R1-CS    LLOCA       LLOCA       R1 CS /RW /SS /SW /CC /LP-LL
                                            /CF

   5 LLOCA-CF       LLOCA       LLOCA       CF /RW /SS /SW /CC /LP-LL /R1

   6 LLOCA-CF-R1    LLOCA       LLOCA       CF R1 /RW /SS /SW /CC /LP-LL
                                            /CS /CR

   7 LLOCA-CF-R1-CR LLOCA       LLOCA       CF R1 CR /RW /SS /SW /CC /LP-LL
                                            /CS

   8 LLOCA-CF-R1-CS LLOCA       LLOCA       CF R1 CS /RW /SS /SW /CC /LP-LL

   9 LLOCA-LP       LLOCA       LLOCA       LP-LL /RW /SS /SW /CC /CF /CS /CR
```

Figure 26. Sequence Logics for Large LOCA Event Tree.

IRRAS 3.0 also provides the ability to quantify event tree sequences by using the fault tree minimum cut set upper bound values instead of the fault tree cut sets. Sequence cut sets are not generated when this method is used. This method also assumes that the fault trees (both failed and successful) are independent from one another.

<u>Cut Set Generation and Analysis of Large Fault Trees</u>

IRRAS 2.0 has the ability to identify totally independent subtrees (basic events within the subtree appear only once in the entire fault tree) and reserves these structures for processing last. This concept proved to be quite powerful and beneficial. However, IRRAS 2.0 is limited to operations within a 640K main memory. This limits the number of cut sets that can be retained in the system (about 4,000 to 6,000 depending on the size of the individual cut sets). IRRAS 3.0 has continued to improve where IRRAS 2.0 left off. In addition to finding totally independent subtrees, IRRAS 3.0 identifies locally independent subtrees as well. A locally independent subtree can appear several times within the fault tree but the basic events in the subtree always appear together as inputs to the same type of gate. By identifying all subtrees in this manner, IRRAS 3.0 can generate intermediate cut sets in terms of basic events and subtrees, perform the elimination of non-minimal cut sets (called supersetting in IRRAS), and then expand the subtrees. This process reduces the number of cut sets that must be carried through all the steps.

IRRAS 3.0 has broken through the 640K memory barrier imposed on IRRAS 2.0. The cut set generation and supersetting algorithms have been rewritten to allow the allocation of disk space for storage of intermediate cut sets and information. The user has control of which drive is used. If the specified drive is a virtual disk, then much time is saved in input/output over hard disk or floppy disk drives. Access to large amounts of storage space gives IRRAS 3.0 the ability to process fault trees that generate large numbers of intermediate cut sets before reduction to minimal cut sets. Should a fault tree generate many minimal cut sets, IRRAS 3.0 can store them all for proper sorting and display.

Other Improvements

The experience gained from the in-house use and limited distribution of IRRAS 2.0 has provided valuable testing, debugging, and comments/suggestions. As a result, several smaller but highly desirable features have been added to Version 3.0. These improvements fall into three areas. These are graphics, cross-references, and data base interfaces.

In the modeling of many facilities, it is common to have portions of the fault trees with identical logic. This is especially true in highly redundant facilities. To expedite the model development task, IRRAS allows copying pages of the fault tree. However, it was a laborious job to rename all the elements of the copied logic to fit the model. IRRAS 3.0 provides a text editor within the graphics to allow the analyst to change text without the need to delete existing text and inputting new.

The IRRAS fault tree graphics module automatically updates the relational data base with the fault tree logic and adds any new basic events to the data base for assignment of failure and uncertainty data. This is done with a temporary file that is created when a fault tree is saved. The logic and basic event information is extracted from this file when the fault tree graphics module is exited. After the data is read in, the temporary file is deleted from the DOS directory, therefore the user never sees this logic file. This is not a problem except in one situation. For larger projects, it is common practice to have a number of analysts work on various portions of the models. At some point in the analysis, each of these small data bases must come together to form a master data base for model quantification. The need to put all the fault tree graphics files in one directory, execute IRRAS 2.0 on that directory, and save every fault tree into the master data base was too labor intensive. IRRAS 3.0 allows the user to save the fault tree logics to files that can be readily transferred from a working data base to the master data base with much less effort.

To aid the user in understanding all the interfaces within a model and data base, IRRAS 3.0 provides several cross-reference reports. These reports indicate which fault trees contain a specified basic event, and the reverse situation -- which basic events are contained in a fault tree. Other cross-references show which fault trees are called out by a given event tree, which sequences use a specified basic event, and which sequences use a particular fault tree. All these reports provide valuable information when tracking down the impact of small model changes.

The final major improvement in IRRAS 3.0 is the ability to easily interface with a wide variety of other PC-based PRA software. IRRAS 3.0 has been designed to operate on the same database files as two other PRA software packages developed at the Idaho National Engineering Laboratory, the System Analysis and Risk Assessment (SARA) System, and the Models and Results Database (MAR-D) System. All these systems can be run on the same data files. MAR-D has the ability to take PRA information from SETS, TEMAC, CAFTA, NUPRA, and the EI workstation and convert that information for use in IRRAS and SARA. Conversely, IRRAS and SARA data can be converted for use in these other software packages. MAR-D also serves as a repository of PRA models, results, and findings and is currently being loaded with as many PRAs as made available to the NRC. SARA takes the results of PRA models (system and accident sequence cut sets and the associated basic event data) and provides a means of performing sensitivity analyses. This tool is very powerful in the areas of plant configuration change analyses, plant incident/reportable event analyses, and generic issue evaluations.

6. Uses and Applications

IRRAS has been and is currently being used for many different and diverse applications. These applications will be briefly described for each version in this section.

6.1 IRRAS 1.0

IRRAS 1.0 is in use at over 300 different organizations throughout the United States. A number of utilities have IRRAS for use in their risk and reliability work. Most of the national laboratories have IRRAS and have used it to some extent in their work. All of the NSSS vendors in the U.S. own a copy of IRRAS 1.0. Combustion Engineering has used IRRAS in support of the Savannah River facility. Several architect-engineering firms, such as Stone & Webster and Sargent & Lundy, use IRRAS in their reliability projects.

Outside the nuclear industry IRRAS has been very popular. The chemical industry has grown rapidly in the risk analysis field and companies such as Dow Chemical and Union Carbide have adopted IRRAS as one of their tools. The areospace industry has many users of IRRAS including Morton-Thiokol for work on the space shuttle. Another contractor has been using IRRAS as part of the analysis for each space shuttle mission since Galileo. Several universities (M.I.T. and the University of Washington among them) have obtained copies of IRRAS for use in their research and classes on risk and reliability. Idaho State University uses IRRAS as an integral part of their nuclear risk and reliability curriculum.

IRRAS 1.0 has been used in projects ranging from the reliability analysis of an Air Force jet fuel storage facility to the safety of clothes dryers. Several automotive firms have used it in their safety divisions. Three major petroleum producers have the code. Environmental risk assesments for the Los Angeles County Fire Department and the State of New Jersey have involved IRRAS. Approximately three to four requests per week for IRRAS 1.0 are processed by the NRC Risk Analysis Unit of EG&G Idaho.

6.2 IRRAS 2.0

One of the initial applications of IRRAS 2.0 was the Event Sequence Reliability Benchmark Exercise (ES-RBE) sponsored by the Joint Research Centre, Commission of the European Communities, in Ispra, Italy. Fault trees were generated and accident sequences defined. The cut sets were generated each and quantified. The results were benchmarked against NUPRA. The ES-RBE final meeting will be held in Ispra in September 1989.

In another application, the SETS cut sets for the LaSalle PRA were loaded into IRRAS using the SETS to IRRAS interface. Those sequences were then used to help develop a PRA-based inspection of LaSalle.

IRRAS 2.0 also played a key role in the uncertainty analysis of the Zion plant for the NUREG-1150 risk rebaseline analysis. The 204 accident sequences with a frequency greater than 1.0E-09 per reactor year were loaded into IRRAS 2.0 and grouped into 57 plant damage states. 150 Latin Hypercube Sample runs were conducted on the PC in a two-day period at great savings over mainframe computer runs.

IRRAS 2.0 was used to develop and process the models for the resolution of Generic Safety Issue 115 for the Nuclear Regulatory Commission. This issue evaluated the existing Westinghouse Solid State Protection System (SSPS) configuration and six proposed modifications to the SSPS. IRRAS 2.0 was used to create the fault tree models for the base case and each of the options, to generate the cut sets for each case and to quantify the systems.

6.3 IRRAS 3.0

Since IRRAS 3.0 is still being developed, a lot of the capabilities are still being tested. The ES-RBE has been used to debug IRRAS 3.0 event tree features and the improved cut set generation algorithms. The LaSalle sequences provided tests for large numbers of cut sets and the use of the sequence features and the report generation capabilities of IRRAS 3.0.

7. Summary and Conclusions

The technological advances in the fields of probabilistic risk analysis and microcomputers have made possible the development of powerful tools for both PRA analysts and those involved in the risk management of nuclear power plants. Risk-based decision-making in the areas of plant design, operations, and regulation is possible now more than ever before.

The IRRAS 2.0 system is the result of significant modifications and improvements to the IRRAS 1.0 system. This new fault tree analysis system is more comprehensive and easier to use than IRRAS 1.0 and incorporates features which greatly improve the PRA analyst's ability to perform an analysis. IRRAS 3.0 is an improvement over version 2.0.

Continued research in the area of PRA analysis tools being conducted by the U. S. Nuclear Regulatory Commission and the great strides in microcomputer performance and useability provide a bright future for more and better tools for performing risk analysis.

Acknowledgments

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