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PRAAGE-1988: An Interactive IBM-PC Code for Aging Analysis of NUREG-1150 Systems

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ABSTRACT

Probabilistic Risk Assessments (PRA) contain a great deal of information for estimating the risk of a nuclear power plant but do not consider aging. PRAAGE (PRA+AGE) is an interactive, IBM-PC code for processing PRA-developed system models using non-aged failure rate data in conjunction with user-supplied time-dependent nuclear plant experience component failure rate data to determine the effects of component aging on a system's reliability as well as providing the age-dependent importances of various generic components. This paper describes the structure, use and application of PRAAGE to the aging analysis of the Peach Bottom 2 RHR system in the LPCI and SDC modes of operation.

1. Introduction

Aging, as it is used in this report, refers to the end-of-life region of the wearout curve (mortality curve) in which the probability of failure is no longer characterized by a constant failure rate but is increasing with time. The report Higgins, 1988, discussed in some detail the mathematical modeling of the wearout process and its approximation as a linear increase in the failure rate with time. The theory of linear aging was presented in Vesely, 1987, as being the result of Poisson-distributed assaults on a component until it finally fails. This assault model predicts a failure rate that linearly increases with time starting when the component is new. Higgins, 1988, using nuclear power plant experience data, showed that certain classes of components such as pumps and valves do not show such a simple dependence but characterization as two connected linear dependencies is required. The first segment is a constant failure rate, i.e., the failure rate is independent of time; the second segment is a continuation of the first but with a discontinuity in slope after which the failure rate linearly increases with time. Both the rate of increase and the location in time at which the break occurs are characteristic of the component.

System aging is the sum of failure rates of its components for each time step only in the special case of non-redundant systems. If a system is redundant, it ages at a rate that is the train aging rate raised to the power of the redundancy. For example, a system composed of three redundant trains each of which ages at a rate of 10%/year, will have a system aging rate of 30%/year. (This system effect is discussed further in Higgins, 1988). Because systems, not individual components, protect the public safety, aging analysis should be performed in a system context.

The first major modeling of two nuclear power plant, their systems and components to determine their risk and the reliability of the safety systems was WASH-1400. This was followed by further PRA methods development, PRA applications to regulatory issues and PRAs for many power plants. (Fullwood and Hall, 1988 provides a review of PRA development in this period.) A major

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development in improving the quality of PRAs is the NUREG-1150 study for the analysis of which, PRAAGE-1988 is designed.

The Reactor Risk Reference Document, NUREG-1150 provides the results of major risk analyses to five different US plants (Surry, Zion, Sequoyah, Peach Bottom and Grand Gulf) using state-of-the-art methods. This work provides a data base and insights to be used for a number of regulatory applications: 1)Implementation of the NRC Severe Accident Policy Statement, 2) implementation of NRC Safety Goal Policy, 3) consideration of the NRC Backfit Rule, 4) evaluation and possible revision of regulations or regulatory requirements for emergency preparedness, plant siting, and equipment qualification, and 5) establishment of risk-oriented priorities for allocating agency resources.

The work presented here is a further application of the NUREG-1150 work by applying these system models to the investigation of aging in the residual heat removal system (RHR) at Peach Bottom -the oldest of the plants analyzed in NUREG-1150. Because of the quality of the PRA work in the NUREG-1150 models, one of the ground rules for the work presented here was to accept the PRA system models without modification in the form of system cutsets (Fullwood and Hall, 1988). The PRA system models are described in NUREG/CR-4450 and were provided to us along with the probability data by the Sandia National Laboratory. This information was transferred to a floppy disk for use in an IBM-PC and constituted the default data to be replaced by nuclear power plant experience data showing aging effects when obtainable from a companion study, Lofaro 1988 included in these papers.

Higgins, 1988 used an early version of PRAAGE (called PRAAGE-1987) for modeling the CCW system at Indian Point based on the Indian Point Probabilistic Safety Study (IPPSS). PRAAGE-1987 took advantage of certain symmetries in the cutsets to implement them in a unique, compact matrix format. While this worked well for this particular case, the method is not generally applicable and a major thrust of PRAAGE-1988 was a code that could operate directly with cutset input.

The organization of this paper is the introduction, just presented, the next section describes the design criteria for PRAAGE-1988. Section 3 presents structure of PRAAGE, section 4 describes how to use the code and section 5 presents results from its application to the RHR system in the LPCI and SDC modes of operation.

2. Design Criteria for PRAAGE

PRAAGE-1988 was designed on the bases of the experience with PRAAGE-1987 to include additional enhancements for current aging work. The principal criteria were:

- Perform an accurate analysis of the affects of aging of the Peach Bottom RHR system,

- Accept aging data in the bilinear form found to be necessary as reported in Higgins, 1988,

- Include any test and maintenance models that are developed in the data modeling,

• Be easily converted to analyzing the aging of other systems for which cutset and data block information are available. Easy convertability is taken to mean that it can be done in a few hours or less.

• Minimize the manual inputting of data,

• Be operable on all grades of IBM and compatible personal computers using the MDOS operating system with a disk drive and graphics adapter.

• User friendliness by instructing the operator and providing default values which the operator may choose to modify.

• Perform the calculations rapidly enough that the operation may be considered interactive. The current longest computation time is 30 seconds in which the unreliability, normalization and all the necessary importance information is calculated.

• Perform generic groupings of components. This is needed because component specific data are not available and such a large number of components is difficult to manipulate and interpret. Presently PRAAGE is dimensioned for 20 generic components. Generic components may be grouped by any ANDing and/or ORing of the four-element component name identifiers. The search mask for generic component construction is constructed in this fashion to assist the operator and avoid the possibility of typographical errors which would result in no component selection. PRAAGE assumes that the operator will select the generic components of present concern but that these selection may not include all components. Those components omitted are grouped as a "residual" generic component and treated the same as those specifically identified i.e. subjected to the aging and T&M models as will probability modification as a group.

• Allow individual component probability modifications.

• Record the parameters used in an aging analysis and the results,

• Print numerical and textual results,

• Provide graphical displays and printed output.

All of these criteria were met with the exception of test and maintenance modeling (T&M). This is a very complex problem because the aging data obtained from nuclear power plant experience reflects the effects of the T&M that is performed on each component in each plant. To introduce an explicit T&M model into PRAAGE would require that the effects of T&M be removed from the data and a generic T&M model be developed and applied in the system model.

Other limitations in current PRAAGE (which may be circumvented if need be) are:

• PRAAGE-1988 operates in the small probability approximation. This means that it will not calculate accurate results if probabilities are set to "1" as is commonly done to simulate a component outage. (This feature was provided in PRAAGE-1987 but was not used in PRAAGE-1988 for reasons of calculational simplification. Its inclusion would increase the code complexity and running times.)

• The data input to the cutsets are probabilities - not failure rates. If a component is modeled as failing during a mission time, the failure rate must be multiplied separately by the mission time. (PRAAGE-1987 identified and accepted both types of data and performed the necessary multiplication when needed. It will probably be necessary to modify the data representation if the T&M module is implemented.)

• The maximum problem sizes used to data sizes are 701 cutsets, 134 components, 20 generic components, and six time steps but the ultimate limitations have not been explored. It is likely that if overlay techniques are used in the code that much larger problems can be analyzed.

3. Structure of the Code

Figure 1 shows the computational flow that takes place in PRAAGE. The basic input information is obtained by down-loading a data block and the cutset

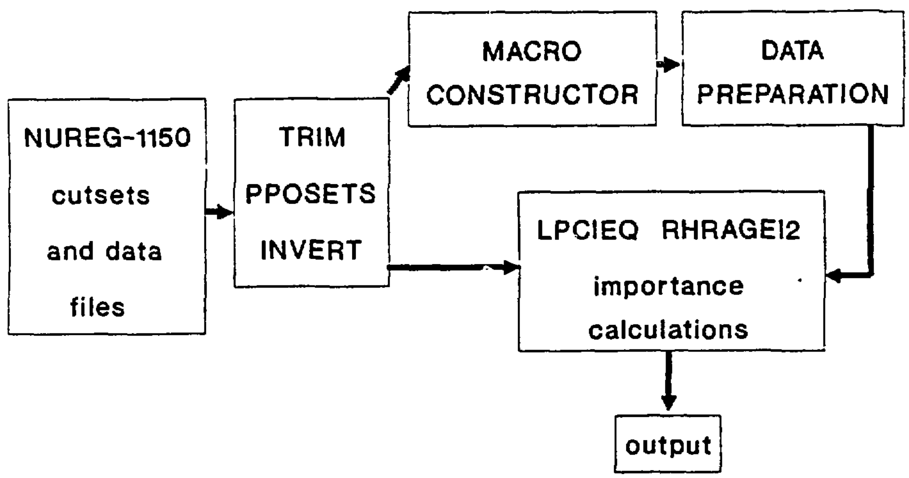

Figure 1
Computational Flows in PRAAGE

results from a SETS (Worell, 1985) code analyses of the fault trees representing the RHR mode being studied. The data block contains probability data (not failure rate) for 384 components. The 4 configurations of the RHR system are: LPCI, SDC, RHR and CSS. This work studied LPCI, which has 494 cutsets using 127 components and SDC which has 701 cutsets involving 134 components. Since memory requirements are a paramount concern in personal computer programming, the extraneous data is removed by the independent preprocessing code TRIM.

The new data block containing only data for the components in the cutset block being processed are stored on floppy disk to provide the input to PPOSETSI (Post Processor of SETS, Indexed). PPOSETSI converts the component names and the component probabilities into indexed variables, p[i,1][1], and nam(i), respectively, for array processing. Beginning with the name of the first selected component, PPOSETSI looks at each component name in each cutset. If a match is detected, the cutset is modified by replacing the 16 character name with p[i,j]. This process continues until the whole equation block has been converted into a form using indexed variables. PPOSETSI goes a step further and decomposes the original cutset block which is one long equation into many separate equations - one for each cutset. This transformation is performed automatically to produce programming in the Pascal language. These many new equations are stored on floppy disk for reading into LPCIEQ which does the processing of the equations. In this sense PPOSETSI is a program that actually writes some of the Pascal programming language used in the LPCIEQ computer program.

PPOSETSI is followed by INVERT which takes the cutset file with the components identified by number and determines the cutsets in which a component appears. The results of this is to provide a directory to LPCIEQ for the grouping of cutset values to form the importances.

The cutset transfer to LPCIEQ is done in a very unusual fashion. The equations cannot be read in as string variables because these are programming instructions for LPCIEQ. The manner of entry is to read them into the LPCIEQ program as a block transfer in the editor mode. Further discussion of LPCIEQ will be deferred until completion of the discussion of the macro construction and data preparation.

The macro constructor code (MCROCON1) groups similar components for common treatment. A component name in the NUREG-1150 format is made up of 4 elements or subnames. These four subnames for the component respectively represent the system it is in, the dominant failure cause, the dominant failure mode and a unique identification for the component. MCROCON1 requests a name for the generic component and then lets the operator construct the generic component by ANDing and ORing the contents of each selected column. When the operator indicates completion, all components not selected for one of the generic groups are placed in the "residual" group. This is a fairly lengthy selection process, not to be frequently repeated, so the generic component groupings thereby constructed are saved to disk where they can be reused without having to repeat the generic grouping process. MCROCON1 also offers a simpler assembly process by selecting on first subname which is the system identification. There is good physical reason for the use of system groupings but it is also faster then individually tailoring the groupings and was very convenient for code development.

This menu also provides for a printout of generic component groupings but this is actually the compressed file used for generic component storage and transfer and is not easy to understand. So far, there has been no reason to make it more user-friendly but it is retained for its usefulness in code diagnostics. The first number indicates the number of components, next the number of generic

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[1] The "i" index is the component designator; the second, "j" index, is the time designator for use in the aging analysis. Since PPOSETSI sets up the component probabilities for the components when new, the time index is set to "1".

components, then by the number of components in each group, by the component identifying numbers in each group and finally by the names of the generic components. If the first column construction method of generic component construction is selected, the name of the generic component is the same as the search mask.

This generic component code is passed to the data preparation code (DATAPREP) which allows the modification of the probability of failure at startup time (t = 0, j = 1) for each of the components by directly changing the values. The operator may modify the failure probabilities of all of the components in a group by the multiplication of their values by a common multiplier. (A common multiplier produces a proportional change even if the absolute value of each component probability is different). The parameters for each aging model are specified by the analyst in an interactive process. When aging model preparation is selected, the analyst is requested to select a generic component for aging model preparation. Then the analyst is requested to input the time at which aging starts followed by the aging slope in percent per year. This process is repeated until all generic components subject to aging have had their model specified. If no aging model is specified, it is assumed there is no aging (the aging slope is set to zero).

After the aging models have been specified, they are not automatically applied to the time zero probabilities but the analyst is required to order their incorporation. This is done to allow the analyst a last opportunity to modify the data. However to perform the aging analysis, the models must be implemented which results in the construction of the component failure probabilities for each time step. (The time steps are 0, 2, 5, 10, 20, and 50 and cannot presently be changed by the analyst without recompiling the code). These time dependent failure rates may be stored on floppy disk for use by LPCIEQ.

LPCIEQ may retrieve the time-dependent probability data as well as the generic component descriptor data from floppy disk or LPCIEQ may access the data from memory. If the latter is the case, it is necessary precede the running of RHRAGE by selecting and running MCROCON1 and DATAPREP.

LPCIEQ is rather slow starting (requiring about 30 seconds) because the code is calculating all 494 or 701 cutset equations involving 127 or 134 components for six aging times and executing a complex assembly process to construct the Birnbaum and Inspection importances. Upon completion, the remaining operations are very fast because the code is only grouping importances for the individual components into the generic component groupings and performing the necessary computations for the importance measure selected. When the calculation is complete, the results are automatically displayed. The results can be displayed, printed, graphed or saved to disk. The graphs may also be reproduced on a dot matrix printer.

4. Using PRAAGE-1988

Table 1 lists the present contents of the PRAAGE-1988 distribution disk. It is written in Turbo Pascal 4.0 (TP4 by Borland International). This code is considerably different from Turbo Pascal 3.0 which was the language used for PRAAGE87 as reported in Higgins, 1988. A major change in the codes was in discontinuing chaining and overlays in favor of "units". This is done by setting up an executive code, PRAAGE2.exe with a "uses" statement that names

Table 1
List of Codes Comprising the PRAAGE Ensemble
RHR/SDC Mode

Name	Size (kilobytes)	Purpose
PRAAGE2.exe	132608	Main program calling units
MAINTITL.tpu	1664	Global data file
MCROCON1.tpu	12736	Performs generic groupings
DATAPREP.tpu	21456	Data edit, aging and T&M
LPCIEQ.tpu	70608	Computes the cutset equations
RHRAGEI2.tpu	21600	Importance assembly and graph
GENCOMP1	660	Generic component identification
INVBLOK.pas	8491	Inverse file
NAM1PREP.PAS	104	First column component name
NAM2PREP.PAS	121	Second column component name
NAM3PREP.PAS	133	Third column component name
NAM4PREP.PAS	715	Fourth column component name
NAMBLOK	2093	Full component names
DATBLOK	3939	Default time zero data
AGEPDAT1	21802	Aging data file
BANNER.exe	47840	Title and synopsis
PRAAGE.bat	43	Calls BANNER and PRAAGE2

the "units" that it uses. Units can also use other units. These are compiled codes designated as "TPU" for Turbo Pascal Unit that contain a public section declaring variables and subroutines accessible to programs that have the units name in the uses statement. When the disk is loaded, the user simply types "PRAAGE". This calls PRAAGE.bat - a batch file which calls "BANNER.exe". This displays a full screen sign stating "Brookhaven National Laboratory presents PRAAGE - PRA applied to Aging"which is followed by a synopsis of the code. On a key press, the main program, PRAAGE2.EXE, is called. It calls MAINTITL.tpu to present a default problem title and request for identification of the default path and drive. With this information, it presents the main menu shown as Figure 2. These tasks may be performed in any order but if they are performed out of sequence, they use results stored from previous runs. If it is an entirely new

```
                MAINMENU
Select the Tasks to be performed for:
          the NUREG-1150 Peachbottom RHR/SDC Aging Study
================================================================
     1    Define the Generic component Groupings

     2    Modify Individual or Generic component Groups,
              Aging and Test and Maintenance Models

     3    Compute, Display, Print and Graph Age Dependent
              System Unavailability and Generic Component
              Importances

     4    Quit


Select the Number of the Task to be Performed
```

Figure 2
The Main PRAAGE-1988 Menu

```
            Generic Component Menu
==============================================================

   1:  Construct Generic Component Grouping
   2:  Construct Grouping from First Column of Component Id.
   3:  Record the Constructed Groupings
   4:  Print the Constructed Groupings
   5:  Leave the Generic Component Construction

       Select the Number Identifying Your Job
```

Figure 3
Generic Component Construction Menu

problem, they must be run in sequence. If task 1 is selected, the menu shown in Figure 3 will bepresented. Only the first 2 tasks are actually used in generic component definition. By far the most versatile is selection 1. If this is selected, PRAAGE asks for a name for the generic component which may contain 12 characters. Then the Figure 4 menu is presented in which a dialogue takes

```
      Construction of a Generic Component (x1x-x2x-x3x-x4x)
  ------------------------------------------------------------
  What component i.d. position do you want to key on?
  1
  1 ACP, 2 CSS, 3 DCP, 4 DGACTA, 5 DGACTB, 6 DGACTC, 7 DGACTD,
  8 ECW, 9 EHV, 10 ESF, 11 ESW, 12 HSW, 13 IAS, 14 LCI,
  15 RBC, 16 RHR, 17 SDC, 18 LOSP,
  Select part of the Generic Component Mask
  1
  You selected,"ACP", is that correct? (Y/N)
  Do you wish to "and" this with another identifier? (Y/N)
```

Figure 4
Menu for Forming a Generic component by ANDing and ORing

place between the analyst and the code. To understand the meaning refer to Figure 5 showing typical names for the components in the model. As stated earlier, the first column is the system designator, the second column is the cause, third, the mode and the last column is the unique identifier. In the dialogue shown, the analyst indicated to key on the first subnames. Then PRAAGE displayed all of the first subname designators and the operator selected "1" from this list. PRAAGE responded by saying that ACP (AC power) was selected and asking if this is correct. When the operator replied "Y" for yes, PRAAGE asked the operator if he wished to AND this with another designator. When the operator said "N" (no), PRAAGE displayed the information shown in Figure 6. After the display, PRAAGE asked the analyst if he wanted to OR the designator with something. If he said yes, then he could perform further ANDing operations to construct a composite mask using these logical operations. In this case, the operator said no and PRAAGE asked if another generic component is to be constructed. If he had said yes the whole process would have been repeated starting with a name for the generic component. Since no was designated, the construction process was ended. But note only a few components were included

ACP-PHN-LP-ESWG
ACP-TAC-LP-EDG1
ACP-TAC-LP-EDG2
ACP-TAC-LP-EDG3
ACP-TAC-LP-EDG4
CSS-MOV-MA-MV26A
DCP-BAT-LP-A2
DCP-BAT-LP-B2
DCP-BAT-LP-C2
DCP-BAT-LP-C3
DCP-BAT-LP-D2
DCP-BAT-LP-D3
DCP-INV-LP-24C
DCP-INV-LP-24D
DCP-PHN-LP-BATR
DCP-REC-LP-2
DCP-REC-LP-4
DGACTA
DGACTB
DGACTC

Figure 5
Four Subname Component Naming Used in NUREG-1150

```
      Construction of a Generic Component (x1x-x2x-x3x-x4x)
----------------------------------------------------------
What component i.d. position do you want to key on?
1
1 ACP, 2 CSS, 3 DCP, 4 DGACTA, 5 DGACTB, 6 DGACTC, 7 DGACTD,
8 ECW, 9 EHV, 10 ESF, 11 ESW, 12 HSW, 13 IAS, 14 LCI,
15 RBC, 16 RHR, 17 SDC, 18 LOSP,
Select part of the Generic Component Mask
1
You selected,"ACP", is that correct? (Y/N)
Do you wish to "and" this with another identifier? (Y/N)
--------Generic Name: acp Consists of:--------------------------
Components selected are: 1 ACP-PHN-LP-ESWG
Components selected are: 2 ACP-TAC-LP-EDG1
Components selected are: 3 ACP-TAC-LP-EDG2
Components selected are: 4 ACP-TAC-LP-EDG3
Components selected are: 5 ACP-TAC-LP-EDG4
Components selected are: 135 ACP-BAC-LP-416A
Components selected are: 136 ACP-BAC-LP-416B
Components selected are: 137 ACP-BAC-LP-416C
Components selected are: 138 ACP-BAC-LP-416D
No. of acp  items selected: 9
Do you want to "OR" with other selections as the same generic component (Y/N)
Do you want to construct another generic component? (Y/N)
```

Figure 6
Display of the Components Selected by the First Subname,
First Designator Mask

in the generic components defined. To avoid losing information, PRAAGE assigns the remaining components to a generic component called "Residual" so the minimum number of generic components is two.

If the operator had selected 2 in the generic menu, the screen would blink and state that the first column construction (i.e. system groupings) is complete.

In the laborious process of building the generic components by AND and OR groupings, the operator will probably want to save these definitions on disk. This is done by selecting item 3 in the generic component menu (Figure 3). If item 4 is selected (print the generic groupings), a rather cryptic printout results. The first number is the number of components, the second number is the number of generic components, The next number-of-generic component lines provide the decoding of the following string listing the numbers of the individual numbers of the components in the groups. This is followed by the names of the generic components that have been assigned.

Leaving the menu is executed by selecting "4" from the generic menu which returns to the main menu (Figure 2). Following the sequence, the operator selects "2" to modify the component probability data. The purpose of this menu (shown in Figure 7) is not just to edit data, inject the aging or T&M but it also

Individual and Generic Component Modification Menu

```
1:  Modify Components in Generic Component Groupings
2:  Modify Individual Component Probabilities in PRA Order
3:  Modify and Prepare the Aging Models
4:  Modify and Prepare the Test and Maintenance Models
5:  Implement Aging into the Probabilities
6:  Implement Test and Maintenance into the Probabilities
7:  Record the Time Dependent Probability Data Base
8:  Display the Time Dependent Probability Data Base
9:  Print the Time Dependent Probability Data Base
10:  Leave the Component Modification
```

Figure 7
Data Modification and Aging Model Menu

creates the remaining probabilities for the time steps. If this is not done RHRAGE will fail. If task 1 is selected, the editing is convenient by dealing with the components according to the generic component definitions. This results in the menu shown in Figure 8 being displayed. This lists the names of the generic components what were previously constructed. The operator can change selected generic components change in whatever order he chooses or if most of them will be changed, he can select "C" for cycle and it will cycle through the names thereby obviating the need for designating individual names. When a name is selected, the menu in Figure 9 is displayed showing not only the component name but also the current probability value. If the operator chooses to change these as a group, he enters a multiplier (positive but may be greater or less than one) and PRAAGE responds with a new menu displaying the effects of the operator's modification. If the change is wrong, it can be corrected by

```
          The Generic Component Names Are:
=====================================================

1 ACP    2 CSS    3 DCP
4 DGA    5 ECW    6 EHV
7 ESF    8 ESW    9 HSW
10 IAS    11 LCI    12 RBC
13 RHR    14 SDC    15 LOS

Select Number of Individual Generic Component for Change
Or Type "C" to Cycle Or  Type Q to Quit
```

Figure 8
List of Generic Component Names for Selecting Data Modification

```
Generic Component No.1 named ACP Is Composed Of:
============================================================

1 ACP-PHN-LP-ESWG    1.0E-0002;
2 ACP-TAC-LP-EDG1    2.2E-0002;
3 ACP-TAC-LP-EDG2    2.2E-0002;
4 ACP-TAC-LP-EDG3    2.2E-0002;
5 ACP-TAC-LP-EDG4    2.2E-0002;
135 ACP-BAC-LP-416A    1.1E-0005;
136 ACP-BAC-LP-416B    1.1E-0005;
137 ACP-BAC-LP-416C    1.1E-0005;
138 ACP-BAC-LP-416D    1.1E-0005;

Select # and Enter New Probability in "E" or 0.xx Format or "G"
for Generic Multiplier, "Q" to Quit, or "N" for Next Cycle
```

Figure 9
Component Names Contained within a Generic Grouping
The Analyst Selects the Number of a Component whose Value is to be Changed

multiplying by the reciprocal of the previous change.

If it is necessary to change a probability value within a generic grouping, the operator may select "2' from the data modification menu and a listing of components by number, name and probability value is presented (not shown). From this, the operator selects the number of the component for modification. If this is done, PRAAGE repeats the old value and requests a new value in real format as shown in the menu. If a typo such as a letter is typed, a notice is displayed to retype the number. If integer format is used, no warning is displayed and no change is made. Then the values of the un-aged probabilities are as desired, PRAAGE returns to the main data modification menu and the operator designates task 3 to inject the aging models.

This results in the menu shown in Figure 10 being displayed (this Figure is the composite of considerable dialogue) and the operator is asked to designate a generic component for age modeling. In this case the operator chose item 1 and PRAAGE answered back that ACP was selected and asked for confirmation. PRAAGE then asks for the time that aging begins. The operator responds in real format and PRAAGE repeats the entry so the operator can check it. PRAAGE then asks for the slope of the aging ramp in fractional (not percent) change per year in real format. The operator responds and PRAAGE repeats the response and asks the operator is another aging model is to be constructed for some other generic component. If the answer is no PRAAGE returns to the main data modification menu.

When PRAAGE is finished, undoubtedly, the operator will want to enter a T&M model but since this has not been done it will not be discussed.

Before leaving the data modification menu, it is essential that aging be

```
                 The Generic Component Names Are:
==============================================================

1 ACP    2 CSS    3 DCP
4 DGA    5 ECW    6 EHV
7 ESF    8 ESW    9 HSW
10 IAS    11 LCI    12 RBC
13 RHR    14 SDC    15 LOS

Select a Generic Component for Age Modeling Or  Type Q to Quit
1
You Selected No. 1 named ACP
When Does the Aging Ramp Begin? (years from startup, x.x)
5.0
What is the Slope of the Ramp? (fraction/year, x.x)
0.1
You Specified Start  5.0E+0000 and Slope  1.0E-0001
Do You Want to Prepare Another Model?
```

Figure 10
Implementing an Aging Model

implemented into the failure probability data to cause construction of all but the time zero probabilities which come from the data base as modified by the analyst. This is done by selecting tasks 5 and/or 6 in the main data modification menu. If task 7 is selected, the time dependent probability data will be saved to disk under a name of the operator's selection or a default name may be used.

If the operator wishes to see the data that will be used in RHRAGE, he selects task 8 and a printout results as sample of which is shown in Figure 11.

After the printout and return to the main data modification menu, the operator selects "9", returns to the main menu and selects "3" to go to RHRAGE for the importance calculations. After some preliminary questions the main importance menu is presented (Figure 12). Seven importance measures are displayed for selection. (Percent unavailability contribution per component as done in PRAAGE-1988 is not implemented.) In this figure, the analyst selected "2" for the Inspection Importance. Nearly immediately (since the individual importances were precalculated) the importances are displayed as shown in Figure 14. If the operator decides to print out the results, task 8 is selected from the main importance menu. If plotting is desired, task 9 is selected to result

The Age Dependent Probabilities Are: Prob. No./Initially		2nd Year	5th Year	10th Year	20th Year	50th Year
1	1.0E-0002	1.0E-0002	1.0E-0002	1.5E-0002	2.5E-0002	5.5E-0002
2	2.2E-0002	2.2E-0002	2.2E-0002	3.3E-0002	5.5E-0002	1.2E-0001
3	2.2E-0002	2.2E-0002	2.2E-0002	3.3E-0002	5.5E-0002	1.2E-0001
4	2.2E-0002	2.2E-0002	2.2E-0002	3.3E-0002	5.5E-0002	1.2E-0001
5	2.2E-0002	2.2E-0002	2.2E-0002	3.3E-0002	5.5E-0002	1.2E-0001
6	8.0E-0004	8.0E-0004	8.0E-0004	8.0E-0004	8.0E-0004	8.0E-0004
7	1.3E-0003	1.3E-0003	1.3E-0003	1.3E-0003	1.3E-0003	1.3E-0003
8	1.3E-0003	1.3E-0003	1.3E-0003	1.3E-0003	1.3E-0003	1.3E-0003
9	1.3E-0003	1.3E-0003	1.3E-0003	1.3E-0003	1.3E-0003	1.3E-0003
10	1.3E-0003	1.3E-0003	1.3E-0003	1.3E-0003	1.3E-0003	1.3E-0003
11	1.3E-0003	1.3E-0003	1.3E-0003	1.3E-0003	1.3E-0003	1.3E-0003
12	1.3E-0003	1.3E-0003	1.3E-0003	1.3E-0003	1.3E-0003	1.3E-0003
13	1.3E-0002	1.3E-0002	1.3E-0002	1.3E-0002	1.3E-0002	1.3E-0002
14	1.3E-0002	1.3E-0002	1.3E-0002	1.3E-0002	1.3E-0002	1.3E-0002
15	2.7E-0001	2.7E-0001	2.7E-0001	2.7E-0001	2.7E-0001	2.7E-0001

Press key for next page

Figure 11
Time Dependent Probabilities after Aging Implementation

Select Importance Measures for:
the NUREG-1150 Peachbottom LPCI Aging Study

1	Birnbaum Importance
2	Inspection Importance
3	Percent Unavailability Contribution
4	Unavailability Budget Contribution
5	Vesely-Fussell Importance
6	Risk Achievement Worth Increment
7	Risk Reduction Worth Increment
8	Print Selection
9	Plot Part of Selection
10	Print Component Unavailability Fract.
11	Quit Menu

Figure 12
Importance Measures Selection Menu

in a display such as shown in Figure 13. No provision for saving the results to disk has been made because the input data necessary for recalculation has been saved.

5. Description of the RHR System in the LPCI and SDC Modes

The function of the SDC mode of RHR is to remove decay heat during accidents in which the reactor vessel integrity is maintained. The RHR system is a two-loop system consisting of motor-operated valves (MOV) and electric motor driven pumps (Figure 14). There are two pump/heat exchanger trains per loop, with each pump rated at 10,000 gpm at a head of 20 psid. Cooling water is taken from the wetwell and flows through the heat exchanger for recirculation in the reactor vessel in the SDC mode. In the LPCI mode, water is taken from the reactor vessel and flows through the heat exchangers for recirculation in the reactor vessel. These two systems are fault tree analyzed in NUREG/CR-4450 but these fault trees are not exhibited because of space limitations in this paper.

Some modeling assumptions that were employed in the fault tree preparation are:

1) SDC system failure from misaligned valves is neglected.

2) The fault tree considers components being out of service for maintenance. This is only considered to be possible if there is double blockage for high pressure piping and single blockage for low pressure piping.

3) Pump isolation due to spurious faults is neglected.

4) The control circuitry is not modeled in detail.

5) The pumps are assumed to fail when the suppression pool reaches saturated conditions.

6) Failure due to a test-diverting flow is neglected because this mode is manually initiated and aligned.

7) A suction path must be available from either the suppression pool or the reactor vessel path to start a pump.

8) Failure of the suppression pool from random failure plugging of the strainers is neglected.

6. Using Nuclear Power Experience Data in the RHR Aging Investigation

After PRAAGE-1988 was working, it was tested by comparing its calculations with the same problem calculated by the SETS code for the system reliability which is the only parameter that both codes calculate. The agreement was extremely good. This was not surprising because both code work in the small probability approximation.

The next investigation was a study of the prioritization of components in the SDC and LPCI modes using the probability data from NUREG/CR-4450. (This was done before the BNL data investigation for the Peach Bottom RHR had been completed). Results from this are shown in Table 2. It will be noted that the dominant contributor to unavailability is the emergency service water system which may be regarded as external to the RHR. Table 3 is an examination of the LPCI with the effect of the supporting systems removed to exhibit the percent contributions to unavailability of components specific to the RHR in the LPCI mode. Table 4 shows a similar calculation for the SDC mode.
Lofaro et al. (in these proceedings) compiled nuclear plant experience data to determine the aging rate as well as new non-aging failure frequencies. These are shown in Table 5. This results in the aging of the generic components as shown in Figure 13 and in the RHR system reliability aging (LPCI mode) shown in Figure 15.

Table 2
Component Importances: LPCI Mode using PRA Data

System/Component	Percent of Unavailability
ESW System:all modes	53%
Pressure/Level Sensors: miscalibration	18
MOVs: failure to transfer	7.9
MOVs: out for maintenance	5.0
Pressure Sensor: loss of function	4.1
Ventilation System: all modes	3.9
Diesel generators: failure to start	1.3
AC Power: all modes	0.9
Level Sensor: loss of function	0.4
Pipe Segment Fault	0.3

Table 3
LPCI Mode Component Importance using PRA Data

Component: Failure Mode	Percent of Unavailability
Sensor: miscalibration	48%
MOV: failure to transfer	23
MOV: out for maintenance	15
Pressure Sensor: loss of function	12
Pipe Segment Faults	1
Others	1

Table 4
Component Importances: SDC Mode using PRA Data

Component: Failure Mode	Percent of Unavailability
MOVs: failure to transfer	56%
Pressure Sensors: loss of function	24
MOVs: out for maintenance	12
MOVs: limit switch failure	3.7
Sensors: miscalibration	1.9
RHR Pumps: failure to start	0.54
RHR Pumps: failure to run	0.4
RHR Pumps: out for maintenance	0.3
Other	1.2

Table 5
BNL Analysis of Failure Probabilities

Component	PRA mean value	BNL mean value	BNL maximum value	Aging Rate %/year
MOV: failure to transfer	3.8E-3	1.0E-5	1.3E-3	0.11
Pressure Sensor: loss of function	2.5E-3	6.0E-4	8.4E-4	0.02

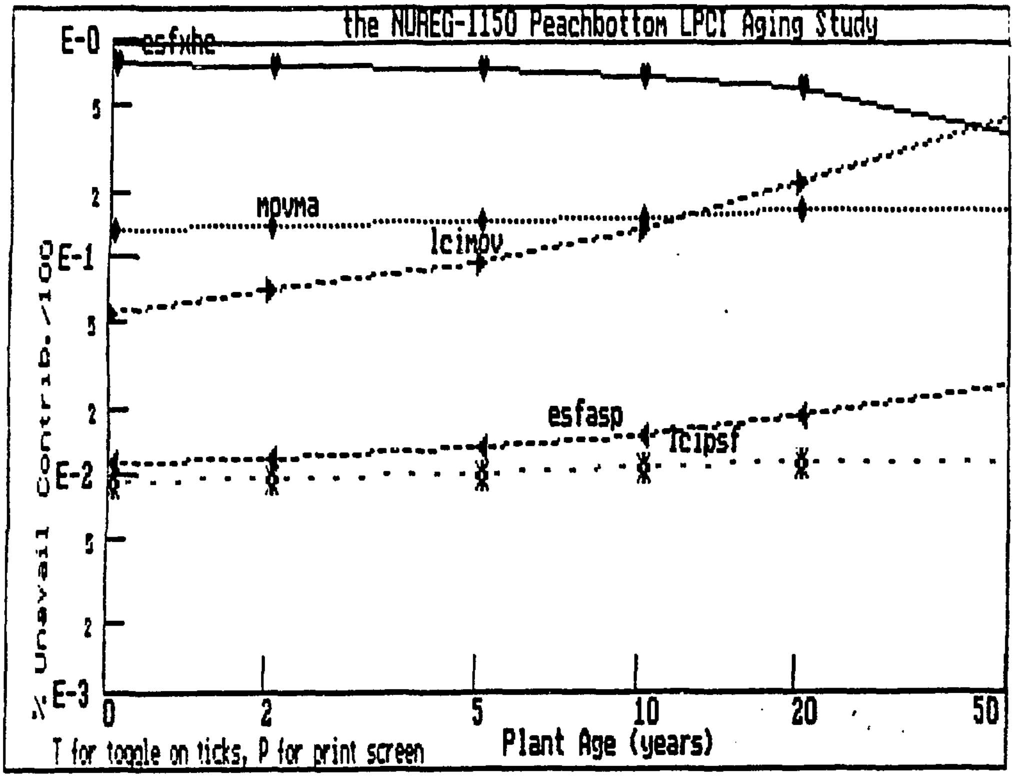

Figure 13
Copy of PRAAGE-1988 Graphical Output in Low Resolution
(Acronyms are: esfxhe - engineered safety features (ESF) human errors, movma- MOV out for maintenance, lcimov - LPCI MOV, esfasp - ESF pressure sensor and lcisf - LPCI pipe section.)

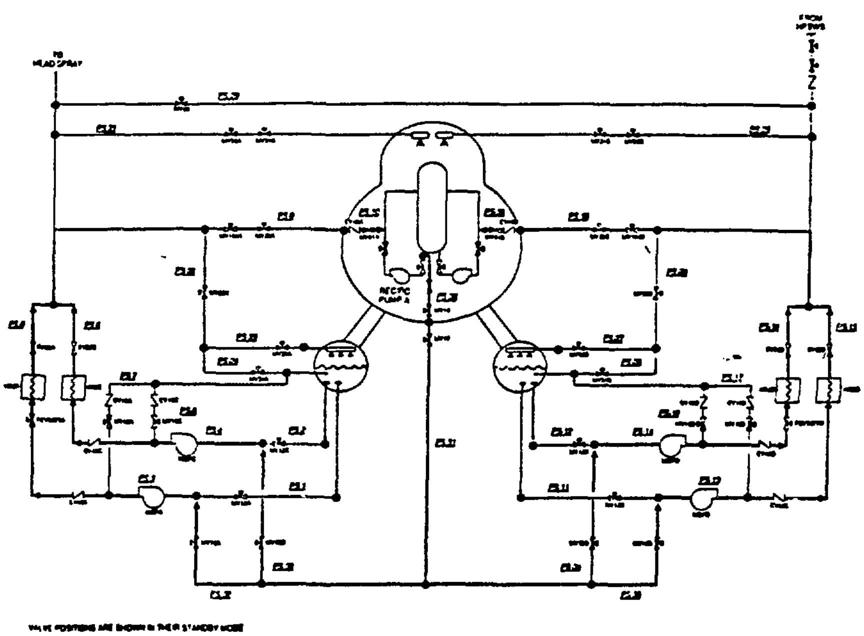

Figure 14
Simplified Schematic of the Residual Heat Removal System

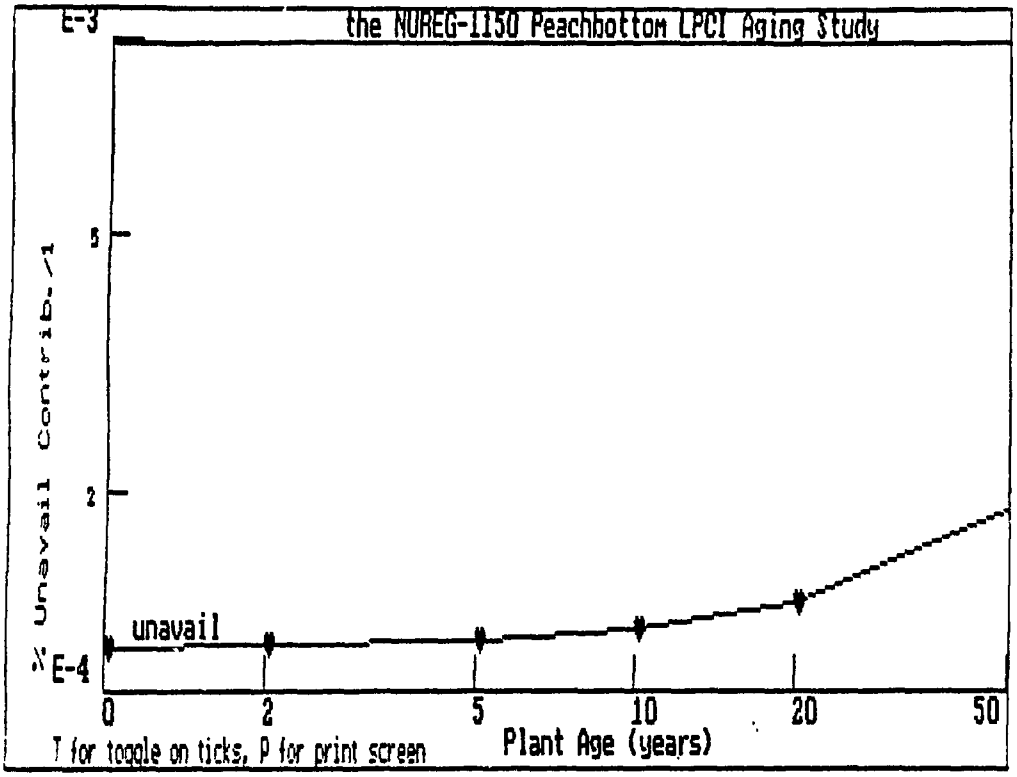

Figure 15
The Effects of the Aging of the Components shown in Table 3
on the RHR System in the LPCI Mode

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