RELIABILITY ANALYSIS OF NUCLEAR POWER PLANT PROTECTIVE SYSTEMS

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PREFACE

Much has been said about the safety of nuclear reactors compared to other facilities of modern industry. In fact, the safety record of the nuclear industry is without parallel. But we dare not be complacent for the fact remains that a large nuclear plant contains within itself an immensely significant amount of radioactive material. Thus, we must not relax; rather, we must continue to press for better understanding, better control of safety. Perhaps we can go so far as to quantify the notion of safety. That is, perhaps we can learn to provide definitions and rules by which one can arrive at a numerical figure of merit indicating the level of safety of a particular plant. Or, perhaps it will be a small cluster of figures of merit which collectively tell the story. Any quantification of this sort will be an aid so that people (designers, operators, regulators) can make better judgments of merit and risk, so that they can more rationally decide for or against various designs, sites, and operating procedures.

How then does one go about making precise and quantifying so vague a concept as that of level of safety? Clearly, the concept involves knowledge of the origins, likelihoods, and consequences of accidents. And clearly, it involves knowledge of routine and expected, though random, wearing out and failure of equipment and personnel. Such knowledge in turn derives from study and understanding of the basic physical phenomena and of the particular system in question. It derives also from study of the experience record of systems and facilities already in being. Assuming the concept of level of safety can be defined in crisp mathematical terms, we will still need the input, the basic physical data, the probabilities of component failure, and so on. Thus, we need two things: clarification of concept and collection of actual operating data.

In the present study and those preceding it, ^(1, 2, 3) we have taken steps to satisfy both these needs. We have gathered information, and we have identified and experimented with methods of interpreting and synthesizing the information into a quantified measure of safety. We have made detailed recommendations for a reliability monitoring program - for better methods of collecting and interpreting pertinent safety, reliability, and availability information.

The task has been a tedious one involving sifting, searching, and analyzing hundreds of in-plant records including instrumentation and equipment logs, maintenance work orders, and all manner of control room logs. It included lengthy discussions with utility executives, plant superintendents, plant engineers, operators, maintenance personnel, government employees, and design personnel. It involved many different plants, manweeks of effort to reconstruct plant systems in diagram form, data compiling and analyzing, and writing, writing, and writing. It was approached in this manner because all the easy ways seemed to lead to nothing. Like good design, good safety is based on details. It is based on knowing the day-to-day problems of plant operation. It is based on observing first-hand the recording and handling of data. Only this provides a solid foundation for a more quantitative basis for safety evaluations.

Finally, we must ask ourselves how the results of greater quantification will be revealed in the day-to-day practice of nuclear safety. Obviously, there will be direct benefits. Much needed reliability data will be generated. This data will serve as the grist for many

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- (1) B. J. Garrick, W. J. Costley, and W. C. Gekler, "A Study of Test Reactor Operating and Safety Experience," HN-172 (Vols. I and II), U. S. Atomic Energy Commission, May 1963.
 - (2) B. J. Garrick, W. C. Gekler, J. M. Duncan, R. H. Karcher, and B. Shimizu, "A Study of Research Reactor Operating and Safety Experience," HN-180, U. S. Atomic Energy Commission, June 1964.
 - (3) B. J. Garrick, W. C. Gekler, and H. P. Pomrehn, "An Analysis of Nuclear Power Plant Operating and Safety Experience," HN-185 (Vols. 1 and 2), U. S. Atomic Energy Commission, December 1966.

other activities. Statistical bases will arise to more clearly define the performance of equipment. Industry norms will be established for comparing equipment and isolating unsatisfactory reliability performance. Test frequencies will be related to statistical expectations and we can approach ever closer to recognition of the underlying statistical distributions which give rise to the observed behavior.

We should also look for indirect benefits, not the least of which will be the enhancement of reliability analysis as a safety tool. Reliability data will permit this technique to be used in quantifying system reliability and establishing the relative importance of various components to system reliability. This knowledge can, in turn, provide a valuable lever for improving and controlling safety. Systems offered for the same safety function will be compared on the basis of expectation as well as capability. Physical modifications and procedural changes which improve the reliability of a system will be identified. Ultimately we will arrive at the goal of a figure of merit to quantify safety.

It is our hope that this work will be used to realize these and other benefits and thereby further increase our understanding of safety.

B. John Garrick
Study Director

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ABSTRACT

Data and analytical requirements for a reliability monitoring program in nuclear safety have been identified. A data management system is defined incorporating a method for equipment and event classification and a plan for data collection. Equipment classification is accomplished by use of a 9-digit generic code which identifies equipment type, environment, and operating load. The event classification provides coded identification of failure mode, effect, and cause, as well as an index of accumulated experience.

The data collection plan uses a two-step recording process to enable use of existing plant practices and operating staffs. The first step entails in-plant recording of failure or repair data and operating and test data. The second step requires transferral of operating and failure data to coded input for a centralized data bank. Subsequently, data bank processing will convert and report accumulating experience as failure rate and repair data.

The accuracy and flexibility of the Automatic Reliability Mathematical Model (ARMM) technique has been increased for evaluation of the reliability of engineered safety systems. A computer program, Systems Analysis by Fault Tree Evaluation (SAFTE-1), has been developed to implement the fault tree concept.

Applications of both techniques to sample problems using estimated or available reliability data demonstrate that they provide useful reliability estimates. Results of these applications show that the quality of these estimates is determined more by the analyst's skill than the limitations of the techniques. It is revealed that the questioning and documentation process required in preparation for quantitative reliability estimates is of value in identifying potential trouble spots and suggesting procedural or design changes which can eliminate or reduce the adverse effects of component failures on safety.

It is concluded that reliability analysis can contribute to a more quantitative, systems-oriented measure of safety; techniques adequate for safety analysis of nuclear power plants now exist; the data necessary

to support these analyses can be obtained through the suggested data management scheme; and the resulting reliability monitoring program can be executed without need for expanding nuclear power plant operating staffs. It is recommended that the reliability monitoring program be instituted in operating nuclear power plants at the earliest possible date to enable the accumulation of data of quality appropriate to reliability analysis of engineered safety systems.

INTRODUCTION

In an earlier study⁽¹⁾ it was noted that the usefulness of reactor operating experience could be greatly increased if this data were collected in a form suitable for reliability analysis. An investigation has been made of data and analysis requirements for a reliability monitoring program in power reactor safety.

One objective has been the definition of a system for the collection and analysis of operating, maintenance, inspection, and testing data on components of engineered safety systems⁽²⁾. This data management system will provide currently unavailable input data for assessing engineered safety system reliability. A second objective has been the investigation of techniques for the evaluation of reliability and the application of these techniques to engineered safety systems typical of water-cooled and -moderated power reactors. The applications provide information about the form and type of data which would be required in an operating reliability monitoring program. They also serve to illustrate the expected results.

In this report, the material has been arranged in the order of consideration expected in the reliability monitoring program. That is, the requirements for a reliability data management system are outlined in Chapter 1. Methods for using data to assess reliability are discussed in Chapter 2. Finally, Chapter 3 illustrates steps required for the application of anticipated data to reliability models of selected engineered safety systems in recently designed water-cooled and -moderated reactors. While specific reliability analysis methods and engineered safety systems have been cited in this study, they are not intended to exclude other methods or systems which can be used in a given reliability analysis. Rather, these examples are meant to illustrate the requirements for establishing a program for evaluating and monitoring reliability in nuclear safety. A glossary is provided in Appendix G to indicate the meaning of selected terms used in this report.

(1) Garrick, B. J., W. C. Gekler, and H. P. Pomrehn, "An Analysis of Nuclear Power Plant Operating and Safety Experience," HN-185, U. S. Atomic Energy Commission, December 15, 1966.

(2) Engineered safety systems is now the preferred terminology for systems previously referred to as engineered safeguard systems; i. e., systems provided to prevent or mitigate various possible reactor accidents.

SUMMARY AND CONCLUSIONS

Reliability analysis can contribute to a more quantitative systems-oriented measure of safety. The techniques for analysis exist, having been tailored to meet the needs peculiar to safety analysis of nuclear power plants. The data necessary to support these analyses can be obtained through implementation of the data management scheme detailed in this report. The resulting reliability monitoring program can be executed without the need for expanding nuclear power plant operating staffs.

As noted in the Preface, a reliability monitoring program can benefit nuclear safety and the nuclear industry in many ways. Realization of these benefits is dependent on the effectiveness of the reliability monitoring program. Program effectiveness is, in turn, contingent on three factors: (1) the availability of suitable data; (2) analytical techniques which can describe system behavior; and (3) proper application of these data and techniques.

The requirements and techniques associated with proper treatment of each of these factors have been investigated and the results of this work are presented in this report in the form of a data management system, the review and development of two analytical techniques suitable to reliability analysis, and step-wise examples of application of these techniques and anticipated data to engineered safety systems.

DATA MANAGEMENT

In Chapter 1, a data management system has been defined for collection and evaluation of reliability data from operating plants and equipment manufacturers or vendors. This system consists of a method of classification and a plan for data collection which were derived from consideration of generally available data management systems in both nuclear and non-nuclear industry. The data classification concepts are based primarily on nonnuclear-oriented reliability programs while the data collection plan is strongly slanted to conformance with recording and reporting practices now used in nuclear power plants. The data classification system provides access to reliability data at the plant, system, or component level. It allows selective grouping for statistical searches or investigations of failure rate data as well as standardized format for reporting reliability data by system and generic component. Among

data requirements considered in the classification system are the mode, cause, and effect of failure and the repair time associated with each failure. To convert specific occurrences of failure into failure rate information, a use event classification is described which allows correlation of failure to accumulated use or age.

With respect to data collection, it has been found that current practices in operating power reactors should lend themselves readily to orderly collection and processing of reliability data. Furthermore, the effort associated with collecting this data should result in little or no increase in operating staff workload. Much of the required data is already called for in existing practices. Some modification of existing records and recording procedures may be required but the basic ingredient for success will be the establishment and adherence to good record keeping practices, many of which already exist in these facilities. Encouragement of such practices can be enhanced by illustrating the potential value of reliability data to those involved in its collection and by procedures which assure that resulting data will be handled in a manner that objectively and fairly serves the interest of the designer, manufacturer, operator, and the public. An information flow scheme which would assure proper use and dissemination of data from the reliability monitoring program is shown in Figure 1.

As proposed, the data collection plan entails a two-step recording practice with subsequent processing by a data reduction agency. The first step involves completion of failure or maintenance report forms only slightly different from those currently in use by the plant personnel normally reporting and recording maintenance. The second step involves transferral of the failure information on these forms as well as use data from operating and outage summary reports to reliability data loadsheets. This transferral can be accomplished by in-plant personnel after a brief training period or by a representative of the data collection agency during periodic plant visits. Subsequently, the loadsheet data would be reduced and reported as failure rate and repair data summary information. Such information would be directly applicable to reliability analyses of engineered safety systems. It also would be of some use to any nonsafety pursuit of improved plant or system availability.

ANALYTICAL TECHNIQUES

A number of mathematical techniques or machine codes have been investigated which can be used in evaluating engineered safety system

reliability. Two promising techniques utilized in aerospace applications have been examined in detail. They are the Automatic Reliability Mathematical Model (ARMM) and fault tree analysis. These techniques have been tailored to permit application to engineered safety systems.

The ARMM program possesses many attributes desirable in evaluating engineered safety system reliability. Among its capabilities are the simulation of redundancies, interdependence and mutually exclusive failure modes, and the operation of standby equipment. Results of an ARMM analysis include: (1) the probability of successful system operation; (2) each component's contribution to the probability of system failure; and (3) the failed component combinations which are major contributors to system unreliability. In the course of understanding and using ARMM, modifications have been made in program subroutines to better suit it to engineered safety system applications. These modifications are described in Chapter 2 along with identification of several other changes which, if made, would further improve the program. Perhaps the most important result of working with ARMM is recognition that its effectiveness is limited by the user's skill, especially in the initial applications.

Fault tree analysis is particularly appealing because it parallels reactor safety analysis practices. Fault tree analysis generates a logical statement of events which, in combination or separately, can lead to an undesired event, i.e., nuclear incident. The approach is to state the undesired event in real, measurable terms and subsequently identify the event sequences necessary and sufficient to cause the undesired event. The result is a gated logic (AND and OR gates) which identifies human errors, equipment malfunctions, and operating conditions necessary to the occurrence of an event. To enable use of fault tree analysis in nuclear safety, a computer program has been developed and written having the code name SAFTE-1 (Systems Analysis by Fault Tree Evaluation). SAFTE-1 is a computerized probabilistic model of the logic which allows simulation of system operation through a large number of trials in a short period of time to identify the likelihood of the undesired event and the relative contributions of various initiating component failures to this event. Application of SAFTE-1 to an engineered safety system has shown that the program yields reliability estimates. However, continued research is required to realize the full and highly desirable benefits of the program.

Regardless of format, any mathematical method for making quantitative reliability estimates is a simulation of system behavior. As the simulation

becomes more realistic, its input requirements increase. The two methods previously referred to are believed to be near the upper bounds of practical simulation for reliability evaluation of engineered safety systems. They can allow changes in operating mode and configuration; they can accommodate repair and testing practices; they can recognize dependencies and redundancies; and they can incorporate human error either as a combined input with component failure rate or as a separate input.

APPLICATION

In reliability analysis the methods for operating, maintaining, and testing a system are described to lay a basis for careful, step-by-step evaluation of the cause and effect of each failure mode of each critical component. These failure mode and effect analyses, sometimes called failure analyses, identify critical components in terms of failure effect and provide formalized documentation of actions which can be taken to eliminate the cause of failure or reduce the effect of failure. The components identified in a failure analysis are then introduced into reliability models or logical models of system operation. When properly developed, these models graphically display the relationship between components including such concepts as interdependence and redundancy.

As pointed out in Chapters 2 and 3, the primary factor in the usefulness and credibility of a reliability analysis for an engineered safety system, or for that matter, for any system is the analyst's skill and experience. Similar conditions hold for other engineering analyses in nuclear systems. Without proper background the analyst is confronted with what appears to be a rather complex bookkeeping task. With adequate background he is able to identify the equipment and operating patterns which most adversely affect system reliability and then concentrate his efforts in these areas.

The steps involved in applying data and mathematical models to a reliability analysis have been illustrated in Chapter 3 by example applications to four engineered safety systems from pressurized and boiling water reactors. These steps include:

1. System description.
2. Operating and testing procedure review.
3. Failure analysis.

4. Reliability model development.
5. Reliability data selection.
6. Reliability analysis.
7. Evaluation of results.

In developing these applications, it has been found that the questioning and documentation required in preparation for quantitative reliability estimates are as valuable as the estimates themselves. These preparatory functions identify many of the trouble spots which are subsequently confirmed by reliability estimates. They also direct attention to procedural or design changes which can eliminate or reduce the adverse effects on safety of component failures.

The investigative processes involved in preparing for a reliability analysis also occur in the course of discussions between operator and designer, and between regulator and operator. Such discussions result from a need to make reliability judgment. It is believed that when properly applied, reliability analyses can readily provide orderly documented answers and permit a more detailed evaluation of systems important to reactor safety.

The example applications presented in Chapter 3 also illustrate the quantitative results of a reliability analysis and indicate ways in which these results may be used to benefit safety.

Specific examples of these results include:

1. Components or design features to which reliability improvement efforts may be most effectively applied.
2. Components contributing to system failure at a given probability level.
3. The effect of adding or removing redundancy on the reliability of the system.
4. Variations in system reliability which result from altered testing frequencies or procedures.
5. The sensitivity of system reliability to errors in component failure rate and repair data.

In conclusion, the reliability monitoring program described in this study provides a means for generating much needed statistical reliability data

as well as guidelines for application of the data to quantitative reliability estimates. When initiated, it is believed that the program will prove useful in every step of the activity associated with design, manufacture, evaluation, and operation of engineered safety systems. Among the specific benefits are reliability data for use in evaluating new engineered safety system designs; a more quantitative basis for comparison of new and existing designs; evaluation of the significance of preoperational and operational testing practices; and a feedback mechanism for improvement of equipment and procedures in new and existing systems by identification of conditions adversely affecting reliability.

RECOMMENDATIONS

Analytical techniques and mathematical models necessary to perform a reliability analysis of typical commercial power reactor safety systems are now available. This study has also developed a data management system designed and tailored to collect and reduce experience data to reliability data for components of power reactor protective systems. What remains to be done is implementation of an active reliability monitoring program.

In view of the fact that approximately 17 water-cooled and -moderated power reactors with output greater than 50 Mwe are expected to be in operation by December 1969 and an additional 24 with outputs greater than 400 Mwe by December 1972, it is recommended that steps be taken now to initiate operation of the reliability monitoring program in operating power reactors.

From the standpoint of urgency, the most important aspect of the program is the collection and reduction of experience into useful reliability data. There is some demand for this data now and it can be expected to increase rapidly. Furthermore, there is strong justification to initiate data collection now in order to minimize the loss of currently accumulating experience. It is exceedingly difficult and expensive to attempt recovery of this experience in a reliability data sense using existing documentation practices.

While data collection is the most urgent aspect of the reliability monitoring program, there is also a need to verify the integrated concept of the program in actual practice. That is, a pilot test should be made to demonstrate the collection and reduction of data and the application of this data to the reliability analysis of well defined operating systems.

Finally, this pilot test could provide a means of experimenting with other activities concerned with data collection problems. ^(1, 2)

(1) Computer Handling of Reactor Data for Safety, CHORDS, under development by the Nuclear Safety Information Center.

(2) Griffin, C. W., Outline Plan for Collection, Evaluation and Dissemination of LMFBR Facilities Incident Report Information, Liquid Metal Engineering Center, March 15, 1967.

FIGURE 1

RELIABILITY MONITORING PROGRAM
INFORMATION FLOW CHART

CHAPTER 1

RELIABILITY DATA MANAGEMENT SYSTEM

CHAPTER 1

RELIABILITY DATA MANAGEMENT SYSTEM

INTRODUCTION

A primary objective of this study has been the identification of a data management system for the collection and analysis of operating, maintenance, inspection, and testing data on the components of power reactor protective systems which will provide the necessary input for assessing protective system reliabilities. To be successful, a reliability data management system for reactor safety must be practical and flexible. The program must also recognize a variety of data sources, the most important of these sources being operating reactors. Within these general constraints, a data management system has been defined. The system concentrates primarily on the collection of useful reliability data from operating facilities. It also recognizes the very important source of reliability data represented by test programs in manufacturer's facilities and national laboratories. The approach used is based on the fact that significant amounts of information necessary to development of reliability data, particularly failure rate data, is being generated in a gross form via other administrative activities requiring data collection. What is now required is a method of selectively culling this existing information to arrive at a useful set of reliability data. This requirement can be accomplished by setting forth procedures and formats for collecting and classifying reliability data from available data. Listed in Figure 1.1 are the system objectives and the type of required information with which these objectives can be fulfilled.

To arrive at a selected data management system, a number of similar systems either proposed or in operation have been reviewed. These systems represent both nuclear and nonnuclear applications. Most of them are scoped to develop failure rates on the basis (1) that the collected failure data derive from chance failures and exclude failures due to wearout, or (2) that all failures are chance failures. The system outlined in this report has been developed to provide a systematic means of collecting component failure data and to permit the analysis of failure modes, and the identification of failure distribution functions associated with the various failure modes, wherever possible.

Reliability data management can be broadly divided into (1) data collection efforts which encompass collection, reduction and evaluation of in-plant or field data and manufacturer's or test data; and (2) classification of

the collected data by equipment and event types in order to facilitate evaluation and correlation of data. Both activities must be predicated on the end use of the data. A breakdown of functions required in data collection and classification is illustrated in Figure 1.2. Since data classification identifies many of the format requirements for data collection, it will be discussed first.

DATA CLASSIFICATION

Present Practices

In considering the requirements for data classification, seven classification systems have been reviewed, along with current practices in several commercial nuclear power plants operating in the United States. Current practices in several U.S. power plants are summarized in Appendix A. Since there currently is no formalized reliability program in U.S. nuclear power plants, the data classification activities in these facilities is largely dictated by other management and maintenance goals, e. g., cost control, spare parts inventory, and general availability measurement. Of the seven classification systems reviewed, three were related to nuclear plants here and abroad. The remainder were nonnuclear in orientation. These classification systems which are summarized in Appendix B are:

1. United Kingdom Atomic Energy Authority (UKAEA), Reactor Fault Reporting System.
2. Computer Program for Military Nuclear Power Plant (PM-1) Data.
3. Uniform Subject Index for Nuclear Power Demonstration (NPD) Project.
4. Maritime Administration (MARAD) Classification of Merchant Ship Systems.
5. Edison Electric Institute (EEI) Outage Classification Code.
6. Interservice Data Exchange Program (IDEP), Guided Missile Data Exchange Program (GMDEP), and Failure Rate Data Program (FARADA).
7. AEC Uniform System of Accounts.

While the majority of these systems deal with the subject of failure rate data, many of them also included other missions, as shown in Figure 1.3, which makes it difficult to compare directly all parameters between different classification systems. For example, the PM-1 systems classification is understandably simple because of the simplicity of the installation and the single unit application. Simplicity of the Canadian (NPD) classification also derives to some extent from its single installation application. The UKAEA classification is relatively more complicated since it includes not only light-water reactors but also heavy-water, gas-cooled, and liquid-metal reactors. In any case, it is obvious that there is more than one good classification system.

To demonstrate the relative complexity of these classification systems, the number of levels, groups, and digits used, and some typical examples of combined plant/system/component classification are shown in Figures 1.4 and 1.5 respectively. Disadvantages of these classifications are that (1) systems classifications are hardware rather than function-oriented; (2) component classifications are not in generic codes and thus by component classifications alone, similar components cannot be placed into common groups; and (3) multiple components of the identical kind cannot be distinguished.

The NPD and MARAD classifications provide functional system breakdowns, the FARADA classification provides component generic codes, and the PM-1 classification provides multiple component identification numbering. All of these are considered desirable qualities for a good data classification system.

A classification system which deserves special attention is the AEC Uniform System of Accounts which was developed primarily for cost accounting and estimating purposes. The functional breakdown provided in this system, particularly for the reactor plant, is rather appealing. It should be noted that the NPD classification system which is used to collect reliability data as well as to assist scheduling and accounting activities, was developed from the same source as the AEC system, namely the Federal Power Commission (FPC) Uniform System of Accounts.

Another important task in selecting a classification system is determining the number and detail of classification categories for describing failure events. These categories must be practical for use of field data and at the same time permit statistical examination. The tendency is to construct an extensive and detailed event classification system and identify field data collection procedures and forms which permit use of

the classification system. The UKAEA and PM-1 fault classifications with 200 and 65 fault categories, respectively, show the extent of detail which may be required. Such an approach can prove difficult to implement without adding extra burden to the workload of operating personnel. A checklist form such as that used in the MARAD program illustrates the type of field data requirement which may result. While more detailed failure event classification codes yield better failure data, it is considered desirable to match these codes as closely as possible to the capability of existing in-plant data recording and reporting practices.

The data classification system recommended in this study is effectively a composite of concepts derived from the systems summarized in Appendix B. The recommended system has been scoped for use in reliability data generation on engineered safety system components. It also reflects consideration of broader potential application to all nuclear systems and the possibility of eventual incorporation into data management systems concerned with all components in nuclear power plants. The immediate concern, however, has been reliability data for engineered safety systems. While the classification system presented here may be adaptable to broader use, it must be recognized that there are others which may be equally applicable. The point is there is a definite need for early standardization of nuclear power plant data management systems to avoid unnecessary duplication of data management activities while achieving useful data.

Recommended Plan

Data classification is divided into (1) systems classification which establishes the hierarchy of hardware or equipment in nuclear plants, and (2) event classification which identifies the how and why of failure as well as other events.

Systems Classification - It is desirable that the classification code be adaptable to all plant systems and at the same time be suitable for acceptance of vendor data. Such an approach is to identify individual components by the system to which they belong and by the function which they perform. The systems classification code outlined in this section is considered to satisfactorily accomplish the preceding goals. While complete, detailed development of the classification code can be performed by using the classifications described in Appendix B as guides, it is believed that such an effort should be preceded by a coordinated evaluation by all potential users at the outline stage in order that the detailed classifications are of maximum utility.

As presented, the systems classification permits identification of data from a specific component in a system for a particular plant; it allows

collecting data on a specific system in more than one plant; and it permits grouping of data on generically similar components in a single plant or all plants. The method of classification as discussed in the following sections includes plant identification, functional system identification, and in-plant and generic component identification.

Plant Identification - Identification of a nuclear power plant should be unique. Thus, classification of a particular plant has been made by use of a portion of the docket number associated with its utilization facility license. Serialized portions of docket numbers are preceded by "0" for those licensed under Part 50* and by "5" for those under Part 115*. Thus, a reactor with Docket No. 50-206 can be identified by 0206, while that with Docket No. 115-4 can be identified by 5004. Note that in order to match the column allocation, 0's are used when the serialized portion of the docket number is less than three digits.

Functional System Identification - After reviewing the nuclear and non-nuclear equipment classification systems summarized in Appendix B, it is concluded that an adaptation of the approach used in the AEC Classification of Construction Accounts will give the best basis for formalizing functional systems for reliability purposes. This classification system is derived from the Federal Power Commission's Uniform System of Accounts, which applies to government records on all types of power generation and transmission facilities.

Another reason for using the AEC system as a basis for classification is that it already covers both pressurized and boiling water reactors and, in addition, provides for coverage of organic moderated, sodium graphite, and fast breeder reactors.

In adapting the AEC code to the reliability monitoring program, the first digit of the AEC code (the number 2) has been dropped, since this digit indicates a nuclear power plant which is the only type of facility presently under consideration. The resulting functional classification system uses a numerical designation, generally consisting of five digits. A first-level breakdown of the system is shown in Figure 1.6. The first digit is a functional classification within the power plant. As can be seen, most of the equipment classes of interest will fall in the "2" or reactor plant group.

The first level is in turn provided with up to 9 major system classes by a second digit, also shown in Figure 1.6. The third, fourth, and fifth digits provide further subsystem breakdowns, as required. Figure 1.7 gives the numerical designations presently identified at the third and fourth levels. The primary difference between this breakdown and that contained in the AEC system is inclusion of the reactor containment (system class 21.9) as part of the reactor plant rather than under structures and improvements. This move is considered desirable because of the close

*Code of Federal Regulations, Title 10

relationship between containment operability and reactor safety. An example of a further breakdown to the fifth digit is shown in Figure 1.8. Of course, some systems do not require four or five digit breakdowns.

Component Identification - Classification of a component has been made (1) by its plant identification number which is familiar to all first-line operating personnel and also distinguishes it among multiple components in any given system; and (2) by its generic code which allows grouping of data from similar components and comparison of vendor data to in-plant data for similar components.

1. **Plant Identification -** The plant identification number for a component can be most expeditiously established on a plant-by-plant basis by adapting, for example, equipment numbers shown on the system diagrams, those appearing on the equipment history cards, or any other administrative numbering system that is used throughout the plant. After adopting the appropriate scheme, component identification numbers can be cross-indexed with the generic code for further utilization.
2. **Generic Classification -** A three-digit index number followed by three two-digit subclass groups has been used to provide generic component identification. The three-digit number is assigned from one of two groups of numbers, 001 to 199 or 200 to 999, depending upon the class of component involved. (000 is used if there is no heading necessary at the component level.) The first group of numbers (001 to 199) is for components which are unique to a given plant or reactor design, and for which a generic code has not been established. These unique components are assigned consecutive numbers within each facility from the 001 to 199 group and are associated with the systems classification for identification, until such time as a new generic code is established.

The second group of numbers (200 to 999) are for components which are common to many facilities and for which failure data can be accumulated from both in-plant and equipment vendor programs. For these components the numbers are preassigned. The suggested generic code is shown in partial development in Figure 1.9.

Following the three-digit component index number are several subclass index groups of two-digit numbers which identify service, material, size, type, function, operation, etc. Several subclasses, e. g., service, material, and size, are

applicable to a number of components. In these cases, common subclassifications are used as detailed in Figure 1.10. In all other cases, appropriate subclasses are created to suit the particular component. (00 is used if there is no heading at any subclass level.)

While the preceding generic classification is similar in format to that used in the FARADA system, the specific code for components is different. This is considered desirable to assure that users apply generic data derived from equipment of the type found in nuclear power plants. Some FARADA data is applicable to nuclear systems but the user should be aware of the FARADA subclassifications and avoid using inapplicable failure rates. Other reasons for avoiding blanket use of the FARADA classification include (a) many FARADA components are not used at all in reactors (88 of 463 components in an available list have no counterpart in reactor systems), thus many component classification numbers (first three digits) are used for inapplicable data; and (b) some subclassifications (two digit numbers) pertain to variable ranges not encountered in reactor systems, e.g., motors over 1 hp are lumped into a single subclass and operating media include exotic materials such as rocket fuels.

Complete system-component classifications of two representative systems in a typical PWR-type nuclear power plant are shown in Figures 1.11 and 1.12. In-plant component identification numbers were taken from system diagrams.

Event Classification - The primary need in preparing reliability data is to relate failures to accumulated use under specific operating conditions. Both failures and use are considered to be events in this classification system. In this context, failure events identify the how and why of failure; and use events provide a basis for correlating failures to accumulated use.

Failure Events - To evaluate failure data and allow proper use of this data for reliability analyses, it is necessary to classify individual failure events by (1) functional manifestation of the failure, i.e., failure mode; (2) physical manifestation or failure cause; and (3) effect of failure on system performance. The first two items are important because if we know how and why a failure occurred, we can learn to prevent it. The third item, failure effect, allows the most efficient use of failure analysis efforts to eliminate importance failure causes and/or failure modes.

1. Failure Modes - (The way in which a component fails) - To generate a listing of all types of functional failures for every possible component can lead to an almost endless list of

failure modes. However, a very useful listing can be formulated by considering failure modes to be characterized as: (1) failure to open; (2) failure to close; (3) failure to start; (4) failure to stop; (5) failure to continue operation; (6) spurious failure, i.e., premature operation of a component when not called for; (7) degradation; (8) erratic operations; (9) scheduled service; and (10) scheduled replacement.

These functional failures are classified as shown in Figure 1.13. Applying a reasonable interpretation it can be shown that any conceivable failure will involve one of these functional manifestations. Being functional phenomena, these failure modes are potentially detectable when they occur. Also, they have physical precursors (causes) which can be identified; hence, component failures become always theoretically predictable and preventable. However, they are not predictable until the cause is present.

2. Failure Causes - (What made the component fail the way it did)—
A generalized classification of failure causes is difficult, but not because of the outward appearance of many causes; rather, it results from the fact that, if pursued far enough, the root cause of every failure involves human action or inaction. Tentatively, however, it is believed that cause classifications should be oriented to stages in a component's life--a use-oriented classification. This method of classification is considered use-oriented because in analysis of cause-effect relationships the desire is to eliminate or counteract those causes giving rise to undesirable effects. This goal can best be attained by identifying that part of a component's life wherein the causes of failure most frequently are generated. Put another way, it is desirable to know if the cause resulted from weak or improper design, poor fabrication, or improper use in operation. On the basis of the preceding discussion, three major causal categories are defined. They are design, fabrication, and operation. Detailed definition of these different categories is shown in Figure 1.14.

Design causes reflect those failure causes resulting from improper or incomplete recognition of actual use conditions and environments; e.g., no anticipation of high humidity or incomplete heat transfer analysis. These causes may also result from lack of or misdirected developmental testing which, in turn, allows fabrication of weak components.

Fabrication causes are broken down into abnormalities in component configuration and abnormalities in material composition. Configuration abnormalities include the commonly

referred to failure causes resulting from poor assembly practices. Design and fabrication causes are more likely to be found in vendor's data.

Operation causes, with few exceptions, are generally unpredictable, since the causes are external to the component in question and lie in the future unless the misuse is chronic and has already resulted in wear or some other detectable degradation. Operation causes probably should dominate most of the in-plant failures.

3. Failure Effects - (What happened to system when component failed the way it did) - Even when performance levels are fairly well established, evaluation of failure effects will require some good engineering judgment. For ease of judgment, failure effects have been classified with respect to their importance to system performance. They are specifically divided into (1) no loss of performance, (2) partial loss of performance, and (3) total loss of performance. Use of many more levels of judgment has been shown to lead to inconsistency in repeated evaluation of marginal cases. The effect classification code is shown in Figure 1.15.

The effect of failure events on reactor performance is indicated by the use classification code which encompasses both failure and nonfailure or use data.

Use Events - The recommended classification code for use events is shown in Figure 1.16. This code provides a basis for characterizing or establishing the accumulated use on pieces of equipment. This objective is achieved by using changes in plant operating status and the occurrence of system tests outside the normal schedule as indices. The desire here is to relate each bit of reliability data to the plant status during the time in which the data was developed. Thus, a failure event will include a use classification which defines the plant status during the time that the data was accumulated. As indicated in Figure 1.16, the use codes are defined in such a way that they can be readily identified by operating or reviewing personnel.

DATA COLLECTION

Present practices in operating nuclear power plants include collection of (1) use data as a part of periodic management reports, (2) failure and repair data as an adjunct to performing maintenance operations, and (3) additional experience data in conjunction with special reports and studies. After reviewing these existing data sources, a recommended plan for data collection has been formulated using the previously defined classification system.

However, before outlining the recommended data collection practices, it is desirable to briefly review existing practices in nuclear power plants in the United States and in other nonnuclear and foreign nuclear activities.

Present Practices

U. S. Nuclear Power Plants - As indicated in Appendix A, it is customary for commercial nuclear power plants in the U. S. to prepare periodic management reports in which plant operations and outages are summarized. In most cases, these reports provide adequate use data but little reliability information. These reports are derived from more basic records accumulated in the power plants for purposes of guiding maintenance and providing a historical record of operations. The basic records include documents such as the reactor log, control room log, supervisor's log, and shift foreman's log. None of these records possesses a format which includes consideration of reliability data generation, although they provide much of the basic input for reliability data.

Probably the single greatest source of failure data in commercial power plants is the documentation generated to direct and control maintenance. These records may be called maintenance memorandums, maintenance requests, work item cards, or deficiency reports. Several examples of the formats for existing records are given in Appendix A along with descriptions of the records and their respective routing procedures. Here again the formats in use are not completely compatible to reliability data development; however, it is believed that a collection mechanism for failure data useful in reliability analysis can be developed from existing maintenance records with very little added effort.

Other Facilities - In the reliability data management programs that have been reviewed, data recording has been accomplished by either the checklist or narrative approach. In the checklist approach, plant personnel make an initial record of all data by filling blanks with quantitative data and checking boxes opposite applicable statements. Narrative statements are necessary only to describe unusual events not evaluable within the scope of available data requirements. The data on these forms are transferred directly to punch cards or other reliability evaluation forms which are used to derive summary data such as failure rates, repair time, repair costs, and availability. This approach has the advantage of eliminating or reducing to a minimum data transferral activities between data collection groups (operating and maintenance staffs) and data analysis and evaluation groups. On the other hand, it requires additional effort and knowledge on the part of the initial recorder to fill out a fairly elaborate form. An example of such a form, recommended for use by the Maritime Administration, is shown in Appendix B, Figure B.3. Of course, this form was developed to provide more data than required

strictly for reliability information. Another possible drawback to checklist forms is the rather formidable appearance they present to personnel whose primary mission is to maintain and operate a plant in a safe and efficient manner.

In the narrative approach, a memorandum type work request form requiring a minimal amount of specific data is used as the primary source of failure and repair data. The form is reasonably simple and does not require familiarity with a set of terminology peculiar to subsequent uses of the raw data. The major disadvantage of this approach is that a reliability engineer or a person familiar with nuclear power plant systems and data analysis must translate the raw information into reliability data and transfer the data to records or input forms suitable for reliability evaluation. Such an approach is currently in use by the Ontario Hydroelectric Power Commission (HEPC) at its Nuclear Power Demonstration (NPD) Reactor. The basic record used at the NPD reactor is a deficiency report (DR) form. A sample of this form is shown in Appendix B, Figure B.18. The primary use of the DR form is to initiate and control maintenance. Its contents and method of handling are also scoped to assure that periodic review by a reliability engineer (from the HEPC central offices) can quickly identify all failures and repairs associated with each component in the systems of interest. The DR review system is completely manual. Experience with this system is believed to show that virtually all of the reportable component failures are identified. It also has been reported that the reliability engineer requires one to two weeks per system per year in reviewing and reporting on the accumulated DR's. The use of a reliability engineer review is considered necessary to properly evaluate the significance of the data.

Typical narrative type work request forms, used in the U. S. power reactors, are shown in Appendix A, Figures A.3, A.4, and A.10. Comparing these examples with the Canadian deficiency report form suggests that current work requests might be used as failure report forms with little modification. Success of such an approach in the accumulation of failure data is contingent upon strong interest in implementation by plant supervisory personnel (as would be true of any recording system), and the provision of a person knowledgeable in reliability data requirements to translate work request data into input for data collection and evaluation.

Recommended Plan

Based on the preceding discussions, a narrative type approach to data collection is recommended. It is believed that this approach will provide adequate information and at the same time be most compatible to use in

existing activities such as maintenance, control, and documentation. A plan whereby necessary data for reliability analysis can be collected is shown schematically in Figure 1.17. Because of the different degree of data reduction performed in operating plants and in manufacturing test facilities, entirely separate approaches will be made in collecting reliability data from each of these sources.

In-Plant Data - There are two sources of in-plant data that are of primary importance for reliability analysis. One is that generated by the operating group. It includes records of all use data for tests and normal operations. The second source is that resulting from failure events observed by the operating group and subsequently corrected by the maintenance group. These failure events are generally recorded on failure report and maintenance request (FR/MR) forms. In essence, use data are mainly concerned with length in time, while failure events are related to point in time. The recommended plan for collection and correlation of these data follows.

1. Failure Data - When a failure has been reported, some type of preliminary investigation becomes necessary to determine the basic failure cause and effect. Otherwise, only a superficial description of abnormal symptoms will result. Usefulness of raw data collected for reliability analysis depends largely on the information required of the investigator.

Minimum information expected from the investigator for reliability purposes includes:

- a. Component identification by name and system to which it belongs.
- b. Component failure description including cause, mode, effect on system performance and plant operation, and time at which failure occurred or was discovered.
- c. Component repair description including whether repair or replacement was made, length of time for repair, and time at which repair was completed.

In Figure 1.18 a list is presented for specific information required of in-plant personnel for eventual use in reliability analysis. Identification of the individual component is necessary in order to be able to calculate the length of time between failures for specific components as well as for identical or similar components in similar service. This is particularly

important if it is desired to perform failure distribution analyses. Date and time of component failure and repair completion provide basic input to the calculation of failure rates and, if desired, the evaluation of failure distribution assumptions. Total repair time is the total elapsed time from the occurrence of a failure event to the completion of repair including time in which no active maintenance occurs. If a failed component is replaced by another new or repaired component, completion of repair occurs at the time installation of the new component is completed. Repair time is needed to compute actual use time and allows attainment of maximum effectiveness in reliability evaluation techniques such as fault-tree analysis. An example of a fault-tree type of technique is given in Chapter 2.

Mode of failure allows apportionment of the overall component failure rate among various critical failure modes. Mode and cause of failure are also important in evaluating failures and failure rates. For an unusual type of failure or a failure occurring at an unusually high rate, mode and cause data provide a means for retrospective review of failure data to permit detection and correction of gross deficiencies. Knowledge of failure effect on system performance and plant operation is necessary to link failure data to use data, i.e., effect data provides a means of identifying components put in operation or shutdown by a failure event. Effect data also provides a source of information for use in corroborating failure mode and effect assumptions in system reliability analyses.

Description of repair is required to the extent that it identifies the extent of repair, and particularly, whether failed items were replaced by completely new or repaired components, repaired in place with some part replacement, or adjusted or calibrated without any new parts. Component replacements must be identified in any analysis of failure distribution functions, especially when these replacements reflect component wearout.

2. Use Data - Use data is defined as the time element or "use time" by which successful operation of the plant or a system is measured. Individual entries from which use data can be derived are recorded chronologically in various log books; however, the most convenient sources of this information are periodic Operating and Outage Summary (O/OS) reports used in conjunction with the failure data.

In any system whose operation is continuous and directly measurable by length in time, the use time can be measured by one of the following time elements:

- a. Calendar Time - e.g., a radiation monitor which operates continuously with no relation to plant operation.
- b. Plant Operating Time - e.g., reactor operating time and/or turbine-generator (T/G) operating time.

There are systems whose use times are not exactly the same as those listed above but are proportional to them. For these systems, use time can be modified by a use fraction, K, and computed as follows:

Use time = $K \times$ Calendar time, or
 $K \times$ Reactor operating time, or
 $K \times$ T/G operating time.

Any component operation which is continuous in nature can be measured by one of the above use times. In order to facilitate the bookkeeping for various use times, the following rules are suggested:

- Rule 1: Unless a system failure is reported, the use time of any system will correspond to that of the plant operation (reactor or T/G), appropriately modified by a use fraction.
- Rule 2: Unless a component failure is reported, the use time of any component will correspond to that of the system to which it belongs.

This type of recording practice, namely "data management by exception," where only exceptions to normal operation are recorded already exists in preparing O/OS reports. By extending the same technique, the paper work involved in recording use data can be simplified to initial identification of use fractions for components or systems in a plant. Subsequently, use for a component is computed by the product of the use fraction and the appropriate operating time less component down time recorded in failure event data.

Use time for any test operation which is cyclic in nature and not directly dependent on the length in time cannot be measured by the calendar time or plant operating time. Test intervals of routine operational tests required by the technical specifications* and operating procedures will provide a useful guide in

*Code of Federal Regulations, Title 10, Part 50.

predicting the actual number of tests performed on any given system or component. In general, the number of successful tests of any component will correspond to that of the system to which it belongs; however, operational test procedures must be carefully studied to verify that individual components are indeed operationally tested when testing the entire system operation. For example, when an emergency core cooling system is periodically tested during power operation, not all components may be tested operationally with each test.

Typical intervals for operational tests are summarized in the technical specifications issued for a power plant, as shown in Figure 1.19. From this listing, the following "use fractions" can be obtained:

- a. Number of tests/calendar time.
- b. Number of tests/reactor operating time.
- c. Number of tests/T/G operating time.

By multiplying the appropriate use fraction by the calendar time or the appropriate plant operating time, the cyclic use of protection system components can be estimated.

In addition to components whose use times can be defined as above, there are some components which are also operated with each reactor startup and shutdown; e.g., reactor protection circuits. For components in this category, it becomes necessary to identify all plant startups and shutdowns, including reactor scrams, and to include these occurrences as part of the overall use.

Data Recording and Reporting - In-plant data recording and reporting will be accomplished in a two-step approach. The first step will be performed by operating and maintenance personnel using FR/MR forms to record all failure and repair data, and by periodic O/OS reports to record all use data. This data recording activity already exists in nuclear power plants and can be upgraded to a level suitable for use in reliability evaluation by minor modification of the existing forms and reports, and provision of simple procedures to assure that all pertinent data are recorded on them. Of course, any changes in these forms should not detract from their original purposes.

Much of the failure and repair information is already available in existing FR/MR forms. In order to ascertain what additional information will be required from operating personnel, the required information, shown in Figure 1.18, has been compared with the information asked for on some

of the existing work order formats in Appendix A, Figures A.3, A.4, and A.10, and in Appendix B, Figure B.18. This comparison is shown in Figure 1.20.

Based on the comparison given by Figure 1.20, a suggested FR/MR format with necessary reliability information is shown in Figure 1.21. Although the suggested format differs in some respects from any in current use, these differences are small. In most cases existing forms could be adapted easily to the reliability oriented format by use of a rubber stamp form on the front or back of the existing form. An example of such a modification is given in Figure 1.22.

The next step in in-plant data collection requires periodic translation and transferral of raw data generated by the operating personnel to data forms suitable for data handling, indexing, storing, and retrieving with the possible use of computerized data handling systems. This step requires an engineer or technician familiar with both the subject plant systems and the reliability data classification requirements.

The use data reported in O/OS reports and failure data reported on FR/MR forms would be codified onto an 80-column loadsheet using appropriate field allocations as shown in an example in Appendix C, Figure C.3.

These data inputs may be described as follows:

1. Date of Report - Date will be reported as Day (01 to 31), Month (01 to 12), and the last two digits of the calendar year.
2. Data Source - Identification number of the data source, i.e., plant I. D.
3. System Code - Refer to the classification of functional systems.
4. Component I. D. Number - Plant assigned I. D. No. of the failed component. Generic component identification is provided during data reduction.
5. New component I. D. Number - Enter only when repair is accomplished by replacement with a new component of different design.
6. New Component Manufacturer's Code - Enter only when repair is accomplished by replacement with a new component from a different manufacturer.
7. Time of Event - Time of the day when event occurred in Hours (00 to 24) and Minutes (00 to 60). If information on time is not available, 0800 will be used. This is used to identify multiple failures or startups and shutdowns within the same day.
8. Total Repair Time - Enter to the nearest hour.

9. Date of Recovery - Date will be reported in the same manner as for date of reporting in item (1).
10. Failure Mode - Refer to failure classification, Figure 1.13.
11. Failure Cause - Refer to failure classification, Figure 1.14.
12. Failure Effect - Refer to failure classification, Figure 1.15.
13. Use - Refer to use classification, Figure 1.16.
14. Description of Event - Enter in 20 letters or less, and in case of failure event it should identify the failed parts and indicate whether they were replaced, repaired, adjusted, or calibrated.

Two basically different line entries are made in the input loadsheet to assure proper correlation of use and failure data in generating failure rates and repair data. They are (1) entries which define the beginning of plant startups, and scheduled shutdowns; and (2) entries which define each failure event.

Using these line entries, including the failure effect and use codes, the operational history of each component can be reproduced either by hand calculation or a computer program. The proposed method of data reduction is explained in a subsequent section, and salient points in loadsheet preparation are demonstrated in Appendix C, with the use of a hypothetical system consisting of several components operating continuously, as well as cyclically.

Vendor Data - Qualification tests, production tests, and other tests are routinely conducted by various equipment vendors; and the reports summarizing these tests represent an additional source of reliability data. Consideration is given here to the requirements for collection of reliability data from equipment vendors in a form compatible with that from in-plant sources. The objective is to allow eventual accumulation of all these data into one data bank.

To assure collection of vendor data in a form consistent with the in-plant data, the vendor's reliability input data format shown in Figure 1.23 is recommended for use in the reliability data program. In this format component identification can be made by model number or part number; but in any case it should also be identified by the generic code previously developed for in-plant data. The test condition entry called out in item 5 of Figure 1.23 may be divided into the following categories.

<u>Test Condition</u>	<u>Description</u>
Life Test	Component operating in long-term test.
Proof Test	Component operating in short-term test, e.g., production test, qualification test, etc.
Start-up Test	Component operating in-plant startup.

Items 6, 7, 8, and 9 are the basic statistical data necessary in evaluating failure rate. If known, the confidence level and assumed failure distribution should be noted as indicated in item 9. Functional modes of failure are the same as those defined for in-plant data. Another important data entry in reporting component failure rate is the derating factor. Headings are given in item 11 for the more commonly used derating parameters. Other environmental stress factors should be noted in item 12, if known. Finally, to avoid submission of the same data from different sources, it is necessary to reference the test document from which the test data were derived.

It should be noted that the format in Figure 1.23 suggests the necessary data from vendor sources. If existing vendor reports include the information indicated in Figure 1.23 then these reports may be used as the first level input to the generalized data collection form. Reduction of both in-plant and vendor data is discussed in the following section.

Data Reduction - Reliability data collected from in-plant sources and equipment vendors should be compiled in a manner that allows easy retrieval and updating of all data. The formats illustrated in Appendix C are considered to satisfy this need. The output provided in this recommended format will yield the following information for reliability analysis:

1. Failure rates by a single component.
2. Failure rates by components of the same generic code.
3. Failure rates by failure mode for each component.
4. Mean repair time.
5. Standard deviation of failure rates or mean time between failure.
6. Standard deviation of mean repair time.
7. Time between failure of a single component which will enable detailed examination of failure distribution functions with accumulation of sufficient failure events.

As suggested in Appendix C, Figures C.4, C.5, and C.6, the formats can be arranged as computer output sheets. These formats also can be readily converted to calculation forms suitable for manual computation. The recommended formats are as follows:

Type 1 Output Data Sheet - Listing of Component Failures

Column 1	<u>Date of Report</u> - Date of report will be reported in the same manner as in the input loadsheets.
----------	--

Column 2	<u>Component I. D. No.</u> - Plant or manufacturer's I. D. No. for component, e.g., see Appendix C, Figure C.3.
Column 3	<u>Manufacturer's Code</u> - A unique three-digit code number assigned to the manufacturer of the equipment item on which data is to be given.
Column 4	<u>Failure Mode</u> - Same as shown on the input loadsheet (see Appendix C, Figure C.3).
Column 5	<u>Hours or Cycles</u> - To distinguish the unit of use associated with the operation of the component.
Column 6	<u>Time to Failure in Million Hours or Cycles</u> - Time from the initial use until the failure of a single component or the time since the last failure of the component.
Column 7	<u>Accumulated Time in Million Hours or Cycles</u> - The sum of <u>Times to Failure in Million Hours or Cycles</u> from the initial operation to the end of reporting period for a specific component.
Column 8	<u>Repair Time</u> - Same as the input loadsheet (see Appendix C, Figure C.3).
Column 9	<u>Description of Repair</u> - Same as the input loadsheet (see Appendix C, Figure C.3).

Type 2 Output Data Sheet - Summary of Failure Rate Data

Column 1	<u>Component I. D. No.</u> - Plant or manufacturer's I. D. No. for component on which data is being given (see Column 2 of Type 1 Output Data Sheet).
Column 2	<u>No. of Components</u> - Number of components identified with the component I. D. No. given in Column 1.
Column 3	<u>Failure Mode</u> - Same as Column 4 on Type 1 Output Data Sheet.
Column 4	<u>No. of Failures</u> - Number of component failures identified on each component and for all components of a generic type from initial operation to end of reporting period.
Column 5	<u>Hours or Cycles</u> - Same as Column 5 on Type 1 Output Data Sheet.

- Column 6 Accumulated Time in Million Hours or Cycles - The sum of Times to Failure in Million Hours or Cycles from initial operation to the end of reporting period.
- Column 7 Failures per Million Hours or Cycles - This is the quotient of No. of Failures divided by Accumulated Time in Million Hours or Cycles. The use of failure rates implies assumption that the observed failures relate to the chance or exponential failure distribution. With this assumption, the failure rate for nonfailed components may be reported as the inverse of Accumulated Time with 63 percent confidence. Failure rates, hence reliabilities, for both failed and nonfailed components may be estimated at other confidence levels using the methods outlined in Appendix H or statistical charts such as provided in Appendix 4 of HN-185.*
- In vendor's input data, failure rates may be provided with either the number of failures and accumulated time or the estimated confidence level. The first form is the more desirable since it is better suited to estimating failure rates at other confidence levels. Another variation which may occur in reporting failure rates is the use of different units. For convenience, a conversion table is provided in Figure 1.24 to allow conversion to the suggested units of failures per million hours or cycles.
- Column 8 Failure Rate Standard Deviation - Standard deviation of the failure rate for generically similar components. This number may be calculated when the number of components is equal to or greater than three.

$$\text{Standard Deviation} = \sqrt{\frac{\sum (x - \bar{x})^2}{N}}, \text{ hr}$$

where x = Mean time between successive failures for a specific component in hours or cycles,

*Garrick, B. J., Gekler, W. C., and Pomrehn, H. P., "An Analysis of Nuclear Power Plant Operating and Safety Experience," HN-185 December 15, 1966.

$\bar{x}$ = Average mean time between failures for all generically similar components in hours or cycles, and

N = No. of components.

Note that a similar test can be applied to mean times between failure for a single component when more than three failures have occurred.

Column 9 Accumulated Repair Time - The sum of all Repair Time from the beginning to the reporting date.

Column 10 Mean Repair Time - The quotient of Accumulated Repair Time divided by No. of Failures or repairs.

Column 11 Repair Time Standard Deviation - Standard deviation may be calculated when No. of Repairs is equal to or greater than three.

$$\text{Standard Deviation} = \sqrt{\frac{\sum (r - \bar{r})^2}{N}}, \text{ hr}$$

where r = Repair time for individual failure in hours,

$\bar{r}$ = Mean repair time in hours, and

N = No. of failures

Many of the items noted above are direct inputs from the input loadsheets. However, it should be noted that Type 1 Output Data Sheet has line entries for failed components only while the Type 2 Output Data Sheet tabulates all components whether they failed or not during a particular reporting period.

To bridge the gap and provide information on successful (nonfailed) components, the principle of "data management by exception" mentioned earlier under the heading of Use Data must be used. Proper interpretation of this principle for data reduction computations may be accomplished by use of the following rules:

Rule 1: If no component failure is reported in the input loadsheet, the use time of any components will correspond

to that of the plant operation, modified by the appropriate use fraction.

Rule 2: If a component failure accompanied by no loss in system performance is reported, the use time of other components in the same system will correspond to that of the system to which they belong in the same calendar period.

Rule 3: If a component failure accompanied by system loss is reported, the use time of other components in the same system will be decreased by the repair time identified for the failed component.

The key to use of the foregoing rules is proper identification of the failed component and the effect and use codes entered in the input loadsheets. One should be familiar enough with the systems operation or the computer subroutine should be written so that the status of all nonfailed components in the same system can be identified with the component failure in the system, or in case of no failures all components within the same system can be identified. Specific examples of these mathematical operations are given in Appendix C.

Program Objective	Data Management Information		
	Available	Minimal	Proposed
System/Component Classification	By Name	By Generic Description	By Generic Code
Component Failure Rate	No. of Failures Total Operating Time	No. of Failures Total Operating Time	No. of Failures Total Operating Time
Failure Distribution Function	None	Identification of Wearout or Chance Failures	Length of Time or No. of Cycles to Failure
Failure Mode and Effect Analysis	Safety Analysis Reports	Final Safety Analysis Report; Complete Descriptions of Systems, System Functions and Operating and Testing Procedures	Failure Mode, Cause and Effect Analyses
Repair Data	Repair Description	Repair Description Repair Time	Repair Description Repair Time

FIGURE 1.1
COMPARISON OF DATA MANAGEMENT INFORMATION

FIGURE 1.2
PROPOSED DATA MANAGEMENT SYSTEM

Classification	Organization	Purpose
UKAEA	United Kingdom Atomic Energy Authority	<ol style="list-style-type: none"> 1. Fault and incidence report. 2. Safety assessment. 3. Failure rate data.
PM-1	U. S. Air Force	<ol style="list-style-type: none"> 1. Plant performance and economics report. 2. Safety assessment. 3. Availability report. 4. Failure rate data.
NPD	Nuclear Power Demonstration, Ontario Hydro-Electric Power Commission	<ol style="list-style-type: none"> 1. Safety assessment. 2. Failure rate data. 3. Scheduling. 4. Cost Accounting.
MARAD	Maritime Administration, Department of Commerce	<ol style="list-style-type: none"> 1. Failure rate data. 2. Maintenance cost minimization. 3. Inspection frequency optimization.
EEI	Edison Electric Institute	<ol style="list-style-type: none"> 1. Outage data. 2. Equipment availability report.
IDEP-FARADA	Interservice Data Exchange Program and Failure Rate Data Program, DOD and NASA	<ol style="list-style-type: none"> 1. Failure rate data. 2. Part/component test data.
AEC Uniform System of Accounts	U. S. Atomic Energy Commission	<ol style="list-style-type: none"> 1. Cost accounting. 2. Cost estimating.

FIGURE 1.3

LIST OF EXISTING CLASSIFICATIONS

CLASSIFICATION	SYSTEM CODE		COMPONENT CODE		FAULT CODE		USE CODE	
	Level	Digit	Level	Digit	Group	Digit	Group	Digit
UKAEA	8	8	6	6	3	2, 4, & 5	2	2
PM-1	1	3	1	5	2	2	2	2
NPD	3	3	2	2	2	(2)	1	(2)
MARAD	3	3	4	8	4	(3)	1	(3)
EEI	1	1	1	3	(1)			
IDEP/FARADA			7	9	(4)			
AEC Uniform System of Accounts	6	6	(5)					
Proposed System	6	6	7	9	3	1	1	1

Notes

- (1) Fault identified with component.
- (2) Yes or No only.
- (3) Checklist form.
- (4) Number of fault groups varies with components.
- (5) Component identified only to extent necessary for cost accounting.

FIGURE 1.4
NUMBERS OF LEVELS, GROUPS, AND DIGITS OF EXISTING
AND PROPOSED CLASSIFICATION CODES

PROPOSED

0 2 0 6 / 2 1 4 1 0 / 2 0 2 5 6 5 4 5 2 / M 0 V 8 5 1 A

San Onofre Unit #1

Reactor Plant

Reactor

Reactor Auxiliary Cooling and Heating Systems

Safety Injection System

Valve

Service, water

Material, stainless steel

Size, over 12 inches

Type, gate

Function, shutoff

Operation, motor

Multiple component number

UKAEA

3 1 / 1 5 1 3 5 3 0 0 / 3 2 3 2 1 0 / None

Calder Hall 1

Reactor

Heat exchange circuit

Primary

Air/gas system

Vacuum pump

Valve

Mechanical

Liquid system

Valves

Control valve

Automatic

WESTINGHOUSE

P M I / P I A / R Y A / 3 6

Air Force Sundance Reactor

Annunciator and temperature scan systems

Relay alarm

Location number

CANADIAN

None / 7 1 2 / 2 0 / None

NPD

Common processes and services

Water supply system

Circulating water system

Pumps

MARAD

2 6 4 7 0 4 / P B B / 0 0 1 D 0 2 / 0 1

S. S. President Arthur

Power and propulsion system

Steam subsystem

Steam Supply Unit

Boiler

Bent tube type

Steam drum

Starboard

FARADA / IDEP-II CODES

None / None / 9 2 5 2 0 7 5 8 9 / None

Valves

Fuel, exotic

Pressure, 200 psig

Function, shutoff

Type, globe

Activation, solenoid

FIGURE 1.5

COMPARISON OF PLANT/SYSTEM/COMPONENT CLASSIFICATION/
MULTIPLE COMPONENT IDENTIFICATION NUMBERS

- 21 Reactor
- 22 Heat Transfer
- 23 Fuel Handling
- 24 Not Used
- 25 Radioactive Waste Treatment and Disposal
- 26 Instrumentation and Control
- 27 Feedwater Supply and Treatment
- 28 Steam, Condensate, Feedwater Piping
- 29 Other Reactor Plant Equipment

FIGURE 1.6
NUCLEAR POWER PLANT CLASSIFICATION

20	Reactor Plant
21	Reactor Equipment
21.1	Reactor Vessel
21.11	Vessel Supports
21.12	Vessel
21.13	Vessel Internals, Removable (excluding full moderator, reflector and reactivity control components)
21.2	Reactor Controls
21.21	Control Rods
21.22	Housing
21.23	Drive Mechanisms or Systems
21.24	Supplementary Control Systems
21.25	Neutron Source
21.3	Reactor Shielding
21.31	Thermal Shield
21.32	Biological Shield
21.33	Blast Shield
21.34	Shield Cooling System
21.4	Reactor Auxiliary Cooling and Heating System
21.41	Safety Injection System
21.42	Emergency Shutdown Cooling System
21.43	Decay Heat Removal System
21.44	Component Cooling System
21.45	Preheating Systems
21.46	Post-Incident Cooling System
21.47	Pressure Suppression System
21.5	Reactor Plant Containers (in the form of tanks installed within a building)
21.51	Containers (including supports)
21.52	Floors and Barriers
21.53	Drain Systems
21.54	Ventilation and Cooling System
21.6	Moderator and Reflector
21.7	Reactor Plant Cranes and Hoists (not fuel handling)
21.9	Reactor Containment
21.91	Foundation Material
21.92	Bearing Piles and Caissons
21.93	Substructure Concrete

FIGURE 1.7

REACTOR PLANT CLASSIFICATION SYSTEM

21.94	Superstructure
21.95	Lighting and Electrical System
21.96	Plumbing and Drainage
21.97	Temperature Control System (heating and cooling)
21.98	Purge System
21.99	Fire Protection
22	Heat Transfer Systems
22.1	Reactor Coolant System
22.2	Intermediate Cooling System
22.23	Intermediate Heat Exchanger and Supports
22.3	Steam Generators, Superheaters, Steam Drums, and Steam Separators
22.31	Steam Generators and Supports
22.32	Superheaters
22.33	Steam Drums and Internals
22.34	Steam Separators
22.35	Reheaters
22.4	Reactor Coolant Receiving, Supply and Treatment (and intermediate, if any)
22.41	Charge, Volume Control, Pressurizing and Relief System
22.42	Purification System
22.43	Chemical Treatment, Blowdown and Sampling Systems
22.44	Coolant Receiving, Storage and Makeup
22.45	Inert Gas Supply and Blanketing System
22.5	Reactor Moderator Auxiliary Systems
22.51	Gas Systems, Supply and Circulation
22.52	Cooling and Purification System for Gas and Liquids
22.7	Conventional Fossil Fuel Fired Superheaters or Boilers
22.71	Superheaters or Boilers
22.72	Firing Equipment
22.73	Coolant Systems
22.74	Fuel Handling and Storage Equipment
22.75	Blowdown Equipment
22.76	Ash Handling and Storage
23	Nuclear Fuel Handling and Storage Equipment
23.1	Cranes and Hoisting Equipment (fuel handling)
23.2	Special Tools and Service Equipment
23.21	Reactor Vessel Servicing Equipment
23.22	Fuel Removal, Assembly and Disassembly Equipment

FIGURE 1.7 (cont.)

23.23	Control Rod Handling
23.24	Television, Other Viewing and Special Lighting
23.25	Containers and Racks
23.3	Spent Fuel Storage, Cooling, Cleaning and Inspection Equipment
23.31	Spent Fuel Cooling and Cleaning
23.32	Spent Fuel Washing (organic coolant)
23.33	Spent Fuel Washing (sodium coolant)
23.34	Inspection Equipment
23.4	Shipping Casks and Cars
25	Radioactive Waste Treatment and Disposal
25.1	Liquid Waste
25.11	Aqueous
25.12	Organic
25.2	Gaseous Waste
25.3	Solid Wastes
25.4	Drain and Vent System, Reactor Coolant
25.5	Drain and Vent System, Intermediate Coolant
26	Instrumentation and Control
26.1	Reactor Plant Control System
26.11	Reactor
26.12	Reactor Shield
26.13	Reactor Auxiliary Systems
26.14	Vapor Containers
26.2	Heat Transfer System
26.21	Reactor Coolant System
26.22	Intermediate Coolant System
26.23	Steam Generators and Superheaters
26.24	Coolant Supply and Treatment
26.25	Coolant Receiving and Storage
26.3	Service to Fuel Handling and Storage
26.31	Spent Fuel Storage Cooling System
26.32	Fuel Wash System
26.4	Service to Radioactive Waste Treatment and Disposal
26.41	Liquid Waste
26.42	Gaseous Waste
26.43	Solid Waste
26.5	Radiation Monitoring
26.51	Process

FIGURE 1.7 (cont.)

26.52	Health Physics
26.53	Off-site Environs
26.6	Steam Generator
27	Feedwater Supply and Treatment System
27.1	Raw Water Supply
27.2	Make-Up Water Treatment
27.3	Steam Generator Feedwater Purification
27.4	Feedwater Heaters
29	Other Reactor Plant Equipment
29.1	Chemical Decontamination System
29.2	Reactor Plant Maintenance Equipment
29.21	Remotely Controlled Tools
29.22	Radioactive Maintenance Facilities
29.23	Portable Shielding

FIGURE 1.7 (cont.)

21.4 Reactor Auxiliary Cooling and Heating Systems

- 21.41 Safety injection system
- 21.42 Emergency shutdown cooling system
- 21.43 Decay heat removal system
- 21.44 Component cooling system
- 21.45 (not used)
- 21.46 Post incident cooling system
- 21.47 Pressure suppression system

21.42 Emergency Shutdown Cooling System

- 21.421 Turbine steam bypass system
- 21.422 Emergency condenser system
- 21.423 Emergency feedwater system
- 21.424 Steam dump system

FIGURE 1.8

REACTOR AUXILIARY COOLING AND HEATING SYSTEM AND
EMERGENCY SHUTDOWN COOLING SYSTEM CLASSIFICATION

- 200 Piping
 - 201 Pipes and Fittings
 - 201.00 Service and Material (common)
 - 202 Valves
 - 202.00 Service and Material (common)
 - 202.00.00 Size (common) and Type
 - .01 Ball
 - .02 Butterfly
 - .03 Flapper
 - .04 Gate
 - .05 Globe
 - .06 Needle
 - .07 Plug
 - .08 Poppet
 - 202.00.00.00 Function
 - .10 Check
 - .20 Multifunction
 - .30 Relief
 - .40 Servo
 - .50 Shutoff
 - .60 3-Way Selector
 - .70 4-Way Selector
 - 202.00.00.00 Operation
 - .01 Manual
 - .02 Motor
 - .03 Pilot (remote manual)
 - .04 Pressure
 - .05 Solenoid
 - 203 Filters and Strainers (nonelectrical)
 - 203.00 Service (common) and Filtering Material
 - .01 Cloth
 - .02 Ceramic
 - .03 Earth
 - .04 Fiberglas
 - .05 Paper
 - .06 Resin
 - .07 Sintered Metal
 - .08 Spaced Plates
 - .09 Wire Mesh

FIGURE 1.9

PARTIAL LIST OF COMMON COMPONENT CLASSIFICATION

203.00.00 Pressure (common)
 203.00.00.00 Operation
 .01 Chemical
 .02 Centrifugal
 .03 Electrostatic
 .04 Gravitational
 .05 Mechanical
 220 Pump
 221 Pump
 221.00 Service and Material (common)
 221.00.00 Capacity
 .10 Under 10 GPM
 .20 10 up to 100 GPM
 .30 100 up to 1000 GPM
 .40 Over 1000 GPM
 221.00.00 Type
 .01 Axial
 .02 Centrifugal
 .03 Diaphragm
 .04 Electromagnetic
 .05 Gear
 .06 Reciprocating
 .07 Rotary
 240 Heat Exchangers
 240.00 Service and Material, primary side (common)
 240.00.00 Service and Material, secondary side (common)
 240.00.00.00 Pressure (common)
 400 Tanks
 400.00 Service and Material (common)
 400.00.00 Capacity
 .10 Under 1 gallon
 .20 1 up to 10 gallons
 .30 10 up to 100 gallons
 .40 100 up to 1000 gallons
 .50 Over 1000 gallons
 400.00.00 Type
 .01 Drain
 .02 Holdup
 .03 Relief
 .04 Storage
 .05 Sump
 .06 Surge
 .07 Waste
 400.00.00.00 Pressure (common)

FIGURE 1.9 (continued)

500 Industrial Instrument

500.00 Service, Media Measured (common)

500.00.00 Type
 .10 Controller
 .20 Indicator
 .30 Meter
 .40 Switch
 .50 Testing
 .60 Transmitter

500.00.00.00 Readout
 .10 Audio
 .20 Dial
 .30 Digital
 .40 Plotting
 .50 Recording
 .60 Video

800 Nuclear Equipment

801 Flux Detector

801.00 Type
 .01 Ion Chamber
 .02 Fission Chamber
 .03 BF₃ Counter
 .04 G-M Tube
 .05 Scintillator
 .06 Semi-Conductor
 .07 Detector Lead

802 Preamplifier

803 Amplifier

803.00 Type
 .01 Linear
 .02 Log
 .03 Magnetic
 .04 Pulse
 .05 Period
 .06 Bistable

804 Power Supply

804.00 Service
 .10 Low Voltage
 .20 High Voltage

804.00.00 Voltage Rating (common)

FIGURE 1.9 (continued)

Service, Media Handled

- . 1 Air
- . 2 Gas
- . 3 Hydraulic
- . 4 Liquid Metal
- . 5 Water
- . 6 Heavy Water

Pressure Range

- . 1 Vacuum
- . 2 Ambient
- . 3 0 up to 100 psig
- . 4 100 up to 1000 psig
- . 5 Over 1000 psig

Size

- . 1 Under 1 inch
- . 2 1 up to 3 inches
- . 3 3 up to 6 inches
- . 4 6 up to 12 inches
- . 5 Over 12 inches

Voltage Rating

- . 1 Under 1 mV
- . 2 1 up to 10 mV
- . 3 10 mV up to .1 V
- . 4 1 to 100 V
- . 5 100 to 1000 V
- . 6 1 to 10 KV
- . 7 Over 10 KV

Material

- . 1 Aluminum
- . 2 Brass/Bronze
- . 3 Copper
- . 4 Steel, Carbon
- . 5 Steel, Galvanized
- . 6 Steel, Corrosion Resistant
- . 7 Nonmetallic
- . 8 Multimetallc
- . 9 Composite-Metallic and Nonmetallic

Service, Media Measured

- . 01 Flow
- . 02 Level
- . 03 Pressure
- . 04 Temperature
- . 05 Vacuum
- . 20 Conductivity
- . 21 pH
- . 22 Hydrogen Con-
centration
- . 23 Hydrazine Con-
centration
- . 24 Oxygen Con-
centration
- . 25 CO₂ Concentration
- . 30 Current
- . 31 Power
- . 32 Resistance
- . 33 Voltage
- . 40 Count Rate
- . 41 Dose Rate
- . 42 Flux
- . 43 Period
- . 50 Position
- . 51 Revolution
- . 52 Torque
- . 53 Speed
- . 54 Vibration
- . 60 Time
- . 70 Light

FIGURE 1.10COMMON SUBCLASSIFICATION

System Code	Generic Code	COMPONENT	
		Identification Number	Name
21.410	221.46.42	G50A	Safety Injection Pump
21.410	221.46.42	G50B	Safety Injection Pump
27.500	221.46.42	G3A	Feedwater Pump *
27.500	221.46.42	G3B	Feedwater Pump *
21.410	400.56.54.20		Refueling Water Storage Tank
21.410	202.56.54.52	MOV853A	Feedwater Inlet Valve
21.410	202.56.54.52	MOV853B	Feedwater Inlet Valve
27.370	202.56.35.55	CV36	Condenser Hotwell Valve
27.370	202.56.35.55	CV37	Condenser Hotwell Valve
21.410	202.56.43.14	867A06C58	Check Valve
21.410	202.56.43.14	867B06C58	Check Valve
21.410	202.56.43.14	867C06C58	Check Valve
26.132	500.01.20.60	FI912	Flow Indicator
26.132	500.01.20.60	FI913	Flow Indicator
26.132	500.01.20.60	FI914	Flow Indicator
26.132	500.01.60	FT912	Flow Transmitter
26.132	500.01.60	FT914	Flow Transmitter
26.132	500.01.60	FT914	Flow Transmitter

(*) These components normally functioning in different systems.

FIGURE 1.11
SAMPLE CLASSIFICATION OF SAFETY INJECTION SYSTEM

System Code	Generic Code	COMPONENT	
		Identification Number	Name
26.111A	801.03	NE1201	BF ₃ Detector
26.111A	801.03	NE1202	BF ₃ Detector
26.111A	802.00	NM1201.4	Preamplifier
26.111A	802.00	NM1202.4	Preamplifier
26.111A	803.02	NM1201.1	Log Count Rate Amplifier
26.111A	803.02	NM1202.1	Log Count Rate Amplifier
26.111A	001	ND1201	Power Supply Cutoff Assembly
26.111A	001	ND1202	Power Supply Cutoff Assembly
26.111A	002	NT1201	Test and Calibration Assembly
26.111A	002	NT1202	Test and Calibration Assembly
26.111A	500.04.20.60	TA1200.1	Thimble Temperature Indicator
26.111A	500.04.20.60	TA1200.2	Thimble Temperature Indicator
26.111A	500.04.40	TE1201	Thimble Temperature Detector
26.111A	500.04.40	TE1202	Thimble Temperature Detector
26.111A	500.40.20.60	NFA1201.5	Log Count Rate Alarm
26.111A	500.40.20.60	NFA1202.5	Log Count Rate Alarm
26.111A	500.40.20.60	NLA1201.1	Log Count Rate Alarm
26.111A	500.40.20.60	NLA1202.1	Log Count Rate Alarm
26.111A	500.40.30.20	NLI1201	Log Count Rate Meter
26.111A	500.40.30.20	NLI1202	Log Count Rate Meter
26.111A	500.40.20.50	NRL1201	Log Count Rate Recorder
26.111A	500.40.20.50	NRL1202	Log Count Rate Recorder

FIGURE 1.12

SAMPLE CLASSIFICATION OF NEUTRON MONITOR SYSTEM
SOURCE RANGE CHANNEL

Mode Code	Functional Failure Mode
1	Failure to close
2	Failure to open
3	Failure to start
4	Failure to stop
5	Failure to continue operation
6	Spurious failure - premature operation
7	Degradation
8	Erratic operation
9	Scheduled service
0	Scheduled replacement

FIGURE 1.13
FAILURE MODE CLASSIFICATION

Cause Code	
10	DESIGN
	11 Not suitable to normal operating conditions.
	12 Not designed to withstand design environment.
	13 Not suitable for simultaneous application of all design stresses.
	14 Useful life too short for design application.
	15 Marginal design leading to reduced performance of several parts under stress.
20	FABRICATION
	21 Configuration Abnormality
	a) Breaks or cracks.
	b) Distortion or deformation.
	c) Part left out.
	d) Presence of foreign objects, parts, or material.
	e) Improper size or shape.
	f) Depletion.
	g) Wear or abrasion.
	h) Mechanical or electrical maladjustment, including loose parts and faulty positioning.
	22 Composition Abnormality
	a) Wrong material used.
	b) Excessive impurities in component material.
	c) Change in composition or grain structure.
30	OPERATION
	31 Actual environmental stresses exceed normal stresses called for in operation.
	32 Actual operating conditions exceed those called for.
	33 Maladjustment.
	34. Operating error as a direct cause of failure.
	35 Operation beyond stipulated design life.
00	UNSPECIFIED

FIGURE 1.14
FAILURE CAUSE CLASSIFICATION

Effect Code	Failure Effect on System Performance
1	No loss of performance
2	Partial loss of performance
3	Total loss of performance

FIGURE 1.15
FAILURE EFFECT CLASSIFICATION

Use Code	Type of Use Event
0	No Operation (Plant Remains Shutdown)
1	Startup Operation
2	Continue Operation
3	Shutdown, Normal
4	Shutdown, Scram
5	System Test

FIGURE 1.16
USE EVENT CLASSIFICATION

FR/MR denotes Failure Report and Maintenance Request
O/OS denotes Operating and Outage Summary

FIGURE 1.17
RELIABILITY INPUT DATA FLOW CHART

Item	Required Information
1. Component/System	Name of component and system to which it belongs. Where two or more identical components exist in one system, individual component must be identifiable.
2. Date/Time of Failure	Occurrence or discovery of failure in day, month, year, hours, and minutes.
3. Total Repair Time	Total repair time, including off-hours, recorded to the nearest hours and maintenance man-hours.
4. Completion Time of Repair	Time when repair was completed and system became operational.
5. Functional Mode of Failure	The way in which a component failed, i. e., to close, open, start, stop, or continue operation; premature, degrading, or erratic operation; or scheduled service or replacement.
6. Cause of Failure	What made the component fail the way it did?
7. Effect of Failure on System Performance	The degree to which system performance was affected, i. e., no loss, partial loss, or total loss of performance.
8. Result of Failure on Reactor Operation	The way in which reactor operation was affected, i. e., none, shutdown or scram.
9. Description of Repair	Description of failed parts and whether they were replaced, repaired adjusted, calibrated etc.; and name of manufacturer if replaced with unit of different make.

FIGURE 1.18

REQUIRED RELIABILITY INFORMATION

TYPE OF TEST	INTERVAL BETWEEN ROUTINE TESTS	SECTION IN TECHNICAL SPECIFICATIONS
Exercise control rods.	Daily during periods of sustained power operation.	Section V-B-2
Gas treatment system checks.	Daily during periods of sustained refueling operation.	Section VIII-B-4
Operate transfer scheme for emergency section of 480 volt a-c system.	One month or less.	Section VI-B-7
Calibrate stack gas, liquid waste air vent, area monitoring systems and portable dose rate instruments.	One month or less.	Sections VII-B-2, 4, 6
Refueling Building leak rate test.	One month or less during periods of operation.	Section III-B-4
Exercise liquid poison injection valves.	One month or less during periods of operation.	Section V-B-3
Gas treatment system checks.	One month or less during periods of power operation.	Section VIII-B-5
Exercise automatically initiated dry well motor operated isolation valves.	One month or less during periods of power operation.	Section III-B-2
Check calibration of off-gas monitoring systems and test their automatic functions.	One month or less during periods of power operation.	Section VII-B-1
Calibrate emergency condenser vent monitoring systems.	One month or less during period. of power operation.	Section VII-B-3
Exercise air ejector off-gas isolation valve.	One month or less during periods of power operation.	Section VIII-B-4
Control rod drive performance.	Once each quarter.	Section V-B-2
Dry well top and bottom access head joints and suppression chamber access opening leak tests.	Prior to power operation each time these penetrations are opened.	Section III-B-1
Verify control rod following by coupling integrity check.	Prior to commencement of each refueling operation or series of low level critical tests.	Section V-B-2
Functionally test Refueling Building ventilation system automatic operation.	Prior to each regularly scheduled refueling outage.	Sections III-B-5 and VII-B-5 and 6
Functionally test all manual, motor operated, air operated and solenoid operated isolation valves.	During each regularly scheduled refueling outage.	Section III-B-2
Functionally test core spray and post incident cooling system automatic operation.	During each regularly scheduled refueling outage.	Section III-B-3
Control rod drive performance.	During each regularly scheduled refueling outage.	Section V-B-2
Functionally test all scram, automatic dry well and isolation valve closure.	During each regularly scheduled refueling outage.	Sections VI-B-1 and III-B-2
Functionally test master reactor switch.	Prior to each regularly scheduled refueling outage.	Section VI-B-3
Functionally test control rod withdrawal permissive circuits.	During each regularly scheduled refueling outage.	Section VI-B-4
Functionally test Refueling Building high differential pressure protection system.	During each regularly scheduled refueling outage.	Section VI-B-5
Functionally test emergency condenser control system.	During each regularly scheduled refueling outage.	Section VI-B-6
Dry well and suppression chamber vacuum breaker tests.	24 months or less.	Section III-B-1
Leak rate tests on sample dry well electrical penetrations.	24 months or less.	Section III-B-1
Reactor safety valves testing.	24 months or less.	Section IV-B-3
Emergency section of the 480 volt a-c system load test.	24 months or less.	Section VI-B-7
125 volt d-c system load test.	24 months or less.	Section VI-B-7
Dry well and suppression chamber leak tests.	Discussed in Section III-B-1.	Section III-B-1

FIGURE 1.19

TYPICAL OPERATIONAL TESTING SUMMARY
FOR NUCLEAR SAFEGUARDS SYSTEMS

Items	Yankee	Indian Point	Shipping-port	NPD
(1) Component/System	Yes	Yes	Yes	Yes
(2) Time of Failure	Yes	No	Yes	Yes
(3) Repair Time	No	No	Yes	No
(4) Completion Time of Repair	Yes	No	Yes	Yes
(5) Functional Mode of Failure	No	No	No	No
(6) Cause of Failure	No	No	No	No
(7) Effect of Failure on System Performance	No	No	No	Yes
(8) Result of Failure on Reactor Operation	No	No	Yes	Yes
(9) Description of Repair	Yes	Yes	Yes	Yes

FIGURE 1.20
COMPARISON OF REQUIRED INFORMATION

1. Component/System _____
2. Date/Time of Failure ____ / ____ / ____ : ____
3. Functional Mode of Failure (circle one)
Failed to (a) close (b) open (c) start (d) stop or (e) continue
operation (f) premature operation (g) degradation (h) erratic
operation (i) scheduled service (j) scheduled replacement
4. Cause of Failure (if known or required) _____

5. Effect of Failure on System Performance (circle one)
(a) no loss (b) partial loss or (c) total loss of performance
6. Effect of Failure on Plant Operation (circle one)
(a) none (b) continue operation (c) shutdown or (d) scram
7. Work to be Performed _____

8. Reported by _____

9. Work Assigned to _____
10. Date of Completion ____ / ____ / ____
11. Total Repair Time _____ hours
12. Defective/Replaced Parts _____

13. Work Performed _____

14. Name of Manufacturer (if replaced with unit of different make) _____

FIGURE 1.21

FAILURE REPORT AND MAINTENANCE REQUEST FORM
WITH REQUIRED RELIABILITY INFORMATION

DATE and TIME OF FAILURE	SHUTDOWN REQUIRED	REPAIR TIME
FAILURE MODE	FAILURE CAUSE	FAILURE EFFECT

MAINTENANCE MEMORANDUM

Nº 81913

DATE _____

WATCH _____

APPARATUS	WORK

REPORTED BY _____

WATCH FOREMAN

APPROVED FOR INTERDEPARTMENTAL WORK REQUEST _____

13-60 (EA.) 7-62 PRODUCTION

FIGURE 1.22
MODIFIED MAINTENANCE REQUEST FORM

1. Vendor's Name _____
2. Component Name _____
3. Component Identification/Generic Code _____

4. Test Date or Duration _____
5. Test Condition (circle one or describe)
(a) Life Test (b) Proof Test (c) Startup Test (d) Others _____

6. Total No. of Components Tested _____
7. Total No. of Failures _____
8. Total Operating Time _____ million comp - hr. or cy.
9. Estimate of Failure Rate _____ per million hr. or cy.
(a) Confidence Level _____ %
(b) Assumed Failure Distribution _____
10. Functional Mode of Failure by Percent of Total Failures
Failed to (a) close _____ (b) open _____ (c) start _____
(d) stop _____ or (e) continue operation _____
(f) Premature operation _____ (g) Degradation _____
11. Derating Factor by Percent of Rated
(a) Voltage _____ (b) Current _____
(c) Power _____ (d) Frequency _____
(e) Pressure _____ (f) Temperature _____
(g) Others _____
12. Other Environmental Stress Factors _____

13. Reference _____

FIGURE 1.23

VENDOR'S RELIABILITY INPUT DATA FORM

	Bits (% failures per million hours)	% Failures per 1000 hours	Failures per million hours	Failures per hour
Bits (% failures per million hours)	1	10^3	10^2	10^8
% failures per 1000 hours	10^{-3}	1	10^{-1}	10^5
Failures per million hours	10^{-2}	10^1	1	10^6
Failures per hour	10^{-8}	10^{-5}	10^{-6}	1

FIGURE 1.24

FAILURE RATE CONVERSION TABLE

CHAPTER 2

RELIABILITY ANALYSIS TECHNIQUES

CHAPTER 2

RELIABILITY ANALYSIS TECHNIQUES

An objective of this study has been to define requirements and methods of application for data collected in a reliability monitoring program. Basically, what is needed is an examination of the types of reliability analysis techniques which might be used in such a program. The range of candidate techniques either in existence or currently conceivable is large. It includes part-count models requiring all components to function, simple block-diagram models allowing credit for redundancy, more complex block-diagram models accounting for various component interdependencies and standby operation, and logical system simulation models which include human error. As the complexity of technique increases the data requirements increase and the results of the analysis technique can generally be expected to provide more realistic evaluations of the relative contributions to unreliability of the various parts of a system design. As the application of reliability analysis techniques to nuclear safety increases, it can be expected that the techniques will increase in sophistication and complexity.

Various reliability analysis methods currently in use have been investigated in the course of this study. Out of this review two methods have been selected whose data requirements are believed to represent the upper limit which might be encountered in a reliability monitoring program for reactor safeguard systems. These methods are the Automatic Reliability Mathematical Model (ARMM) and fault tree analysis. ARMM is a working, computerized reliability analysis program. Fault tree is a logical analysis concept developed during the Minuteman missile program. A preliminary fault tree computer program, SAFTE-1, has been developed during this study. Both of these methods are described in this chapter. An appreciation for the data requirements and method of data application which would be encountered in a reliability monitoring program is gained from a discussion of ARMM and fault tree. From this discussion, as well as the examples given in Chapter 3, it will be seen that either method is capable of a comprehensive reliability examination of the system, given sufficient information regarding the equipment, the design, and the methods of operation and testing of the system. Items of information which are particularly important in either method include:

1. Equipment relationships determined by both functional and physical design.

2. Significant failure modes for each item of equipment.
3. Failure rate data for each significant failure mode.
4. Time to detect and repair failed equipment.
5. Testing or inspection frequencies which reveal ability to perform or conversely failure to perform on each item of critical equipment which is not continuously monitored.
6. Normal or expected use patterns for aging of each item of equipment.

Finally, it should be noted that in either of these methods a primary limitation on the quality of results is the experience of the user. As repeated applications are made, the user will become aware of the fact that many apparently impossible configurations or sequences can be appropriately simulated. Such an observation applies equally to other promising reliability analysis techniques which were not included here.

AUTOMATIC RELIABILITY MATHEMATICAL MODEL (ARMM) PROGRAM

ARMM^(1, 2) is a general purpose computer program for deriving and solving a mathematical model of the reliability of complex systems. It is based on a sequential application of the conditional probability theorem to the probability of system failure. The program selects those combinations of component failures which cause a system failure, and derives and solves the reliability mathematical model for computing failure probabilities. The output includes (1) the probability of successful system operation; (2) the probability of occurrence of each failure combination; (3) the probability of function failure, its percentage of system failure, and rank of each function of the system; (4) each component's contribution to the probability of system failure, i.e., its percentage of the total probability and rank among the components; and (5) the component combinations which are the major contributors to system unreliability. Other useful aspects of the program are a built-in capability to handle dependent components and mutually exclusive failure modes, and the use of input data requirements which are simplified for engineers not familiar with programming methods.

ARMM was developed by North American Aviation, Inc. under contract to the U. S. Air Force. Subsequently, it has been revised and expanded to allow treatment of larger and more complex reliability models. It has been used by North American to evaluate reliability and reliability achievement in aircraft system design from the conceptual design phase through the detailed design phase. With the availability of test data it also has been found capable of calculating a system's demonstrated reliability; specific examples include analyses of systems in experimental or advanced design aircraft.

It will be noted that ARMM has limitations which can be of importance in some safeguard system reliability analyses; however, these limitations are not believed to be critical to the use of ARMM in nuclear applications. Each of the limitations and suggested modifications are discussed in the description and discussion of use which follow.

DESCRIPTION

Logical Concept

ARMM considers a system to be made up of functions which in turn are made up of components. When a function fails, the system fails if there

are no other operating or standby functions which are alternate to the failed function. The failure of a function is determined by the relative values of the "modes available" and the "modes required" which are assigned to that function. A component can support more than one function, and for each of the functions a component supports it is assigned a "weighting factor." When the component fails, the corresponding weighting factor is subtracted from the modes available of each function it supports. When the modes available of a function become (by this subtraction at each component failure) less than the modes required, the function has failed.

A component is the smallest piece of equipment the reliability analyst wants to consider and for which he has failure rate data. If a piece of equipment has several modes of failure, each mode can be considered as a unique component if there is failure rate data for the different modes. If the failure modes of a piece of equipment are mutually exclusive, i.e., the failure in one mode excludes the possibility of failure in another (e.g., a valve failing open cannot fail closed at the same time), this can be described to the program by making one mode-component a "must not fail" dependent component on the other mode-component. If two components are physically dependent on each other, e.g., a pump and its motor, but not mutually exclusive, this dependency is input to the program as a "must fail" dependency. This latter type of dependency can also be used between components which, though not physically dependent, are dependent in such a way that the failure of one makes consideration of failure in the other superfluous. Use of "must fail" dependency is especially helpful in reducing computer time.

Mathematical Bases

Application of the Conditional Probability Theorem to Reliability - What follows is a determination of the probability of system failure by the application of the conditional probability theorem. The system to be used throughout this discussion is shown in Figure 2.1. It consists of five components arranged on three "success paths." So long as the components on at least one success path are operating, the system has not failed.

According to the conditional probability theorem, the probability of system failure can be written as:

$$P(S) = P(S/A) P(A) + P(S/\bar{A}) P(\bar{A}) \quad (1)$$

where

- S = system failure,
- A = component A is working (not failed),
- $\bar{A}$ = component A has failed (the bar over the component name signifies the component has failed),
- P(S) = probability of system failure,
- P(S/A) = probability of system failure given that component A has not failed,
- P(S/ $\bar{A}$) = probability of system failure given that component A has failed,
- P(A) = probability that component A has not failed, and
- P($\bar{A}$) = probability that component A has failed.

The probability that component A has or has not failed is determined by the failure density function for the component. Evaluated at time t the probability of failure is

$$P(\bar{A}) = \int_0^t f_A(t) dt \quad (2)$$

and the probability of no failure is

$$P(A) = 1 - P(\bar{A}) \quad (3)$$

where

- $f_A(t)$ = failure density function for component A,
- $f_A(t) = \beta \alpha t^{\beta-1} e^{-\alpha t^\beta}$,
- β = Weibull shape parameter. If $\beta = 1$, $f_A(t)$ becomes the exponential failure density function, and
- α = Weibull scaling parameter. If $\beta = 1$, α becomes the failure rate, λ .

Given Equations (2) and (3), the probability of system failure $P(S)$ requires that $P(S/\bar{A})$ and $P(S/A)$ also be evaluated. These terms can be defined by a stepwise application of the conditional probability theorem to the system shown in Figure 2, 1. If A has not failed, the system can fail only if components B , C , and D or D or E also fail. The following equations state this in the notation of Equation (1):

$$P(S/A) = P(S/A, B) P(B) + P(S/A, \bar{B}) P(\bar{B}). \quad (4)$$

Since the system will not fail if both A and B are operating then

$$P(S/A, B) = 0$$

and Equation (4) reduces to

$$P(S/A) = P(S/A, \bar{B}) P(\bar{B}). \quad (4a)$$

The probability of system failure given that B has failed is evaluated as:

$$P(S/A, \bar{B}) = P(S/A, \bar{B}, C) P(C) + P(S/A, \bar{B}, \bar{C}) P(\bar{C}). \quad (5)$$

The first term on the right is zero since the system cannot fail if C has not failed. Equation (5) becomes

$$P(S/A, \bar{B}) = P(S/A, \bar{B}, \bar{C}) P(\bar{C}) \quad (5a)$$

The probability of system failure given that C has failed is evaluated as:

$$P(S/A, \bar{B}, \bar{C}) = P(S/A, \bar{B}, \bar{C}, D) P(D) + P(S/A, \bar{B}, \bar{C}, \bar{D}) P(\bar{D}). \quad (6)$$

Since Equations (4a) and (5a) say that B and C have failed, then if D fails the system fails (i. e., $P(S/A, \bar{B}, \bar{C}, \bar{D}) = 1$). All that remains to be evaluated so that Equation (4a) can be expressed in terms of unconditional component probabilities is the factor $P(S/A, \bar{B}, \bar{C}, D)$. It is evaluated by

$$P(S/A, \bar{B}, \bar{C}, D) = P(S/A, \bar{B}, \bar{C}, D, E) P(E) + P(S/A, \bar{B}, \bar{C}, D, \bar{E}) P(\bar{E}) \quad (7)$$

In Equation (7) D has not failed, so $P(S/A, \bar{B}, \bar{C}, D, E) = 0$ for if D and E have not failed, there remains an unfailed success path. But if E fails then the system fails so $P(S/A, \bar{B}, \bar{C}, D, \bar{E}) = 1$. It is now possible to rewrite Equation (4a) as;

$$P(S/A) = [1 - P(E) P(D)] [1 - P(C)] [1 - P(B)]. \quad (8)$$

The other unknown in Equation (1), $P(S/\bar{A})$, can be evaluated in a manner similar to Equations (4) through (8)

$$P(S/\bar{A}) = P(S/\bar{A}, B) P(B) + P(S/\bar{A}, \bar{B}) P(\bar{B}). \quad (9)$$

Since A has failed

$$P(S/\bar{A}, B) = P(S/\bar{A}, \bar{B}) \quad (10)$$

which has been evaluated by Equations (5a), (6), and (7). So Equation (9) can be rewritten as:

$$P(S/\bar{A}) = [1 - P(E) P(D)] [1 - P(C)]. \quad (11)$$

If Equations (8) and (11) are substituted into Equation (1), the probability of system failure is:

$$P(S) = [1 - P(E) P(D)] [1 - P(C)] [1 - P(A) P(B)]. \quad (12)$$

The probability of system failure for the simple system of Figure 2.1 could have been obtained by recognizing that for this system, with redundant success paths, the probability of failure is the product of the probabilities of failure of each of the success paths. In more complex systems, solution by inspection is difficult if not impossible and the value of this approach is apparent.

ARMM's Use of the Conditional Probability Theorem - ARMM's analysis of the system in Figure 2.1 is, of course, that of a computer. Therefore, it is a sequential application of the conditional probability theorem rather than an "it is clear that ..." approach. ARMM proceeds down the list of components searching for combinations of failed components which cause the system to fail. The user specifies the maximum number of failed components ARMM needs to consider in a combination. Table 2.1 lists, in the proper order, the combinations ARMM would consider for the system in Figure 2.1 if the maximum number of failed components allowed per combination were four.

Note that after the system has failed, it is returned to operation by turning on the last failed component. This is first met by ARMM with the combination $\bar{A}\bar{B}\bar{C}\bar{D}$. Component D is turned on and for the next combination E is failed.

If no system failure occurs with the failure of four components as with the combination $\bar{A}\bar{B}\bar{C}\bar{D}\bar{E}$ then as with a system failure the last failed component is turned back on. However, in this example the last failed component is the last component on the list. What ARMM does here is turn on B and D as well and then fail C.

If the user had specified that component B was a "must fail" dependent component to component A then ARMM would not consider any combination with both A and B failed. So fewer combinations are considered by the program which means a savings in time.

Without the dependency and as shown in Table 2.1, there are six failure combinations. They are: $\bar{A}\bar{B}\bar{C}\bar{D}$, $\bar{A}\bar{B}\bar{C}\bar{D}\bar{E}$, $\bar{A}\bar{B}\bar{C}\bar{D}$, $\bar{A}\bar{B}\bar{C}\bar{D}\bar{E}$, $\bar{A}\bar{B}\bar{C}\bar{D}$, and $\bar{A}\bar{B}\bar{C}\bar{D}\bar{E}$. With the dependency there are four: $\bar{A}\bar{C}\bar{D}$, $\bar{A}\bar{C}\bar{D}\bar{E}$, $\bar{A}\bar{B}\bar{C}\bar{D}$, and $\bar{A}\bar{B}\bar{C}\bar{D}\bar{E}$. Note that since $P(B) + P(\bar{B}) = 1$, these two lists are the same. The first list required more computer time. If only three components were allowed to be failed at a time, and a look at Figure 2.1 shows that really that is all that is necessary, then the two lists would not be the same and there would be an error in the results of the run without the dependency.

The probability of system failure is the sum of the probability of occurrence of each of the failure combinations. For the failure combination $\bar{A}\bar{B}\bar{C}\bar{D}\bar{E}$, the probability of its occurrence is calculated by ARMM as:

$$P(\bar{A}\bar{B}\bar{C}\bar{D}\bar{E}) = P(\bar{B}) P(\bar{C}) P(\bar{E}) [1 - P(\bar{A} + \bar{D})] \quad (13)$$

where

$$\begin{aligned} P(\bar{A} + \bar{D}) &= \text{probability that A or D or both fail,} \\ P(\bar{A} + \bar{D}) &= P(\bar{A}) + P(\bar{D}) - P(\bar{A}) P(\bar{D}) = 1 - P(A) P(D), \\ P(A) &= 1 - P(\bar{A}), \text{ and} \\ P(D) &= 1 - P(\bar{D}). \end{aligned}$$

The factor in brackets in Equation (13) is the probability that neither A nor D fail. The probability of system failure, SF, during each time

interval, is obtained by summing the probability of occurrence of each of the N failure combinations

$$SF_i = \sum_{k=1}^N P_k \text{ (failure combination } k \text{ in time interval } i). \quad (14)$$

This sum is the probability of system failure during time interval i .

The probability that the system has failed by the start of time interval i is given by the relation:

$$TSF_i = TSF_{i-1} + (1-TSF_{i-1}) SF_{i-1} \quad (15)$$

where by convention

$$TSF_0 = 0$$

and, therefore,

$$TSF_1 = 0$$

$$TSF_2 = SF_1.$$

For example, the probability that the system has failed by the start of the third interval $i = 3$ is:

$$TSF_3 = SF_1 + (1-SF_1) SF_2. \quad (16)$$

Equation (16) can be read as the probability that the system failed in interval one plus the product of the probability that it failed in interval two and the probability that it did not fail in interval one. This product suggests the use of the "good as new" approximation for all components at the beginning of each time interval.

Originally, ARMM evaluated the probability of failure of each component for the time interval i from t_i to t_{i+1} by Equation (17)

$$P(\bar{B}) = \int_{t_i}^{t_{i+1}} f_B(t) dt. \quad (17)$$

This does not incorporate the "good as new" approximation. This equation has been changed so that the limits of integration are now from 0 to $(t_{i+1} - t_i)$ which does reflect the "good as new" approximation.

A comparison of the different integration limits can be made as follows. For the exponential density function

$$P^{(1)}(t_{i+1} - t_i, 0) = P^{(1)}(t_{i+1}, t_i) e^{\lambda t_i} \quad (18)$$

where the superscript in parenthesis specifies the value of β .

Here the factors in the argument of P are the upper and lower limits to the integral, respectively. Equation (18) shows that the error in using the limits of Equation (14) is small if λt_i is small. When Weibull distributions are used, the following relation obtains:

$$P^{(\beta)}(t_{i+1} - t_i, 0) = P^{(\beta)}(t_{i+1}, t_i) e^{\alpha t_i^\beta \left[\frac{P^{(1)}([t_{i+1} - t_i]^\beta, 0)}{P^{(1)}(t_{i+1}^\beta - t_i^\beta, 0)} \right]}.$$

$$P^{(1)} \rightarrow P^{(\beta)}, \quad \beta = 1. \quad (19)$$

Hence the values of α and β used will determine the difference involved in using the two sets of limits.

The probability that the unfailed components in the failure combination of Equation (13) do not fail is calculated as:

$$[1 - P(\bar{A} + \bar{D})] = 1 - \int_0^{t_{i+1} - t_i} [(\lambda_A + \lambda_D) e^{-(\lambda_A + \lambda_D)t}] dt. \quad (20)$$

Equations (17) and (20) use the exponential failure density function. ARMM in its present form also is able to use the Weibull failure density function in Equation (17) but not in Equation (20). Equation (20) was generalized in this study to include a Weibull failure density function. This yields

$$[1 - P(\bar{A} + \bar{D})] = 1 - \int_0^{t_{i+1} - t_i} \left[\beta_A \alpha_A t^{\beta_A - 1} + \beta_D \alpha_D t^{\beta_D - 1} \right] e^{-\left[\alpha_A t^{\beta_A} + \alpha_D t^{\beta_D} \right]} dt. \quad (21)$$

The result obtained using Equation (12), and the result obtained by ARMM, Equation (14), are identical for the simple system of Figure 2.1. So for simple systems ARMM gives the same result for system failure during an interval as the conditional probability theorem. For complex systems, since ARMM limits the number of components failed in a failure combination, the results will not be identical to those of the conditional probability theorem. However, Equation (13) shows that the probability of system failure is proportional to the product of the probabilities of failure of each failed component, so for a failure combination with many failed components its contribution to the probability of system failure will be small. However, significant errors can result for simple systems when not enough failures are allowed.

System Probability - Bayes' theorem states:

$$P(\bar{A}/S) = \frac{P(S/\bar{A}) P(\bar{A})}{P(S)} \quad (22)$$

where $P(\bar{A}/S)$ is the probability, that given the system has failed, it was caused by the failure of component A. In other words, it is A's contribution to system failure (or to system unreliability).

ARMM calculates the contribution of each of the components, j, to system unreliability in time interval i by the equation:

$$P_i(j/S) = \frac{C_{ij} SF_i (1 - TSF_i)}{a_i} \quad (23)$$

where

$$C_{ij} = \sum_{k=1}^n \frac{\lambda_j}{\lambda_{fc, k}} \left[\prod_{\ell=1}^m P_{\ell} \right]_k \quad (24)$$

$$\lambda_{fc, k} = \sum_{l=1}^m \lambda_{l, k} \quad (25)$$

$\lambda_{l, k}$ = failure rate of component l which was involved in failure combination k ,

m = number of failed components in a given failure combination,

P_l = probability of failure of component l ,

n = number of failure combinations in which component j was involved,

$$a_i = \sum_{j=1}^N C_{ij}, \text{ and} \quad (26)$$

N = number of "on" components during interval i .

The factor C_{ij} is the sum of the contributions component j makes to each failure combination of which it is a failed component. Its contribution is determined by the ratio of failure rates. For example, for component A in the failure combinations $\bar{A}\bar{C}\bar{D}$ and $\bar{A}\bar{C}D\bar{E}$

$$C_{i, A} = \left[\frac{\lambda_A}{\lambda_A + \lambda_C + \lambda_D} \right] P(\bar{A}) P(\bar{C}) P(\bar{D}) + \left[\frac{\lambda_A}{\lambda_A + \lambda_C + \lambda_E} \right] P(\bar{A}) P(\bar{C}) P(\bar{E}) . \quad (27)$$

The contribution of component j to system unreliability $P_i(j/S)$ is included in the ARMM output for each time interval that component j

has not been turned off by the user. It is also part of the summary output which is the sum of system performance for all the time intervals. The contribution of component j to system unreliability for the entire time, $P_T(j/S)$, is given by:

$$P_T(\bar{j}/S) = \sum_{i=1}^N P_i(\bar{j}/S) \quad (28)$$

for N time intervals.

If component j was turned off during an interval, the $P_i(\bar{j}/S)$ for that interval is zero.

Standby Functions - ARMM can also handle standby functions. These are functions which do not operate until the function to which it is standby fails.

In Figure 2.1, for example, the function which is composed of components D and E could be standby to the function which is composed of component C .

The probability of occurrence of a failure combination which includes a failed standby component is calculated by an equation which is a modification of Equation 13. Since component E is, for this consideration, a standby component which, along with component D , was brought into operation by the failure of component C , the product $P(\bar{C}) P(\bar{E})$ in Equation 13 is replaced by:

$$P(\bar{C}\bar{E}) = \int_0^{t_{i+1}-t_i} \frac{\lambda_C \lambda_E}{(\lambda_C - \lambda_E)} \left[e^{-\lambda_E t} - e^{-\lambda_C t} \right] dt \quad (29)$$

if $\lambda_C = \lambda_E = \lambda$ then:

$$P(\bar{C}\bar{E}) = \int_0^{t_{i+1}-t_i} \lambda^2 t e^{-\lambda t} dt \quad (30)$$

The general form for Equation 29, as used in ARMM, is

$$P(n \text{ failures}) = \int_0^{t_{i+1}-t_i} \frac{\prod_{j=1}^n \lambda_j}{\lambda_1 - \sum_{j=2}^n \lambda_j} \left[\exp\left(-\sum_{j=2}^n \lambda_j t\right) - \exp\left(-\lambda_1 t\right) \right] dt \quad (31)$$

where

λ_1 = failure rate of the operating component whose failure "turns on" all $n-1$ standby components, and

$P(n \text{ failures})$ = probability that the operating component and all of its standby components fail.

Equation 31 is for an operating component, and $n-1$ standby components all of which are brought into operation at the time the operating component fails. In the system in Figure 2.1, D and E are standby to C and both are turned on when C fails; however, the system fails with either component D or E failed, so n equals 2 for this system.

Equation 31 was derived by making the assumption that when the standby components were turned on, the probability of system failure could be written as the product of the probabilities of failure of the individual components. This yields Equation 31 which does not contain the limiting values of one and zero for large and small times, respectively.

Consider a simple standby model with three components A, B, and C, each having exponential failure densities. Component A operates and when it fails both B and C are turned on. System failure occurs when all three components fail. The correct expression for system failure probability in this case is

$$P(t, 0) = 1 - \left[\frac{\lambda_A e^{-\lambda_B t} - \lambda_B e^{-\lambda_A t}}{\lambda_A - \lambda_B} + \frac{\lambda_A e^{-\lambda_C t} - \lambda_C e^{-\lambda_A t}}{\lambda_A - \lambda_C} + \frac{\lambda_A e^{-(\lambda_B + \lambda_C)t} - (\lambda_B + \lambda_C) e^{-\lambda_A t}}{\lambda_A - (\lambda_B + \lambda_C)} \right] \quad (32)$$

The expression for $P(t, 0)$, based on the assumption of product probabilities, is from Equation 31

$$P(t, 0) = \frac{\lambda_B \lambda_C}{\lambda_B + \lambda_C} - \frac{\lambda_A \lambda_B \lambda_C}{\lambda_A - (\lambda_B + \lambda_C)} \left[\frac{e^{-(\lambda_B + \lambda_C)t}}{(\lambda_B + \lambda_C)} - \frac{e^{-\lambda_A t}}{\lambda_A} \right]. \quad (33)$$

An estimate of the difference between the two expressions has not been made. Equation 31 is exact for $n = 2$.

ARMM, in its present form, does not allow for sequential activation of standby functions. That is, it does not consider a system wherein there is a standby function which turns on when another standby function fails. An expression for this configuration was obtained using a three component system model which covers most practical cases. The result is

$$P(t, 0) = 1 - \left[\frac{\lambda_B \lambda_C e^{-\lambda_A t}}{(\lambda_B - \lambda_A)(\lambda_C - \lambda_A)} + \frac{\lambda_A \lambda_C e^{-\lambda_B t}}{(\lambda_A - \lambda_B)(\lambda_C - \lambda_B)} + \frac{\lambda_A \lambda_B e^{-\lambda_C t}}{(\lambda_A - \lambda_C)(\lambda_B - \lambda_C)} \right]. \quad (34)$$

Also, ARMM does not consider Weibull failure density functions for standby functions; it considers only the exponential. In extending this analysis to include Weibull densities, one obtains expressions which are not integrable in closed form. Hence, double integrals will appear and numerical procedures will have to be developed to handle them.

Function Contribution to Unreliability - Included in the ARMM output is the function contribution to unreliability for each function. The one exception of this is when a function has a standby function, then the

contribution of the functions is assigned to its standby. The function contribution for function (m) in time interval (i) is calculated by:

$$P_i (\text{function } m/S) = \frac{(1-TSF_i) SF_i \left[\sum_{k=1}^a \left(\prod_{\ell=1}^n P_{\ell} \right)_k \right]_m}{\sum_{m=1}^N \left[\sum_{k=1}^a \left(\prod_{\ell=1}^n P_{\ell} \right)_k \right]_m} \quad (35)$$

where

n = number of failed components in a given failure combination whose failure is attributed to function m,

a = number of failure combinations whose failure is attributed to function m, and

N = number of failure combinations in time interval i.

A failure combination is attributed to the function supported by the last failed component in that combination. For this reason, it is possible to have two parallel or redundant functions with the same type of components and yet different contributions to unreliability.

The contribution for a function for the entire time is given by the sum of its contribution for each interval it is on.

Serial Probability - The serial probability is the contribution each "on" component makes to system unreliability if all the "on" components in the system are in series. It is calculated by the equation:

$$SP_{ij} = \frac{\lambda_j}{\lambda_T} (1 - \kappa_{i-1}) P_i \quad (36)$$

where

$$P_i = \int_0^{t_{i+1}-t_i} \lambda_T e^{-\lambda_T t} dt,$$

$$\lambda_T = \sum_{j=1}^n \lambda_j ,$$

λ_j = the failure rate of component j ,

n = number of "on" components,

$\kappa_i = \kappa_{i-1} + (1 - \kappa_{i-1}) P_i$, and

$\kappa_0 = 0$.

The factor, $(1 - \alpha_{i-1})$, is the probability that there has been no component failure up to the start of interval i .

The serial probability for the entire time is calculated by

$$SP_{jT} = \frac{\lambda_j \Delta T_j}{\sum_{j=1}^m \lambda_j \Delta T_j} \kappa_N \quad (37)$$

where

ΔT_j = total operating time of the j th component during the N time intervals.

κ_N = the probability of at least one component failure in the total operating time $t = 0$ to $t = t_{N+1}$.

The value of the serial probability is of little significance in systems possessing extensive amounts of redundancy. It does allow a conservative estimate of component contribution to unreliability in complex systems containing extensive cross linking.

USE OF ARMM

As previously indicated, ARMM has been designed for use by engineers who do not have computer experience. To use ARMM to analyze the reliability of a system one is required to (1) prepare a reliability diagram of the system, and (2) identify the functions and their supporting components. Subsequently the information presented in the diagram is translated to numeric and alphanumeric input data.

The function and component summary sheet shown in Figure 2.2 is an aid in organizing the input data. The components are assigned a weight for each function they support. Also, the components are assigned failure rates and the functions are assigned "modes available" and "modes required." The relationship between modes available, modes required, and component weight is developed in detail in subsequent discussions of fields 4B and 5B.

Each of the seven input forms shown in Figures 2.3 through 2.9 has been subdivided into data fields for appropriate input information. The fields are marked with vertical lines and have appropriate headings. Each line or row on a form corresponds to a single punch card of information. In each row columns 73 to 80 are used for assigning card identification or card sequencing numbers which assure correct arrangement of a complete input data deck.

It also should be noted that some of the input data must be given in fixed point numbers, e. g., 386, while other portions of the data must be in floating point numbers, e. g., 386.0. Fixed point numbers must be right adjusted, i. e., placed in the right hand columns within the field. The data fields that require a floating point number have a notation to that effect in the heading. The other fields use only fixed point numbers.

A review of the requirements for filling out each input form follows:

Form A-General Information - Rows 1 through 7

Field 1A - Columns 1 through 3 (Number of Components) - This field instructs the program about the number of components for which it will expect to read input information. This number must agree with the actual number of components for which input information has been provided or the program will reject the problem. The program will handle a maximum of 500 components.

Field 2A - Columns 4 and 5 (Number of Time Intervals) - Every problem must consider 1 or more time intervals. The program is capable of considering a maximum of 20. If the number in this column is not the same as the number of time intervals for which information is provided in Form G entries, the program will not accept the problem.

Field 3A - Columns 6 through 10 (Operating Time) - The operating time is the length of time in hours from the beginning of the first time interval to the end of the last time interval. A floating point number should be used.

Field 4A - Columns 11 through 13 (Maximum Number of Components Failed at a Time) - This field is used to regulate the amount of detail that is to be used in the analysis, which in turn helps regulate the machine time required by the problem. As the maximum number of failed components is increased the machine time increases at a rate greater than that indicated by the linear rate of change in this number. Therefore, the maximum number of failed components considered must be judiciously selected to preserve sensitivity and yet limit computer run time.

Although the value of this number may be 8 or less, it is suggested that as a rule 3 or 4 will give an adequate level of sensitivity without excessive machine time for systems with limited redundancy. For highly redundant systems excessive run times may result if this number is greater than 2 or 3. In this case the depth control feature can then be used to consider failure combinations of a higher number for specific components. As discussed in Field 13C, the depth control allows specific adjustment of the maximum number of failed components considered with any given component. Thus, internal sensitivity control is provided elsewhere in the data, and the overall input level in Field 4A may be set lower than that considered for specific components.

Field 5A - Columns 14 through 16 (Number of Functions) - This input information tells the program the number of functions for which it must read input information. The program will handle a maximum of 300 functions.

Field 6A - Columns 17 and 18 (Number of Integration Intervals) - ARMM calculates probability of failure by integrating a failure density function using Simpson's Rule. Simpson's Rule requires a division of the integration interval into subintervals. The input information gives the program the number of subintervals to use in the integration. The program can accept a maximum of 24 subintervals. As a rule 10 intervals should be sufficient.

Field 7A - Column 19 (Print Equation) - This field should always have a 1.

Field 8A - Column 20 - This field is not used.

Field 9A - Columns 21 through 23 - This field is not used.

Field 10A - Column 24 (Insert Partial Data) - A zero (0) in this column instructs the program to erase all previous data and prepare to read all input data required for this problem. A one (1) in this column instructs the program to keep the input data from the previous problem and prepare to replace portions of the data. There are only certain portions of the data in this program which can be changed without reading all of the input data. These portions are:

1. The number of modes available for a function. Field 4, Columns 25 through 28 of Form B.
2. The number of modes required for a function. Field 5, Columns 29 through 32 of Form B.
3. A component's name, failure rate, beta value for the Weibull distribution, and depth control. These are in Fields 3, 5, 6, 7, 12, and 13 of Form C.
4. Cumulative time to the start of this time interval. Field 3 of Form G. Probability of failure for this time interval. Fields 5 and 6 of Form G.

Field 11A - Columns 25 through 27 (Number of Major Contributors to System Unreliability)- The program can list from 1 to 100 combinations of failed components which cause system failure. Also, it will rank them and print the major combinations. This input governs the number of failure combinations which the program will list. Of course, if there are only X combinations it will only print X combinations if that is less than this input. As a rule it is not necessary to specify a value in this field.

Field 12A - Columns 30 through 72 (Problem Name) - These 42 spaces are provided for the problem name. Any FORTRAN symbol may be used. This name will be printed on each page of the output.

Form A - Descriptive Information - Rows 8 through 27 - Columns 3 through 68 - This space is reserved for any descriptive purpose to which the engineer may wish to apply it. It will accept and reproduce in the output any FORTRAN character. Examples of the use of this capability are a problem description and assumptions made in the analysis.

Each card used for this purpose must be identified with a four (4) in Column 2. A maximum of 55 cards may be used for this purpose.

Form B - Function Data

This form organizes entries for input information describing the system in terms of functions. Each card will contain the information for one function.

Field 1B - Columns 1 and 2 (Function Input Card Identification) - A 1 in Column 2 will identify this information as function information to the program. If a 1 is not in Column 2 of each function card, the program will give an error statement and proceed to the next card or job. In either case, the analysis will not be done.

Field 2B - Columns 3 through 6 (Function ID Number) - The program will accept any integer of 3 digits or less. They do not need to be in any order or have a numbering scheme. The program uses internal index numbers, but will always print the ID numbers. Standby functions are identified by a (-) in Column 3.

Field 3B - Columns 7 through 24 (Function Name) - The program will accept an 18 letter name for each function. It will print this name in the input data printout and again in the output. This feature aids in the analysis of the problem printout.

Field 4B - Columns 25 through 28 (Number of Modes Available) - The number to be placed in this field is a numerical value which is given to a function when all components which support the function are in operating condition. As components supporting the function fail, they detract from the operability of the function and when a sufficient number of supporting components have failed the function will be failed. To reflect this change in function operability each component is given a "weighting factor" in each function that it supports. When a component fails, the program subtracts the component weighting factor from the "number of modes available" assigned to each function supported by the component.

A floating point number should be used in this field.

Field 5B - Columns 29 through 32 (Number of Modes Required) - The number to be placed in this field is a floating point number which is used by the program to determine when sufficient component failures have occurred to cause function failure. The program recognizes a function failure when it finds the number of modes available for the function has been reduced to less than the number of modes required.

Field 6B - Columns 33 through 36 (Number of Alternate Functions) - An alternate function is a function which is capable of doing the same job. This input information states the number of function ID's which are alternate to a given function. There is a maximum number of 1100 alternate functions for the problem.

Field 7B through 14B - Columns 37 through 72 in Width (Alternate Functions) - Use only the ID number of the appropriate alternate function. Standby functions are considered to be alternate functions. However, when a standby function is listed as an alternate function, the minus sign should not be used here. Alternate functions should be listed in increasing numerical ID numbers, one function for each 4 column field. The function numbers should be right adjusted and should not have more than 3 digits. If the function has as an alternate a series of functions all of which must work, e.g., function 10 has as alternate functions 20, 30, and 40 and they all must work, then an "A" must be put in the first column of the field of each of the alternate functions in the series except the first alternate function of the series. The "A" signifies the word "and" and indicates to the program that all A connected functions in the series must work to provide an effective alternate function. In the example above, the alternate functions would be input as __20A_30A_40. From the standpoint of program capacity, each function in a series counts as an alternate function. If more than 9 alternate functions are needed, the additional functions should be entered on a following function card with a 1 in Column 2 and alternate function number entries beginning in the field defined by Columns 37 through 40.

Component Information

Forms C, D, and E are used to input information about a single component. When assembling the cards for a specific component, the card from the entry on Form C must be followed by cards from entries on Forms D and E which pertain to the same component if there are numerical entries in Fields 8 and 9 of Form C. There will always be a positive entry in Field 8.

Form C - Component General Information

Field 1C - Columns 1 and 2 - A 2 in Column 2 identifies this card as one which contains component information. Therefore, a 2 must appear in Column 2 of every row used on this page.

Field 2C - Columns 3 through 9 (Component ID Number) - These seven spaces are available for component identification. They provide space for a 3-digit component ID number, a decimal point, and a 2-digit subsystem

identification number which may be used by the programmer for reference information; e. g., the particular failure mode being considered. The subsystem number and the decimal point need not be used; however, in either case, the component ID number should be right adjusted in Field 2C.

Field 3C - Columns 10 through 27 (Component Name) - These 18 spaces are to be used for an alphanumeric component name. They are placed in temporary storage and printed beside the component ID numbers when the input and output data is printed.

Field 4C - Columns 28 through 32 - This field is not used.

Field 5C - Columns 33 through 39 (Cyclic Failure Rate) - This field is to be used only if the component operates cyclically and has a cyclic failure rate. If the component operates continuously, then this field should be left blank. When it is used, the failure rate must be expressed as failures per million cycles. A floating point number must be used.

Field 6C - Columns 40 through 46 (Average Number of Cycles per Hour) - This field must be used if and only if Field 5C is used. A floating point number must be used.

Field 7C - Columns 47 through 54 (Continuous Failure Rate) - If a component operates continuously throughout the time intervals under consideration, then its failure rate must be listed here. The failure rate must be expressed as the number of failures per million hours. A floating point number must be used. If the Weibull function is used for this component, then the input in this field is the parameter α .

Field 8C - Columns 55 through 57 (Number of Functions Supported) - The effect on the system of the failure of components is determined by the effect on the functions that the component supports. The number input in this field is the number of functions in which the component is involved. Since a component may support every function, it can support a maximum of 300 functions. The sum of the numbers placed in this section for every component in the problem must not exceed 1200. If a 0 is placed in this column, the program will not read a card from Form E. If this number is greater than 10, then the program will expect 2 cards from Form E to follow the component card. For each additional 10, the program will expect another card from Form E. A fixed point number must be used and it must be written as far to the right of the field as possible, i. e., it must be right adjusted.

Field 9C - Columns 58 through 60 (Number of Dependent Components) - A component can have 3 kinds of dependent components. They are (1) the "must fail" type of dependent component, (2) the "must not fail" type of dependent component, and (3) the series dependent component. Each will be identified on Form D.

A "must fail" type of dependent component is one which ceases to operate upon failure of the component upon which it is dependent. An example would be a pump which is dependent on a motor because when the motor fails, the pump ceases to perform its function. Clearly, it cannot subsequently fail, so it is taken out of consideration by the program.

A "must not fail" type of dependent component is one which cannot fail when the component on which it is dependent fails. It can be used to represent mutually exclusive failure modes of a single physical component; e. g. , a flip-flop switch which if it fails open in one circuit must fail closed in another circuit. Another example is a valve which can fail either open or closed. These modes of failure can have different effects on the system. Once the valve is considered failed open, it cannot be considered failed closed. Each of these modes of failure is dependent on the other. To consider different failure modes of a single physical component, the physical component must be read into the program as several components.

When components are arranged in a series configuration in a function, some of the components may cease operation upon the failure of an earlier component in the series, while others may not. Those that cease operation have already been mentioned as "must fail" components. Subsequent failures of those components in the series, which are not of this type, have no effect on the system failure, since a preceding failed component has already caused function failure. Hence, these operating components can be taken out of consideration without altering the result and thereby reduce the number of combinations to be considered by the program. So, a component which is in series with and fails after another component whose failure makes its consideration superfluous is considered to be series dependent and may be listed as a "must fail" dependent component.

Components of the first and third type are handled alike. They are listed on Form D with a minus preceding their ID number. Their information must be listed after the information for the component upon which they are dependent.

Components of the second type are listed on Form D without a sign preceding their ID numbers. As an example, consider a switch which may fail open or closed. Let Components 1 and 2 be the switch failing open and closed, respectively. A (2) must be listed on Form D so that it appears in a proper place in the information about Component 1, and a (1) must be listed on Form D so that it appears in the information about Component 2.

If a (0) is placed in Field 9, the program will not look for a card from Form D. For each 18 dependent components, or part thereof, a card from Form D must be coded to follow the component card.

A single component may have any number of dependent components, but the total for all components must not exceed 500.

Field 10C-Column 61 - This field is not used.

Field 11C-Column 62 - This field is not used.

Field 12C-Columns 63-67 (Weibull Shape Parameter) - The program has been coded to use a value of 1.0 for the shape parameter of a component if no number or 0.0 is put in this field. If other values are desired, then they must be put into this field as a floating point number.

Field 13C - Column 68 (Depth Control) - This number controls the maximum number of components which can fail in a failure combination headed by the failure of this component. For this component only it overrides the value of Field 4A of the general information card. Depth control can be used to avoid superfluous consideration of failure combinations, in which a component failure makes no contribution to system failure. Conversely, it allows consideration of failure combinations for a specific component involving more failed components than allowed by the number of Field 4A.

Form D - Dependent Component Information

If Field 9C of the component card is empty or has a zero (0), then no information is required on this form. If Field 9C of the component card has a positive integer, then the fields on Form D must be coded with right adjusted, component ID numbers until the number of fields filled equals that number on the component card. Do not skip any fields. Each field is 4 columns wide.

If a component is a "must fail" type of component, then it must be coded with a minus sign preceding its ID number on this card. Place the minus sign in the first column of the section. If the component is a "must not fail" type, then the first column should be left blank.

The program's analysis will not be correct if a component's "must fail" type of dependent components are listed in the input data before it. For example, if Component 20 is dependent on 10, then the cards for 10 must precede those for 20. The program has been coded to print an error statement and to refuse to execute if it finds any "must fail" type of dependent component earlier in the on-component array than the component upon which it is dependent.

Form E - Functions Supported Information-10 Per Card-Each Field
has 7 Columns

This form has ten 7-column data fields on each line. The first three columns in each field are for the ID of the function which is supported by a component. Do not use any minus signs to differentiate between operating functions and standby functions here. Use only the function ID number.

The last 4 columns in each data field are reserved for the component weight or weighting factor in the respective supported functions. The corresponding component weighting factor will be subtracted from the "modes available" of each of the supported functions upon failure of the component. Thus the weighting factor represents the effect of a component on the operation of a function. This number can be an integer if it is right adjusted. It also can be any nonnegative decimal number which appropriately represents the effect of the component on the function. The number of weighting factors assigned to each component must be equivalent to the number of functions supported as listed in Field 8C. If they are not equal, the program will print an error statement and refuse to execute the problem. If a component supports more than 10 functions, then an additional card should be used from Form E for each additional 10 functions.

The weighting factor for a component in support of a given function must be greater than the difference between modes available (MA) and modes required (MR) for the function, if failure of the component will cause function failure. If two components must fail to cause function failure, then the sum of the failed component weighting factors must be greater than the difference given by MA-MR. Similar analogies are used in larger component failure combinations.

Form G - Time Profile Information

Field 1G - Columns 1-2 Input Card Type 3 - The program will recognize this information as time profile information if it finds a "3" in Column 2 on every card concerning the time profile. Every row coded on this page must have a "3" listed in Column 2. If there are N time intervals, then there should be N + 1 row entries or cards filled out on Form G.

Field 2G - Columns 3-4 (Time Interval) - In order to define a time interval, its beginning and end must be specified. This implies that N + 1 times must be specified to define N time intervals. The time intervals should be numbered as their beginning. The card which enters the time for the end of the last time interval should have this field blank.

The number of intervals listed here must agree with the value coded in Field 2A on Form A, or an error statement will be printed and the problem will be rejected. Twenty time intervals is the maximum that the program will handle.

Field 3G - Columns 5-13 (Cumulative Time to the Start of this Interval) -
This field should have a floating point number equal to the accumulated time at the start of an interval. Thus, the entry on the first card will be 0.0, and the entry in this field on the last card for time profile will be the accumulative time to the end of the last interval.

Field 4G - Columns 14-18 - This field is not used.

Field 5G - Columns 19-32 (Probability of System Success for this Time Interval) - If this probability is known from a previous run, then it may be listed here just as it appears on the print-out of the previous run. When this field is not blank, then the program accepts the value and skips the analysis for this time interval, and begins to consider the next time interval.

Field 6G - Columns 33-48 - This field is not used.

Field 7G - Columns 47-49 (Number of Functions Requiring a State Change) -
Functions may be turned on or off at the beginning of a time interval. Components which support only those functions which have been turned off for this interval will not be considered until those functions are turned on again. Components may support both operating and nonoperating functions during a time interval, but the program will not check nonoperating functions for a system failure.

Standby functions are in the on-function array only after the failure of an associated function is in a nonfailed condition. Since they are brought into consideration in this manner, they are not turned "on" or "off" in this field.

In this field, place the sum of the number of functions to be turned either on or off. Place the ID's of the first five functions in the fields immediately following this field on this card, each preceded by a + or - sign, as described next.

Fields 8G, 10G, 12G, 14G, 16G - (-) Off / (+) On - If a function is to be turned off, then a minus should be placed in this single column field and the function ID should follow in the next section. If a function is to be turned on, then this column may be left blank or have a plus sign.

The program will consider all functions, except standby functions, "on" at the beginning of the first time interval. If a function is not to be considered in the first time interval, then it will have to be turned off.

Fields 9G, 11G, 13G, 15G, 17G - Function ID - These fields must contain the ID of the function whose state is changed by the immediately-preceding function change of state field. If a function is to be turned off, then a minus must be in the preceding field.

If more than 5 functions are to change state at the beginning of a time interval, then the remainder must be listed on following cards, using the format of Form H. In Form H they must be listed in the same pattern, but beginning in Column 3. A (3) must be placed in Column 2 of these cards also.

Data Arrangement

These instructions have been arranged in the order of card type; that is, card type (1) signified function information type, (2) component information and type, and (3) time profile information. The actual deck should be arranged as shown in Figure 2.10.

End of Data

The program must be able to recognize the end of the data for a problem. This is done by a (1) in Column 1 of the last card that contains an input card type entry; i. e., the last card in the time profile information. Several problems can be worked in succession by the program because it will read data until it reads a (1) in Column 1 of a proper card, work the problem, and then read the next set of data. When inserting partial data, the end of the data must be signified in the same manner.

ILLUSTRATION OF ARMM APPLICATION

This section shows how ARMM handles a number of situations encountered in reliability analysis. The design detail has been kept at a minimum to avoid an overly complex system. Example applications of ARMM to real systems are given in Chapter 3. Table 2.2 lists the situations illustrated by examples.

Examples

Reliability Block Diagrams - One of the simplest reliability block diagrams consists of several components connected in series and performing one or more functions. In Figure 2.11 such a series system is shown performing both as a single function and as two functions. The order in which the components are placed in the block diagram does not have to be the same as in the flow diagram. The simple system in Figure 2.11 has been divided into functions in two ways. First the three components are grouped in the same function; this is the simplest way. However, both the tank and pump perform continuously and may be required over several time intervals, but the valve is cyclic and its operation may be required in only one interval. To remove the valve from consideration during intervals when it is not needed it must be put in a separate function which will then be turned off in those intervals. This is shown as the second case in Figure 2.11 and requires a rearrangement of the components (in the diagram).

Dependent Components - In Figure 2.11B, Case 1, Components V and P are dependent components of Component T since once the tank has failed the system has failed, and it is no longer necessary to consider the additional failure of Components V and P. Similarly, Component P is a dependent component on Component V.

Redundancy - In ARMM, redundancy is achieved by either the use of the proper modes available, modes required, and component weighting factors within one function, or the use of alternate operating and standby functions. Consider the three valves in Figure 2.12A as one function. The various redundancy requirements which may be imposed on these valves are none, 2 out of 3 or 1 out of 3. These redundancy requirements are shown in block diagram form in Figure 2.12B. The use of alternate functions is illustrated in Figure 2.13. Here a system of two units of redundant components is described in three different ways by grouping the components in different functions. In the first case each unit is a function and would have to be handled in the same way as the

function in Figure 2.12. In the second case the system is divided into two parallel functions (numbered 3 and 4) each an alternate of the other. In the third case, six parallel functions are used (numbered 5, 6, 7, 8, 9, and 10). Functions 6, 7, 8, 9, and 10 are alternate to Function 5; Functions 5, 7, 8, 9, and 10 are alternate to Function 6; and similarly for Functions 7, 8, 9, and 10. The modes available and required and the component weighting factors for Functions 1, 2, 3, and 5 are given in Table 2.3.

If one of the pumps is in standby then a description of the system similar to Case 1 should be used, except each pump is now a function; the standby pump is a standby function. The other two cases could be used with the functions containing the standby pump input as standby functions.

An interesting situation involving a standby component arises in the placement of bus ties in a power system. This situation and how it can be described in the ARMM input is shown in Figure 2.14. The bus tie is a standby function and is alternate to the two transformers in Function 1. This arrangement assures that when either of the transformers fail the bus tie is turned on.

Partial Data Change - An interesting use of this option occurs in the investigation of the effect of different degrees of redundancy on system reliability. The ARMM program can handle a change between runs, in the number of modes available and modes required for a function, but it cannot handle a change in the number of components which support the function. The sample case illustrated in Figure 2.15 uses a scheme which allows ARMM to calculate the effect of redundancy without having to change the number of components in a function. Case 1 represents a single valve and Case 2 a two valve system. To convert from Case 1 to Case 2 using the partial data option, Case 1 is represented by the two valves of Case 1a. Each of these valves has a fictitious failure rate. The value of these failure rates is found as follows.

If

- $P(V)$ = probability of failure of valve V(Case 1),
- $P(b)$ = probability of failure of Case 1b,
- λ = failure rate of the real valve V, and the two valves of Case 2,
- λ_1, λ_2 = failure rate of the two fictitious valves V - 1 and V - 2, respectively,

and it is desired that

$$P(V) = P(b) ,$$

since

$$P(V) = 1 - e^{-\lambda t} ,$$

and

$$\begin{aligned} P(b) &= 1 - \left[1 - P(V_1) \right] \left[1 - P(V_2) \right] = P(V_1) + P(V_2) - P(V_1) P(V_2) \\ &= 1 - e^{-(\lambda_1 + \lambda_2)t} , \end{aligned}$$

then it follows that for Case 1 and Case 1a to give similar results

$$\lambda = \lambda_1 + \lambda_2 .$$

It is convenient to make $\lambda_1 = \lambda_2 = 1/2\lambda$.

After running the problem as Case 1a, the effect of redundancy can be investigated in the second run by changing the values of λ_1 and λ_2 to λ and by changing the modes available from one to two.

Maximum Number of Components Failed at a Time and Depth Control -

The value, measured in savings in computer time, of a proper choice of either the maximum number of components failed at a time or the depth control on any of the components can be appreciated by considering the way ARMM goes down a list of components in its search for failure combinations. Table 2.4 lists the failure combinations considered by ARMM for the system in Figure 2.13. A value of two has been assumed for the maximum number of components failed at one time. The program considers the failure of components in the order they were read into the program. So the failure of Component P-1 is considered with the four remaining components, while for P-2 only three are considered. Also note that a three component failure combination, which could not have been picked up by the program, would be considered

if a depth control of three had been applied to Component V-1. In arranging components in a block diagram, it saves computer time to place those components with the higher numbered depth control towards the end. This minimizes program consideration of failed component combinations which do not cause system failure.

Similarly, it is advisable to keep the value for the maximum number of components failed and/or depth control at a low level, since some failed component combinations causing system failure do not contribute significantly to the total probability of system failure. To illustrate this point, consider a system composed of components which have a probability of failure of 1×10^{-2} for the particular system operation. The probability of any double failure occurring is 1×10^{-4} . In comparison, the probability of any quadruple component failure is 1×10^{-8} . Since ten thousand of these quadruple combinations are equivalent to one double component failure combination, the contribution to system failure from failure combinations containing four or more components is negligible.

Number of Integration Intervals - Simpson's rules calculate the area under a curve passing through a given set of ordinates spaced at two or three equal intervals, by approximating the curve with a second or third order polynomial, respectively. For two intervals, the method is referred to as the Simpson's first rule and for three intervals as the second rule. In ARMM when the number of integration intervals is even, the first rule is applied half as many times as there are number of intervals. When the number is odd, the second rule is applied on the first three intervals and the first rule on the remaining intervals. As shown in Table 2.5, an estimate was made of the order of magnitude error introduced by use of Simpson's rules in integrating the exponential failure density function. Since ARMM performs numerical integration to eight significant figures, it can be seen that significant integration errors can occur in the ARMM output only when $\lambda T = 1$ and the number of intervals is less than approximately 10. Table 2.5 may also be used to select the proper number of intervals to avoid integration error when λT is less than one. In this case, the integral of the exponential failure density function for time interval 0 to T is of the order of λT . Thus, from Table 2.5 the number of integration intervals can be chosen such that the integration error introduced by using Simpson's rules is at least eight to ten orders of magnitude smaller than λT . In choosing λT look for the component which has the highest failure rate λ . Generally, λT is less than one so the use of 10 integration intervals should yield results without significant error.

Configuration Changes Between Time Intervals - The ability to turn functions on and off at the start of each time interval allows the user to change the configuration of the system with time. An illustration of this is given in Figure 2.16. Pumps in a parallel system are designed with check valves on the downstream side to prevent reverse flow through the failed pump. The system is considered for three time intervals. During the first interval the pumps are to start. During the second and third intervals they are to continue operating. In the first two intervals the failure of any one component fails the system; whereas, in the third interval only one pumping train is required. The system's various configurations are represented by the seven functions indicated in Figure 2.16. The time intervals these functions are on and the components which support them are listed in Table 2.6 .

Mutually Exclusive Failure Modes - In Table 2.6 the check values are given separate designations to signify two different failure modes, i.e., blockage and leakage. These are referred to as mutually exclusive failure modes, since once the check valve has failed by blockage it no longer can fail by leakage. Also note that the second failure mode (leakage) must be in a standby function to the pump, since this failure mode cannot be considered until pump failure has occurred.

Miscellaneous - Additional ways in which computer time can be minimized include (1) the grouping of all the components which are in a long series and which do not have dependencies outside of the group into one representative component, (2) the utilization of only one time interval for preliminary studies, and (3) the placement of several small problems behind one another by use of the partial data option.

Sample Problem

The application of the ARMM program will be demonstrated by combining the examples shown in Figures 2.14 and 2.17 into the single system shown in Figure 2.18. Some minor variations are made to illustrate the use of the partial data option. The reliability of the basic block diagram as shown will be calculated as Problem 1, and that of a modified system as Problem 2.

Connected to the tank is a valve, V, represented by two fictitious valves, V-1 and V-2, each assigned one half of the true failure rate. This enables the valves to assume one out of two redundancy in Problem 2. Following the valves is the block diagram of the electrical system. Next, the diagram splits into two branches. The first branch consists of the two operating pumping trains represented by Functions 30 through 75.

The other branch consists of a standby pumping train represented by Functions 80, 85, and 90. Pertinent data for the functions and components is shown in Table 2.7. Partial data changes to be applied in Problem 2 are noted by asterisks.

Information about the time profile is shown in Table 2.8. During time interval 1 the system is considered to be in a state of readiness. In order to maximize the effect on system unreliability, this interval is the time between periodic testing. In Problem 1 the test interval is assumed to be one month, while in Problem 2 the test interval is reduced to one week. During time intervals 1 and 2, two pumps are required to be operational, while during interval 3 only one pump is required for the system success. The loadsheets for the sample calculations are shown in Figure 2.19. The sequencing card numbers are in Columns 78 to 80. The cards numbered from 1 to 300 are for Problem 1 and those in the 500's are the changes made for Problem 2. The final data deck is arranged as shown in Figure 2.10.

Each of the example situations listed in Table 2.2 has been considered in this sample problem. They are discussed here in the order in which they appear in the loadsheets.

1. The maximum number of failed components in a failure combination (field 4A) is set at two, since nearly all conceivable failure combinations involve two or less components. This setting is modified on two components by use of depth control.
2. The number of integration intervals (field 6A) is chosen as 2 from Table 2.5 since the largest values of λT are on the order of 1×10^{-2} .
3. The partial data change is indicated for Problem 2 by a "1" in field 10A.
4. The number of modes available (field 4B) and modes required (field 5B) are taken from Table 2.7.
5. The standby functions (field 2B) are identified as listed in Table 2.7.
6. Alternate functions (fields 7B to 14B) are selected by reviewing all possible success paths at function level including those of standby functions in the block diagram of Figure 2.18. Many alternate paths can be eliminated

by tracing only those functions that are operating during each time interval. Note that for Function 90 there are three alternate paths and each path contains four alternate functions. Also note that path 50-60-70-75 cannot exist in a real system.

7. A depth control (field 13C) of three is applied to components 140 and 200, in order to include all potentially significant failure combinations. For example, for function 75 to fail all three valves in that function must fail. If a depth control of three is put on the card of the first valve (Component 200), then ARMM is able to consider this failure combination. Also note that for Component 200, the depth control has been reduced to 2 as a partial data change in Problem 2.
8. Dependent components are identified on Form D. For example, Card No. 165 for Check Valve C-1 is followed by Card No. 166 listing Component 170 as a mutually exclusive dependent component and Component 180 as a "must fail" dependent component.
9. The weighting factors of and functions supported by the components are taken from Table 2.7 and listed on Form E. An example of the placement of these cards in the deck is Card No. 167 which follows Card No. 166 cited above.
10. Configuration change with time interval is taken from Table 2.8.

A complete set of computer output for Problem 1 is presented in Figure 2.20; the summary of Problem 2 is presented in Figure 2.21.

SYSTEMS ANALYSIS
BY FAULT TREE EVALUATION, SAFTE-1

Fault tree analysis⁽³⁾ is a technique which provides a concise and orderly description of the various combinations of possible occurrences within a system that can result in a predefined "undesired event." Equally as important, it makes available a means with which to measure the level of safety inherent in any particular configuration. The result is an engineering capability to not only identify potential problem areas but also evaluate their overall system impact.

The concept of fault tree analysis was developed by Bell Telephone Laboratories as a technique with which to perform a safety analysis of the Minuteman launch control system. Bell engineers discovered that the method used to describe the flow of "correct" logic in data processing equipment could also be used for analyzing the "false" logic which results from component failures. Further, such a technique was ideally suited to the application of probability theory in order to numerically define critical fault modes. The Minuteman safety study was successfully completed using the new technique and provided convincing arguments for the incorporation of a number of equipment and procedure modifications.

The Boeing Company^(4, 5) subsequently developed fault tree analysis to the stage of mathematical simulation (Monte Carlo), utilizing hybrid* data processing systems and time decrementing numerical procedures.

In the present study, the simulation of fault tree networks by digital means exclusively has been investigated as has the elimination of costly time decrementing procedures. In connection with this effort, a Monte Carlo fault tree simulation program (SAFTE-1) has been developed. The program, written in FORTRAN IV, assumes exponential failure and normal (Gaussian) repair at the component level. Only single phase operation is permitted. A generalized importance sampling technique has been incorporated into the program and has been tested in a number of cases. Importance sampling is necessary to increase the frequency of unlikely events in the system and thereby accomplish the following results:

1. Make possible the estimation of system failure probability for operating times which are very short compared to the mean life of the components in the system.

*Coupled digital-analog system.

2. Significantly shorten the computation time required to achieve a given level of convergence.

The following sections describe the general features of SAFTE-1, including subroutines, input and output, and importance sampling. The results of sample calculations for an idealized two-out-of-three system and for the Dresden-3 emergency a-c power system are summarized. A listing of the source program is given in Appendix E.

SAFTE-1 PROGRAM DESCRIPTION

The SAFTE-1 program is a Monte Carlo procedure for fault tree simulation. It views the system or fault tree to be analyzed as a statistical assembly of components, each characterized by an exponential failure distribution and a normal repair distribution. The system is simulated mathematically by assigning a randomly determined time to failure (TTF) and time to repair (TTR) to each component. It is then tested to determine the time at which failure occurs at the system level. Estimates of system reliability are then obtained by testing a sufficiently large population of systems in this manner.

The mechanics of the procedure can be described as follows. Initial values of TTF and TTR are computed for each component. The component TTF's are arranged in computer memory according to component I. D. number and order in which failure occurs. The computer examines the list of TTF's in order of failure pausing after each failure to determine if a failed state at the system level has been achieved. If at any step a previously failed component has been repaired, a new TTF and TTR are computed for that component based on the good-as-new assumption; and it is placed back in service at the time repair is completed. The new TTF is inserted in proper sequence in computer memory. This procedure continues until a system failure occurs or a step in time is reached which exceeds a specified maximum time of interest.

The advantages of this approach relative to earlier procedures are:

1. Elimination of the need for stepping-off small time increments and examining the list of TTF's and TTR's after each step.
2. Elimination of misinformation resulting from round-off of TTF's and TTR's to integer multiples of the time increment used.
3. Elimination of the requirement for a hybrid computer.

The major disadvantage is the limitation on problem size due to the requirement for two-dimensional ($n \times n$) array sequencing of component failure times, where n is the number of components in the system. Current 32K computers will handle systems of about 100 to 150 components. The larger computers which are beginning to appear should ease this limitation significantly.

Subroutines

Eight subroutines are used in SAFTE-1. The function of each of these is as follows:

1. MAIN - This routine calls the various subroutines in the proper sequence to execute the program logic. The following subroutines are called: RANDIN, EXPRN, FLTRN, SETLOG, GAUS, SEQNCE, LOGIC, SUM, and EDIT. Input data is read and printed, and the estimator arrays are zeroed. Component TTF's and TTR's are computed, and the logical operations associated with estimator weight correction and undesired event detection are performed.
2. RANDIN - This subroutine is part of a random number package utilized by SAFTE-1, which also includes EXPRN and FLTRN. RANDIN is called by MAIN at the beginning of each case with the argument DUMMY = 0 to initialize the random number generator. EXPRN selects random numbers with an exponential distribution. FLTRN selects random numbers uniformly distributed on the unit interval. This is a machine language routine.
3. SETLOG - This subroutine sets all the logical variables false. SETLOG is called by the main program at the beginning of each trial and whenever a component is repaired and placed back into service.
4. GAUS - This subroutine, written in machine language, generates random numbers with a normal distribution.
5. SEQNCE - This subroutine arranges the current list of component TTF's in a two-dimensional array, ARRAY (I,J). Dimension I corresponds to the component identification number, and dimension J corresponds to the order of failure (e.g., $J = 1$ signifies the component with the smallest TTF).

6. LOGIC - This subroutine contains the logical arithmetic needed to describe a given fault tree. A subroutine LOGIC must be written for each different fault tree to be analyzed. Subroutine LOGIC is called after the occurrence of each component failure to determine if a failed state for the system has been achieved. If the test is positive (signifying failure), the trial is terminated and the appropriate bookkeeping is performed. Given a good fault tree diagram, subroutine LOGIC is usually simple to prepare. An example of subroutine LOGIC is given in Appendix E for the Dresden-3 emergency a-c power system.
7. SUM - When system failure occurs in a given trial, this subroutine is called to perform the bookkeeping operations essential to the calculation.
8. EDIT - When the specified number of trials have been completed, this subroutine operates on the data stored by SUM to compute the failure frequency function and cumulative failure distribution for the system. Several other optional outputs are available also. This includes a detailed statistical error analysis for selected operating times less than or equal to TMAX and an estimate of the probability of a given component failure resulting in the undesired event before TMAX for each component in the system. The error analysis logic has not yet been debugged.

A complete listing of the SAFTE-1 source program is given in Appendix E, including subroutine LOGIC developed for the Dresden-3 emergency a-c power system.

Input Description

A minimum of seven input data cards are required per case. These cards contain the following information and format.

Card A: FORMAT (I5, I5, I5, I5, I5)

- a. NTRIAL: The number of trials.
- b. IMX: The number of components (maximum 90). Must be consistent with subroutine LOGIC.
- c. NOINT: The number of time intervals (maximum 250).
- d. NCONS: A dummy parameter currently not used. Set NCONS = 1.
- e. NP TH: A dummy parameter currently not used. Set NP TH = 1.

a b c d

Card B: FORMAT (E12.5, E12.5, E12.5, E12.5)

- a. TMAX: Maximum time of interest (hours). The trial is terminated if a point in time is reached in the calculation exceeding TMAX before the system achieves a failed state.
- b. AA: Biasing parameter for TTF calculation. Values of AA greater than 1.0 cause short TTF's to be emphasized.
- c. BB: Biasing parameter for TTR calculations. Values of BB greater than 1.0 cause short TTR's to be de-emphasized.
- d. CC: Biasing parameter for TTR calculations. Values of CC greater than 1.0 cause long TTR's to be emphasized.

The direct analog calculation (i.e., unbiased) is performed by specifying a value of 1.0 for each biasing parameter.

a

Card C: FORMAT (6E12.5)

- a. XMTTF(I), I = 1, IMX: The mean time to failure (hours) for each component in the system. The list is sequenced in the same order as the component I.D.'s (i.e., XMTTF (1) corresponds to component No. 1). These parameters are punched six to a card. As many cards C are used as are necessary to specify IMX values of mean time to failure.

a

Card D: FORMAT (6E12.5)

- a. XMTTR(I), I = 1, IMX: The mean time to repair (hours) for each component in the system. The same instructions apply as for Card C.

a

Card E: FORMAT (6E12.5)

- a. SIG(I), I = 1, IMX: The standard deviation (hours) associated with the repair distribution of each component in the system. The same instructions apply as for Card C.

a

Card F: FORMAT (6E12.5)

- a. CONS(I), I = 1, NCONS: Dummy variable of which NCONS values must be entered.

a

Card G: FORMAT (5I5)

- a. K1(I), I = 1, 3: The time interval numbers selected for statistical error analysis. Since this part of the program is not debugged, it is recommended that a single value of K1 = 0 be entered. Error analysis is then omitted.

Successive cases can be performed by inserting the additional case cards A through G necessary to completely specify a problem. A sample data deck listing is given in the section dealing with the Dresden-3 emergency power system calculations.

Output Description

The input to SAFTE-1 is printed out after it is read, allowing an easy verification of the input and providing a written record of the run. In addition, the case results are printed. These include:

1. The probability of system failure before TMAX, P (TMAX).
2. The failure density function of the system failure (the probability per unit time that the system fails at time t), p (t), as a function of time for the time grid specified by the input. This function is in units of hours⁻¹. NOINT values are printed 5 to a line in order of increasing time. The interval size is TMAX/NOINT.
3. The cumulative distribution function for system failure (probability of system failure before time T),

$$P(T) = \int_0^T p(t) dt,$$

as a function of time for the same grid as described under 2. It should be noted that the system reliability at time T is given by

$$R(T) = 1 - P(T).$$

4. A summary table of the contribution from each component $P_i(TMAX)$ to $P(TMAX)$, where

$$P(TMAX) = \sum_{i=1}^{IMX} P_i(TMAX) .$$

Physically, P_i (TMAX) represents the probability that component i is the final failure in a sequence of component failures leading to the undesired event before TMAX. P_i (TMAX) then, is a direct measure of the sensitivity of system reliability to the reliability of component i .

A sample case output is given in the section dealing with the Dresden-3 emergency power system.

IMPORTANCE SAMPLING

The fault tree integral for an "n" component system without repair is

$$P(T) = \int_S W(t_1, t_2, \dots, t_n) \prod_{i=1}^n f(t_i) dt_i \quad (1)$$

where $f(t_i) dt_i$ is the probability that component i fails between t_i and $t_i + dt_i$. In the SAFTE-1 program, where exponential component failure is assumed, $f(t_i) = \lambda_i e^{-\lambda_i t_i}$. S represents n dimensional phase space of which there exists a subset F consisting of all possible system failures before time T . The function W is defined as follows:

$$W(t_1, t_2, \dots, t_n) = \begin{cases} 1, & (t_1, t_2, \dots, t_n) \in F \\ 0, & (t_1, t_2, \dots, t_n) \notin F \end{cases} \quad (2)$$

Thus, $W = 1$ if $t_1 \dots t_n$ is a point contained in F , otherwise $W = 0$.

Fault tree simulation is performed by generating n random numbers $R_1, R_2, \dots, R_n$, and computing a random time to failure t_i for each component from

$$R_i = \int_0^{\lambda_i t_i} f(x_i) dx_i, \quad (3)$$

where $0 \leq R_i \leq 1$.

If each simulation is thought of as a trial, an estimate of Equation (1) is given by

$$\tilde{P} \cong \frac{1}{N} \sum_{j=1}^N W_j, \quad (4)$$

where N is the total number of trials and W_j , as defined by Equation (2), is the Monte Carlo estimator for trial j . This in essence is fault tree simulation by means of analog Monte Carlo.

Analog Monte Carlo is a powerful tool for analyzing system reliability, $R(T) = 1 - P(T)$, for values of $P(T) > 10^{-4}$. The required number of trials and hence computer costs become prohibitive when estimates of $P(T)$ much below this level are desired. For example, 4×10^4 trials are required in order to obtain 50 percent confidence limits of approximately an order of magnitude in the estimate of $P(T) = 10^{-4}$. As $P(T)$ gets smaller, the required number of trials increases. Small $P(T)$ generally occurs when $T \ll 1/\bar{\lambda}$, where $\bar{\lambda}$ is the average failure rate for system components. Inadequate sampling is then obtained in the subset F of phase space to provide adequate statistics.

This inefficiency in the analog Monte Carlo procedure can usually be overcome by what is referred to as importance sampling. To permit importance sampling, Equation (1) is rewritten in the following modified form

$$P(T) = \int_S \left[\frac{W(t_1, t_2, \dots, t_n) \prod_{i=1}^n f(t_i)}{\prod_{i=1}^n f^*(t_i)} \right] \prod_{i=1}^n f^*(t_i) dt_i, \quad (5)$$

where $\prod_{i=1}^n f^*(t_i)$ is the importance function from which t_i is now selected, and the quantity in brackets is the new Monte Carlo estimator W_j^* . The optimum importance function is

$$\frac{W(t_1, t_2, \dots, t_n) \prod_{i=1}^n f(t_i)}{\int_S W(t_1, t_2, \dots, t_n) \prod_{i=1}^n f(t_i) dt_i},$$

and would yield the correct answer in a single trial.

However, for complex systems it is impossible to construct the optimum importance function since an a priori knowledge of the answer to be calculated is required. In simple systems where exact analytical solutions are obtainable, the question of an optimum importance function becomes trivial. In practice, therefore, we try to construct an $\prod_{i=1}^n f^*(t_i)$ which will mimic $\prod_{i=1}^n f(t_i)$ to some extent, but which will sample the subset F more frequently. The condition must also be satisfied

$$\prod_{i=1}^n \int_0^{\infty} f^*(t_i) dt_i = 1 . \quad (6)$$

The current version of SAFTE-1 permits component failure sampling of the following form

$$\prod_{i=1}^n f^*(t_i) = A^n \prod_{i=1}^n \lambda_i e^{-A\lambda_i t_i} , \quad (7)$$

where A is a biasing parameter and corresponds to AA in the program input description.

For values of $A > 1.0$, Equation (7) effectively shortens component mean time to failure. To offset this distortion and preserve expectation values, the Monte Carlo estimator of Equation (4), W , becomes

$$W^*(t_1, t_2, \dots, t_n) = W(t_1, t_2, \dots, t_n) \frac{1}{A^n} \prod_{i=1}^n e^{(A-1)\lambda_i t_i} . \quad (8)$$

The above procedure has been exercised for an idealized two-out-of-three system without repair in order to study its general applicability for fault tree analysis. The exact solution for the two-out-of-three system with identical components is

$$P(\lambda T) = 3(1 - e^{-\lambda T})^2 e^{-\lambda T} + (1 - e^{-\lambda T})^3 , \quad (9)$$

and for $\lambda T \ll 1.0$

$$P(\lambda T) \sim 3 (\lambda T)^2 . \quad (10)$$

Figure 2.22 shows the results of several calculations for values of $A = 1, 2.5, 5, 10$. Since identical components are assumed, it is convenient to express the independent variable in Figure 2.22 as the dimensionless parameter λT . Each calculation represents 5,000 trials. An independent sequence of pseudo-random numbers* was used in each case. The exact solution for the two-out-of-three system is shown by the solid line. Good agreement with the exact solution is obtained using analog Monte Carlo ($A=1$) for values of $P(\lambda T) \geq 4 \times 10^{-4}$. This corresponds to $\lambda T \geq 1.2 \times 10^{-2}$. When $A = 2.5$, the Monte Carlo agreement is within 30 percent for values of $\lambda T \geq 7 \times 10^{-3}$. Samples were obtained for $\lambda T < 7 \times 10^{-3}$ in this case; however, these estimates exhibit extremely large statistical variance, defined as

$$\sigma^2 = \frac{1}{N} \sum_{j=1}^N W_j^{*2} - \left\{ \frac{1}{N} \sum_{j=1}^N W_j^* \right\}^2$$

For the case of $A=5$, the statistical variance is improved somewhat in the range $7 \times 10^{-3} \leq \lambda T \leq 1.25 \times 10^{-2}$. When $A=10$, the solution in the range $\lambda T \geq 6 \times 10^{-3}$ is consistently low by about a factor of two. However, for $\lambda T < 6 \times 10^{-3}$, a significant improvement over previous solutions is obtained.

The calculations of Figure 2.22 show that good estimates of $P(\lambda T)$ of order 10^{-4} are practical using analog Monte Carlo. It is also noted that considerable improvement in estimates of smaller values of $P(\lambda T)$ can be obtained using importance sampling. The degree of importance sampling necessary (i.e., the size of A) depends on the value of $P(\lambda T)$ being estimated as well as the desired accuracy of the result. At present, the value of A appropriate to a given calculation is best determined by experimentation.

SAFTE-1 also contains a provision for importance sampling component repair distributions. The probability per unit time that component i is repaired at time x_i is given by the normal or Gaussian distribution

*Pseudo-random sequence of numbers is a sequence calculated one number at a time as needed from a completely specified prescription so devised that reasonable statistical tests will detect no significant departure from randomness.

The parameters B and C correspond to BB and CC respectively in the input description.

For $B > 1.0$, the above procedure deemphasizes short repair times which result from sampling the left side of the normal distribution (i.e., $\alpha = -1$), and for $C > 1.0$ it emphasizes long repair times which occur in sampling the right side of the distribution (i.e., $\alpha = 1$). As in the case of the parameter A, values of B and C appropriate to a given calculation must be determined through experimentation at the present time.

In order to preserve expectation values when repair distributions are importance sampled, the Monte Carlo estimator (Equation 8) is multiplied by the additional factor

$$\prod_{i=1}^n \frac{r(\tau_i)}{r^*(\tau_i)} = \prod_{i=1}^n \frac{\sigma_i}{\sigma_i'} e^{-\tau_i^2 / 2(1/\sigma_i^2 - 1/\sigma_i'^2)} \quad (15)$$

The repair logic of SAFTE-1 has only been used in the case of very large component mean time to repair (MTTR) and small standard deviations to simulate systems without repair. Calculations for systems with repair have not yet been performed; consequently, this area of program logic has not been verified.

SAMPLE CALCULATION: DRESDEN-3 EMERGENCY A-C POWER SYSTEM

A fault tree was developed for the Dresden-3 emergency a-c power system as depicted in the schematic⁽⁶⁾ of Figure 2.23, and several sample calculations were performed. The fault tree development (Figure 2.24), which was carried to a level of detail commensurate with the schematic, describes the various combinations of possible occurrences within the system that can result in the predefined "undesired event." The undesired event in the system is Loss of Emergency A-C Power. The symbols appearing in Figure 2.24 are defined as follows:

output event

input events

The logical "OR" gate. This gate defines the logical operation whereby one or more input events are required to produce the output event.

$$r(x_i) = \frac{1}{\sigma_i} \frac{1}{\sqrt{2\pi}} e^{-x_i^2 / 2\sigma_i^2} \quad (11)$$

where σ_i is the standard deviation for component i , and x_i is displacement from the mean time to repair μ_i . The elapsed time of repair, d_i , is then given by

$$d_i = \mu_i + \alpha \tau_i \quad (12)$$

where $\alpha \tau_i$ is a randomly determined variation about μ_i .

The value of τ_i is computed from the half-Gaussian

$$R_1 = \int_0^{\tau_i} r(x_i) dx_i = \frac{1}{\sigma_i} \sqrt{\frac{2}{\pi}} \int_0^{\tau_i} e^{-x_i^2 / 2\sigma_i^2} dx_i, \quad (13)$$

and α is a dummy parameter satisfying the conditions

$$\alpha = 1, R_2 \geq 0.5,$$

$$\alpha = -1, R_2 < 0.5,$$

where R_1 and R_2 are independent, uniformly distributed random numbers. Importance sampling is performed by computing τ_i from the modified form of Equation (13),

$$R_1 = \int_0^{\tau_i} r^*(x_i) dx_i = \frac{1}{\sigma_i'} \sqrt{\frac{2}{\pi}} \int_0^{\tau_i} e^{-x_i^2 / 2\sigma_i'^2} dx_i \quad (14)$$

where the following definitions apply

$$\sigma_i' = \sigma_i / B, \alpha = -1,$$

$$\sigma_i' = \sigma_i C, \alpha = 1.$$

The logical "AND" gate. This gate describes the logical operation whereby the coexistence of all input events is required to produce the output event.

The circle defines a basic system component, characterized by a mean time to failure (MTTF) and a MTTR.

The triangle symbolizes transfer. A line from the apex of the triangle denotes transfer - in, and a line from the side denotes transfer - out.

The logical "OR" and "AND" gates appearing in Figure 2.24 are summarized in Table 2.9 with their respective consequences. Subroutine LOGIC for the Dresden-3 emergency a-c power system appears in Appendix E with the SAFTE-1 program listing.

The Dresden-3 emergency a-c power system as defined in Figure 2.24 contains 57 components. These are listed in Table 2.10 with values for MTTF and MTTR. The standard deviations assumed for the repair distributions also are given in the MTTR column. The values listed in Table 2.10 are based on data contained in Appendix D and engineering judgment.

Several calculations were performed for various values of A(i.e., A=1, 1.2, 1.5) in which repair was not considered. Repair was deleted from the model by specifying a fictitious set of values for component MTTR's which were large compared to TMAX. Small values for standard deviation SIG were also specified. This assures that the probability of component repair before TMAX will be zero.

Figure 2.25 shows a listing of the input data card images as they appear in the analog calculation. In each calculation 3,000 trials were performed. The maximum time interval TMAX is 4.2×10^4 hours or 250 weeks. Using NOINT equal to 250 then requires the calculated results to be reported out with a grid size equal to 168 hours or one week. This was a convenient scale to adopt in the present calculations. A value of MTTR = 1×10^5 hours and SIG = 1×10^{-1} hours was assigned to each component.

Figures 2.26A through 2.26F show the most significant elements of computer output for the analog calculation. The calculated results for P(T) have been plotted as a function of time in Figure 2.27 for the three cases. Identical random number sequences were used in each case. The abscissa shows operating time in weeks. As expected, fairly well converged (i.e., low variance) estimates were obtained for P(T) at long operating times (i.e., $T \geq 40$ weeks) using the analog procedure. This corresponds to values of $P(T) \geq 10^{-3}$.

When $A=1.2$, estimates for P(T) are obtained at shorter operating times (~ 24 weeks); however, this appears to be accompanied by poorer convergence in the overall solution. We see this effect become even more pronounced for $A=1.5$ where the tail of the solution looks to be in error by an order of magnitude. The vertical bars shown at the 19 week data point, representing the 50 percent confidence limits for this particular point, encompass the estimated exact solution (solid curve). It is believed that significant improvements in convergence can be achieved by increasing the number of trials N. The extent to which N must be increased in order to obtain satisfactory performance has not been determined.

Figure 2.26F gives a tabulation of the individual contribution $P_i(\text{TMAX})$ from each of the system components in the analog case. $P_i(\text{TMAX})$ represents the probability that component i is the final failure in a sequence of component failures which result in the undesired event previous to TMAX. Figure 2.26F indicates that component X23, the diesel generator, is the largest contributor to P(TMAX). Components X9 and X8, the secondary and primary windings respectively of transformer, T-3, are the next largest contributors. The latter two components should contribute equally to P(TMAX); however, the number of trials performed was inadequate to show this.

Execution time for the analog calculation was approximately 81 minutes on the IC 6000, a 7094 simulator with a disadvantage factor of approximately 3 or 4 to 1. The biased calculations required approximately 100 minutes on the same system. Although an equal number of trials were performed in each case, an increase in execution time for the

two biased cases results from the larger average number of component failures which are considered per trial.

CONCLUSIONS AND RECOMMENDATIONS

The feasibility of fault tree simulation by digital means and without recourse to small time incrementing has been demonstrated. The Monte Carlo procedures outlined and the existing computer program (SAFTE-1) are believed to be useful tools for the mathematical analysis of fault trees. Additional work is necessary to develop these tools to their most efficient state.

It should be possible in most applications to obtain estimates of $P(T)$ as low as 10^{-3} or 10^{-4} using the analog method. Some form of importance sampling will generally be required to improve computational efficiency when smaller values of $P(T)$ are to be estimated. The procedures outlined for this purpose are relatively simple to apply and with further development should prove very useful in this respect.

The principal factors influencing computational costs are the problem size (number of components) and the number of trials to be performed. Computational costs are directly proportional to these factors.

Several areas exist in which additional Monte Carlo methods development and programming effort appear to be justified. These include:

1. Further investigation of importance sampling techniques.
2. Extension to multiphase operation.
3. More general failure and repair distributions.
4. Investigations of repair situations.
5. Human error.
6. More efficient random number generation.
7. Possible elimination of two-dimensional arrays.
8. Check out of error analysis portion of code.

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POSSIBLE FAILURE COMBINATIONS CONSIDERED BY ARMM
OF SYSTEM IN FIGURE 2.1 (NO DEPENDENCY)

Possible Failure Combinations	System	
	Not Failed	Failed
$\overline{A}$	X	
$\overline{A} \overline{B}$	X	
$\overline{A} \overline{B} \overline{C}$	X	
$\overline{A} \overline{B} \overline{C} \overline{D}$		X
$\overline{A} \overline{B} \overline{C} \overline{D} \overline{E}$		X
$\overline{A} \overline{B} \overline{C} \overline{D} \overline{E}$	X	
$\overline{A} \overline{B} \overline{C} \overline{D} \overline{E}$	X	
$\overline{A} \overline{B} \overline{C}$	X	
$\overline{A} \overline{B} \overline{C} \overline{D}$		X
$\overline{A} \overline{B} \overline{C} \overline{D} \overline{E}$		X
$\overline{A} \overline{B} \overline{C} \overline{D}$	X	
$\overline{A} \overline{B} \overline{C} \overline{D} \overline{E}$	X	
$A \overline{B}$	X	
$A \overline{B} \overline{C}$	X	
$A \overline{B} \overline{C} \overline{D}$		X
$A \overline{B} \overline{C} \overline{D} \overline{E}$		X
$A \overline{B} \overline{C} \overline{D}$	X	
$A \overline{B} \overline{C} \overline{D} \overline{E}$	X	
$A \overline{B} \overline{C}$	X	
$A \overline{B} \overline{C} \overline{D}$	X	
$A \overline{B} \overline{C} \overline{D} \overline{E}$	X	
$A \overline{B} \overline{C} \overline{D}$	X	
$A \overline{B} \overline{C} \overline{D} \overline{E}$	X	
$A \overline{B} \overline{C} \overline{D}$	X	
$A \overline{B} \overline{C} \overline{D} \overline{E}$	X	
$A \overline{B} \overline{C} \overline{D}$	X	
$A \overline{B} \overline{C} \overline{D} \overline{E}$	X	

TABLE 2.2
EXAMPLE SITUATIONS

- Reliability Block Diagrams
- Dependent Components
- Redundancy
- Partial Data Change
- Maximum Number of Components Failed at a Time and Depth Control
- Number of Integration Intervals
- Configuration Changes Between Time Intervals
- Mutually Exclusive Failure Modes
- Miscellaneous
- Sample Problem

TABLE 2.3

MODES AVAILABLE, MODES REQUIRED, AND WEIGHTING FACTORS

COMPONENT	FUNCTIONS							
	1		2		3		4	
	Modes Avail.	Modes Req'd.	Modes Avail.	Modes Req'd.	Modes Avail.	Modes Req'd.	Modes Avail.	Modes Req'd.
	2	1	3	1	3	1	1	1
	Component Weighting Factors		Component Weighting Factors		Component Weighting Factors		Component Weighting Factors	
P-1	1				3		1	
P-2	1							
V-1			1		1		1	
V-2			1		1			
V-3			1		1			

TABLE 2.4

FAILURE COMBINATIONS AND THE USE OF DEPTH CONTROL

First Component Failed	Combinations Considered	
	No Depth Control	Depth Control of 3 on V-1
P-1	P-1 (P-1, P-2) P-1, V-1 P-1, V-2 P-1, V-3	P-1 (P-1, P-2) P-1, V-1 P-1, V-2 P-1, V-3
P-2	P-2 P-2, V-1 P-2, V-2 P-2, V-3	P-2 P-2, V-1 P-2, V-2 P-2, V-3
V-1	V-1 V-1, V-2 V-1, V-3	V-1 V-1, V-2 (V-1, V-2, V-3)
V-2	V-2 V-2, V-3	V-2 V-2, V-3
V-3	V-3	V-3

Notes: 1. Maximum number of components failed at a time = 2.

2. Parenthesis indicates a failure combination.

		Integration Error			
λT	Number of Integration Intervals, N	2	4	10	24
1		10^{-5}	10^{-6}	10^{-7}	10^{-11}
10^{-1}		10^{-10}	10^{-11}	10^{-12}	10^{-16}
10^{-2}		10^{-15}	10^{-16}	10^{-17}	10^{-21}
10^{-3}		10^{-20}	10^{-21}	10^{-22}	10^{-26}
10^{-4}		10^{-25}	10^{-26}	10^{-27}	10^{-31}

N: Number of integration intervals

λ : Failure rate

T: Total time

TABLE 2.5

ORDER OF MAGNITUDE INTEGRATION ERROR BY USING SIMPSON'S RULE

Time Interval	Function Number	Supporting Components	Failure Mode
1	1	Pump P-1 Pump P-2 Check Valve C-1 Check Valve C-1	Fail to start Fail to start Blockage Blockage
2	2	Pump P'-1 Pump P'-2 Check Valve C-1 Check Valve C-2	Fail to continue running Fail to continue running Blockage Blockage
3	3	(same as Function 2)	
	4	Pump P'-1 Check Valve	Fail to continue running Blockage
	5 (standby)	Check Valve	Leakage
	6	Pump P'-2 Check Valve C-2	Fail to continue running Blockage
	7 (standby)	Check Valve C'-2	Leakage

TABLE 2.6

TIME INTERVALS OF FAILURE MODES

TABLE 2.7
FUNCTION AND COMPONENT DATA

Function Number	Modes Available	Modes Required	Supporting Components	Weighting Factor	Failure Per Million Hours	Failure Mode
1	1	1	Tank T	1	.1	Excessive leakage
10	1 2*	1	Valve V-1	1	5.0	Fail to open
			Valve W-1*		10.0*	
			Valve V-2	1	5.0	Fail to open
			Valve W-2*		10.0*	
20	1	1	Transformer X-1	1	5.0	Fail to supply power
			Transformer X-2	1	5.0	Fail to supply power
25 (Standby)	2	1	Bus Tie B-T (Others see Function 20)	2	2.0	Fail to close
30 (Interval 1)	1	1	Pump P-1	1	10.0	Fail to start
			Check Valve C-1	1	.25	Blockage
			Pump P-2	1	10.0	Fail to start
			Check Valve C-2	1	.25	Blockage
35 (Interval 2)	1	1	Pump P'-1	1	5.0	Fail to continue running
			Check Valve C-1	1	.25	Blockage
			Pump P'-2	1	5.0	Fail to continue running
			Check Valve C-2	1	.25	Blockage
50	2	1	(Same as Function 35)			
55 (Intervals 2 and 3)	1	1	(See Function 35)			
60 (Standby)	1	1	Check Valve C'-1	1	1.0	Leakage
65 (Intervals 2 and 3)	1	1	(See Function 35)			
70 (Standby)	1	1	Check Valve C'-2	1	1.0	Leakage
75	3	1 2*	Valve V-5	1	10.0	Fail to open
			Valve V-6	1	10.0	Fail to open
			Valve V-7	1	10.0	Fail to open
80 (Standby for Interval 1)	6	1 2*	Pump P-1	3	10.0	Fail to start
			Pump P-2	3	10.0	Fail to start
			Pump P-3	3	10.0	Fail to start
			Check Valve C-1	3	.25	Blockage
			Check Valve C-2	3	.25	Blockage
			Check Valve C-3	3	.25	Blockage
			Valve V-3	3	10.0	Fail to open
			Valve V-4	3	10.0	Fail to close
			Valve V-5	1	10.0	Fail to open
			Valve V-6	1	10.0	Fail to open
			Valve V-7	1	10.0	Fail to open
85 (Standby for Interval 2)	6	1 2*	Pump P'-1	3	5.0	Fail to continue running
			Pump P'-2	3	5.0	Fail to continue running
			Pump P'-3	3	5.0	Fail to continue running
			Check Valve C'-1	3	1.0	Leakage
			Check Valve C'-2	3	1.0	Leakage
			(Others see Function 80)			
90 (Standby for Interval 3)	3	1 2*	Pump P'-3 (Others see Functions 80 and 85)	3	5.0	Fail to continue running

TABLE 2.8TIME PROFILE

Time Interval	Cumulative Time at Start of Interval Hours		Configuration Change
	Problem 1	Problem 2	
1	0.0	0.0	Functions 35, 50, 55, 65, 85 and 90 turned off.
2	720.0	168.0	Functions 30 and 80 turned off and 35 and 85 turned on.
3	721.0	169.0	Functions 35 and 85 turned off and 50, 55, 65, and 90 turned on.
Cumulative Time Attend	745.0	193.0	

TABLE 2.9

LOGICAL "OR" AND "AND" GATES APPEARING IN
DRESDEN-3 EMERGENCY AC POWER SYSTEM FAULT TREE

Logical Gate Identification	Consequence
A1	No Power To T-1
A2	T-1 Fails Open
A3	Line 12 Dead
A4	Line 11 Dead
A5	No Power To Line 13
A6	No Power To T-3
A7	T-3 Fails Open
A8	No Power From T-3
A9	Line 32 Dead
A10	Line 32A Dead
A11	BAB-32 Source Dead
A12	No Power To T-2
A13	T-2 Fails Open
A14	No Power To Line 21
A15	No Power To BAB-31 & No Power To Line 21A
A16	BAB-31 Source Dead
A17	No Power To BAB-42
A18	BAB-51 Fails Open
A19	No Power From BAB-51
A20	No Power From Diesel Generator
A21	BAB-52 Fails Open
A22	No Power From BAB-52
A23	BAB-53 Failed Open
A24	T-8 Fails Open
A25	No Power From T-8
A26	No Power From BAB-53
A27	BAB-42 Failed Open
A28	No Power From BAB-42
A29	BAB-41 Failed Open

TABLE 2.9 (continued)

Logical Gate Identification	Consequence
A30	No Power From BAB-41
A31	BAB-61 Fails Open
A32	No Power From BAB-62
A33	BAB-62 Fails Open
A34	No Power From BAB-62
A35	No Power To T-8
A36	BAB-63 Fails Open
A37	No Power From BAB-63
A38	BAB-54 Failed Open
A39	No Power From BAB-54
A40	No Power To T-6
A41	T-6 Fails Open
A42	No Power From T-6
A43	No Power To BAB-2A
A44	BAB-2A Fails Open
A45	BUS-2A Dead
A46	BAB-64 Fails Open
A47	No Power From BAB-64
A48	No Power To T-7
A49	T-7 Fails Open
A50	No Power From T-7
A51	No Power To BAB-2B
A52	BAB-2B Fails Open
A53	BUS-2B Dead
B1	No Power To BAB-51
B2	BUS-5 Dead
B3	No Power to BAB-61
B4	BUS 6 Dead
B5	Loss of 4160 V Power
B6	Loss of 480V Power
B7	Loss of Emergency AC Power

TABLE 2.10
COMPONENT FAILURE AND REPAIR DATA
FOR DRESDEN-3 EMERGENCY AC POWER SYSTEM

Component I. D.	Failure	MTTF (hours)	MTTR (hours)
X1	T-1 345 KV Bus Connection Fails	1.0×10^6	10 ± 5
X2	345 KV Bus Dead	1.0×10^7	15 ± 7.5
X3	T-1 Primary Fails Open	1.11×10^5	48 ± 12
X4	T-1 Secondary Fails Open	1.11×10^5	48 ± 12
X5	Unit 3 Generator Fails	1.0×10^4	334 ± 50
X6	Line 11 Broken	1.0×10^6	5 ± 2.5
X7	T-3 Bus Connection Fails	1.0×10^6	10 ± 5
X8	T-3 Primary Fails Open	1.11×10^5	48 ± 12
X9	T-3 Secondary Fails Open	1.11×10^5	48 ± 12
X10	Line 32 Broken	1.0×10^6	5 ± 2.5
X11	Line 32A Broken	1.0×10^6	5 ± 2.5
X12	BAB-32 Fails Open	2.0×10^5	8 ± 4
X13	Line 13 Broken	1×10^6	5 ± 2.5
X14	T-2 Primary Fails Open	1.11×10^5	48 ± 12
X15	T-2 Secondary Fails Open	1.11×10^5	48 ± 12
X16	Line 21 Broken	1×10^6	5 ± 2.5
X17	BAB-31 Fails Open	2.0×10^5	8 ± 4
X18	Line 21A Broken	1×10^6	5 ± 2.5
X19	BAB-51 Failed Open	2.0×10^5	8 ± 4
X20	BAB-51 Manual Actuator Fails	2.0×10^5	3 ± 1.5
X21	BAB-52 Failed Open	2.0×10^5	8 ± 4
X22	BAB-52 Auto-Actuator Fails	1.0×10^5	3 ± 1.5
X23	Diesel Generator Fails	1.0×10^5	200 ± 50
X24	Line To Diesel Generator Broken	1.0×10^6	5 ± 2.5
X25	BAB-53 Auto-Actuator Failed	1.0×10^5	3 ± 1.5
X26	BAB-53 Failed Open	2.0×10^5	8 ± 4
X27	T-8 Secondary Fails Open	1.11×10^5	48 ± 12
X28	T-8 Primary Fails Open	1.11×10^5	48 ± 12

TABLE 2.10 (continued)

Component I. D.	Failure	MTTF (hours)	MTTR (hours)
X29	Line From T-8 Broken	1.0×10^6	$5 \begin{smallmatrix} + \\ - \end{smallmatrix} 2.5$
X30	BAB-42 Failed Open	2.0×10^5	$8 \begin{smallmatrix} + \\ - \end{smallmatrix} 4$
X31	BAB-42 Auto-Actuator Fails	1.0×10^5	$3 \begin{smallmatrix} + \\ - \end{smallmatrix} 1.5$
X32	BAB-41 Failed Open	2.0×10^5	$8 \begin{smallmatrix} + \\ - \end{smallmatrix} 4$
X33	BAB-41 Auto-Actuator Fails	1.0×10^5	$3 \begin{smallmatrix} + \\ - \end{smallmatrix} 1.5$
X34	BAB-61 Fails Open	2.0×10^5	$8 \begin{smallmatrix} + \\ - \end{smallmatrix} 4$
X35	BAB-61 Manual Actuator Fails	2.0×10^5	$3 \begin{smallmatrix} + \\ - \end{smallmatrix} 1.5$
X36	BAB-62 Fails Open	2.0×10^6	$8 \begin{smallmatrix} + \\ - \end{smallmatrix} 4$
X37	BAB-62 Auto-Actuator Fails	1.0×10^5	$3 \begin{smallmatrix} + \\ - \end{smallmatrix} 1.5$
X38	Underground Feeder To T-8 Failed	1.0×10^6	$70 \begin{smallmatrix} + \\ - \end{smallmatrix} 35$
X39	34.5 KV Outage	1.0×10^5	$10 \begin{smallmatrix} + \\ - \end{smallmatrix} 5$
X40	BAB-63 Fails Open	2.0×10^5	$8 \begin{smallmatrix} + \\ - \end{smallmatrix} 4$
X41	BAB-63 Auto-Actuator Fails	1.0×10^5	$3 \begin{smallmatrix} + \\ - \end{smallmatrix} 1.5$
X42	BAB-54 Failed Open	2.0×10^5	$8 \begin{smallmatrix} + \\ - \end{smallmatrix} 4$
X43	BAB-54 Auto-Actuator Failed	1.0×10^5	$3 \begin{smallmatrix} + \\ - \end{smallmatrix} 1.5$
X44	Line To T-6 From BAB-54 Broken	1.0×10^6	$5 \begin{smallmatrix} + \\ - \end{smallmatrix} 2.5$
X45	T-6 Primary Fails Open	1.11×10^5	$48 \begin{smallmatrix} + \\ - \end{smallmatrix} 12$
X46	T-6 Secondary Fails Open	1.11×10^5	$48 \begin{smallmatrix} + \\ - \end{smallmatrix} 12$
X47	Line To T-6 Broken	1.0×10^6	$5 \begin{smallmatrix} + \\ - \end{smallmatrix} 2.5$
X48	BAB-2A Fails Open	2.0×10^5	$8 \begin{smallmatrix} + \\ - \end{smallmatrix} 4$
X49	BAB-2A Auto-Actuator Fails	1.0×10^5	$3 \begin{smallmatrix} + \\ - \end{smallmatrix} 1.5$
X50	BAB-64 Failed Open	2.0×10^5	$8 \begin{smallmatrix} + \\ - \end{smallmatrix} 4$
X51	BAB-64 Auto-Actuator Failed	1.0×10^5	$3 \begin{smallmatrix} + \\ - \end{smallmatrix} 1.5$
X52	Line From BAB-64 Broken	1.0×10^6	$5 \begin{smallmatrix} + \\ - \end{smallmatrix} 2.5$
X53	T-7 Primary Fails Open	1.11×10^5	$48 \begin{smallmatrix} + \\ - \end{smallmatrix} 12$
X54	T-7 Secondary Fails Open	1.11×10^5	$48 \begin{smallmatrix} + \\ - \end{smallmatrix} 12$
X55	Line To T-7 Broken	1.0×10^6	$5 \begin{smallmatrix} + \\ - \end{smallmatrix} 2.5$
X56	BAB-2B Fails Open	2.0×10^5	$8 \begin{smallmatrix} + \\ - \end{smallmatrix} 4$
X57	BAB-2B Auto-Actuator Fails	1.0×10^5	$3 \begin{smallmatrix} + \\ - \end{smallmatrix} 1.5$

FIGURE 2.1

EXAMPLE SYSTEM

[illegible]

FUNCTION-COMPONENT SUMMARY SHEET

INPUT FORM A

[illegible]

FIGURE 2.4

INPUT FORM B

FIGURE 2.5

INPUT FORM C

[illegible]

FIGURE 2.6

INPUT FORM D

INPUT FORM E

INPUT FORM G

Function ID.		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
1	3																
2	3																
3	3																
4	3																
5	3																
6	3																
7	3																
8	3																
9	3																
10	3																
11	3																
12	3																
13	3																
14	3																
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73	3																
74	3																
75	3																
76	3																
77	3																
78	3																
79	3																
80	3																

FORM H
ARMM

FIGURE 2.9

INPUT FORM H

FIGURE 2.10

ARMM INPUT DECK GENERAL ARRANGEMENT

2.11A FLOW DIAGRAM

(1) One Function System

(2) Two Function System

2.11B BLOCK DIAGRAMS

NOTE: --- indicates division of functions.
1, 2, and 3 indicate function number.

FIGURE 2.11
SERIES SYSTEM

VALVES

2:12A FLOW DIAGRAM

2:12B BLOCK DIAGRAMS

FIGURE 2.12
PARALLEL SYSTEM

2:13A FLOW DIAGRAM

(1) Two Functions in Series (2) Two Functions in Parallel (3) Six Functions in Parallel

2:13B BLOCK DIAGRAMS

FIGURE 2.13
COMPOSITE SYSTEM

2. 14A LINE DIAGRAM

2. 14B BLOCK DIAGRAM

FIGURE 2. 14
ELECTRICAL SYSTEM

2.15A FLOW DIAGRAMS

2.15B BLOCK DIAGRAMS

FIGURE 2.15

CHANGE FROM NONREDUNDANT TO REDUNDANT
COMPONENTS BY PARTIAL DATA

2.16A FLOW DIAGRAM

2.16B BLOCK DIAGRAM

NOTE: --- indicates configuration change with time intervals.

FIGURE 2.16

HYDRAULIC SYSTEM

FIGURE 2.17HYDRAULIC SYSTEM FLOW DIAGRAM

FIGURE 2.18

ELECTROHYDRAULIC SYSTEM BLOCK DIAGRAM

ARMM INPUT LOADSHEETS

ID No. (1) is col. 3 For Standby	FUNCTION NAME													FORM B ARMM	
	5	10	25	30	35	40	45	50	55	60	65	70	75	80	
/	5	WATER TANK			10									5	
/	10	SUPPLY VALVES			10									10	
/	20	TRANSFORMERS			1	2.5								2.0	
/	25	BUS TIE			1	2.0								2.5	
/	30	PUMPS, INT 1			1	8.0								3.0	
/	35	PUMPS, INT 2			1	8.5								3.5	
/	50	PUMPS, INT 3	2		1	9.0								5.0	
/	55	PUMP, P' - 1	1		1	6.0								5.5	
/	60	CHECK VALVE, C' - 1	1		1	5.5								6.0	
/	65	PUMP, P' - 2	1		1	7.0								6.5	
/	70	CHECK VALVE, C' - 2	1		1	6.5								7.0	
/	75	HEADIER, VALVES	3		10									7.5	
/	80	STANDBY, PUMP, INT 1	6		12	3.0	A, 7.5							8.0	
/	85	STANDBY, PUMP, INT 2	6		12	3.5	A, 7.5							8.5	
/	90	STANDBY, PUMP, INT 3	3		12	5.0	A, 5.5	A, 6.5	A, 7.5	5.0	A, 6.0	A, 6.5	A, 7.5	5.0	9.0
/						A, 5.5	A, 7.0	A, 7.5							9.1
/															
/															
/															
/															
/															
/															
/															
/	10		2												5.0.2
/	75			2											5.0.3
/	80			2											5.0.4
/	85			2											5.0.5
/	90			2											5.0.6
1, 2	3, 4, 5, 6	7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28	29, 30, 31, 32	33, 34, 35, 36	37, 38, 39, 40	41, 42, 43, 44, 45, 46, 47, 48	49, 50, 51, 52	53, 54, 55	56, 57, 58, 59, 60	61, 62, 63, 64	65, 66, 67, 68	69, 70, 71, 72	73, 74, 75, 76, 77, 78, 79, 80		

FIGURE 2.19 (continued)

COMPONENT ID NO.	COMPONENT NAME					PRIOR OPERATING TIME (FL PT. NO.)	CYCLIC FAILURE RATE FAILURES/10 ⁶ CYCLES (FL PT. NO.)	AVG. NO. OF CYCLES/HR.	(FL PT. NO.)	CONT. FAIL. RATE FAILURES/10 ⁶ HRS (FL PT. NO.)	FL PT. NO.	NO. OF FUNCTIONS SUPPORTED.	NO. OF DEPENDENT COMPONENTS	WEIBULL SHAPE PARAMETER "b" FL PT. NO.	DEPTH CONTROL	FORM C ARMM		
	5	10	15	20	25											30	35	40
2	1.0.5	TANK, T								0.1	1	0					1.0.5	
2	1.1.0	VALVE, V-1								5.0	1	0					1.1.0	
2	1.1.5	VALVE, V-2								5.0	1	0					1.1.5	
2	1.2.0	TRANSFORMER, X-1								5.0	2	0					1.2.0	
2	1.2.5	TRANSFORMER, X-2								5.0	2	0					1.2.5	
2	1.3.0	BUS, TIE, B-T								2.0	1	0					1.3.0	
2	1.3.5	PUMP, P-1								1.0.0	2	1					1.3.5	
2	1.4.0	PUMP, P'-1								5.0	4	2		3			1.4.0	
2	1.4.5	PUMP, P-2								1.0.0	2	1					1.4.5	
2	1.5.0	PUMP, P'-2								5.0	4	2					1.5.0	
2	1.5.5	PUMP, P-3								1.0.0	1	6					1.5.5	
2	1.6.0	PUMP, P'-3								5.0	2	6					1.6.0	
2	1.6.5	CHECK, VALVE, C-1								0.25	6	2					1.6.5	
2	1.7.0	CHECK, VALVE, C'-1								1.0	3	2					1.7.0	
2	1.7.5	CHECK, VALVE, C-2								0.25	6	1					1.7.5	
2	1.8.0	CHECK, VALVE, C-2								1.0	3	1					1.8.0	
2	1.8.5	CHECK, VALVE, C-3								0.25	3	5					1.8.5	
2	1.9.0	VALVE, V-3								1.0.0	3	4					1.9.0	
2	1.9.5	VALVE, V-4								1.0.0	3	3					1.9.5	
2	2.0.0	VALVE, V-5								1.0.0	4	0		3			2.0.0	
2	2.0.5	VALVE, V-6								1.0.0	4	0					2.0.5	
2	2.1.0	VALVE, V-7								1.0.0	4	0					2.1.0	
2																		
2																		
2	2.0.0	VALVE, V-5												2		5.0.8	0.1	
2	1.1.0	VALVE, W-1								1.0.0							5.0.7	
2	1.1.5	VALVE, W-2								1.0.0							5.0.8	
1, 2	3, 4, 5, 6, 7, 8, 9	10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80																

FIGURE 2.19 (continued)

[illegible]

FIGURE 2.19 (continued)

[illegible]

FIGURE 2.19 (continued)

[illegible]

FIGURE 2.19 (continued)

[illegible]

AUTOMATIC RELIABILITY MATH MODEL				PAGE	1
ARM APPLICATION -- PROBLEM 1.				00000000, 1900	0000-00
--ILLUSTRATION OF ARMM APPLICATION--					
PROBLEM 1. ARMM APPLICATION TO A SAMPLE SYSTEM.					
PROBLEM 2. EXAMPLE USE OF PARTIAL DATA OPTION.					
NUMBER OF COMPONENTS		NUMBER OF TIME INTERVALS		LENGTH OF MISSION	
22		3		745.000	
NUMBER OF FUNCTIONS		NUMBER OF INTEGRATION INTERVALS		PRINT-OUT INDICATOR	
15		2		1	
MAXIMUM NUMBER OF COMPONENTS FAILED AT A TIME		REINITIALIZE INDICATOR			
2		0			

FIGURE 2.20
COMPLETED COMPUTER OUTPUT - PROBLEM 1

ARM APPLICATION -- PROBLEM 1.			AUTOMATIC RELIABILITY MATH MODEL		PAGE 2		
			FUNCTIONS		00000000, 1900 0000-00		
FUNCTION ID	FUNCTION NAME		MODES AVAILABLE	MODES REQUIRED	ALTERNATE FUNCTION ID		
5	WATER TANK		1.00	1.00			
10	SUPPLY VALVES		1.00	1.00			
20	TRANSFORMERS		1.00	1.00			
					25		
-25	BUS TIE		2.00	1.00			
					20		
30	PUMPS, INT 1		1.00	1.00			
					80		
35	PUMPS, INT 2		1.00	1.00			
					85		
50	PUMPS, INT 3		2.00	1.00			
					90		
55	PUMP P'-1		1.00	1.00			
					60		
-60	CHECK VALVE C'-1		1.00	1.00			
					55		
65	PUMP P'-2		1.00	1.00			
					70		
-70	CHECK VALVE C'-2		1.00	1.00			
					65		
75	HEADER VALVES		3.00	1.00			
-80	STANDBY PUMP, INT 1		6.00	1.00			
					30	A 75	
-85	STANDBY PUMP, INT 2		6.00	1.00			
					35	A 75	
-90	STANDBY PUMP, INT 3		3.00	1.00			
					50	A 55	A 65
					A 75	50	A 60
					A 65	A 75	50
					A 55	A 70	A 75

FIGURE 2.20 (continued)

ARM APPLICATION - PROBLEM 1.		AUTOMATIC RELIABILITY MATH MODEL				PAGE	3	
ID	COMPONENT NOMENCLATURE	FAILURE RATE 6 *10	B	SUPPORTED FUNCTION ID	WEIGHT FACTOR	00000000, 1900 DEPENDENT COMP. ID	0000-00	DEPTH CNTRL
105.00	TANK T	0.09999999E 00	1.00	5	1.000			-0
110.00	VALVE V-1	0.50000000E 01	1.00	10	1.000			-0
115.00	VALVE V-2	0.50000000E 01	1.00	10	1.000			-0
120.00	TRANSFORMER X-1	0.50000000E 01	1.00	20	1.000			-0
125.00	TRANSFORMER X-2	0.50000000E 01	1.00	25	1.000			-0
				20	1.000			
130.00	BUS TIE B-T	0.20000000E 01	1.00	25	1.000			-0
135.00	PUMP P-1	0.10000000E 02	1.00	25	2.000			-0
				30	1.000			
						-165		
140.00	PUMP P-1	0.50000000E 01	1.00	80	3.000			3
				35	1.000			
						-165		
				50	1.000			
						-180		
				55	1.000			

FIGURE 2.20 (continued)

145.00	PUMP P-2	0.10000000E 02	1.00	30	1.000	-175	-0
150.00	PUMP P-2	0.50000000E 01	1.00	80	3.000	-170	-0
				35	1.000	-175	
				50	1.000	-175	
				65	1.000		
155.00	PUMP P-3	0.10000000E 02	1.00	85	3.000	-185	-0
				80	3.000	-190	
						-195	
						-200	
						-205	
						-210	
160.00	PUMP P-3	0.50000000E 01	1.00	85	3.000	-185	-0
				90	3.000	-190	
						-195	

FIGURE 2.20 (continued)

AUTOMATIC RELIABILITY MATH MODEL						PAGE	4	
ARM APPLICATION	PROBLEM 1.					00000C00, 1900	0000-00	
ID	COMPONENT		FAILURE	B	SUPPORTED	WEIGHT	DEPENDENT	DEPTH
	NOMENCLATURE		RATE		FUNCTION ID	FACTOR	COMP. ID	CONTROL
			*10					
							-200	
							-205	
							-210	
165.00	CHECK VALVE C-1		0.25000000E 00	1.00	30	1.000	170	-0
					35	1.000	-180	
					50	1.000		
					55	1.000		
					80	3.000		
					85	3.000		
170.00	CHECK VALVE C'-1		0.10000000E 01	1.00	60	1.000	165	-0
					85	3.000	-175	
					90	3.000		
175.00	CHECK VALVE C-2		0.25000000E 00	1.00	30	1.000	180	-0
					35	1.000		
					50	1.000		
					65	1.000		
					80	3.000		
					85	3.000		

FIGURE 2.20 (continued)

180.00	CHECK VALVE C-2	0.10000000E 01	1.00	70	1.000	175	-0
				85	3.000		
				90	3.000		
185.00	CHECK VALVE C-3	0.25000000E 00	1.00	80	3.000		-0
						-190	
						-195	
				90	3.000		
						-200	
						-205	
						-210	
190.00	VALVE V-3	0.10000000E 02	1.00	80	3.000		-0
						-195	
				85	3.000		
				90	3.000		
						-200	
						-205	

FIGURE 2.20 (continued)

ARM APPLICATION		AUTOMATIC RELIABILITY MATH MODEL				PAGE	5	DEPTH CONTROL
ID	PROBLEM 1. COMPONENT NOMENCLATURE	FAILURE RATE ⁶ *10	B	SUPPORTED FUNCTION IC	WEIGHT FACTOR	00000000, 1900 DEPENDENT COMP. ID	0000-00	
195.00	VALVE V-4	0.10000000E 02	1.00	80	3.000	-210		-0
				85	3.000	-200		
				90	3.000	-205		
200.00	VALVE V-5	0.10000000E 02	1.00	75	1.000	-210		3
				80	1.000			
				85	1.000			
205.00	VALVE V-6	0.10000000E 02	1.00	90	1.000			-0
				75	1.000			
				80	1.000			
				85	1.000			
210.00	VALVE V-7	0.10000000E 02	1.00	90	1.000			-0
				75	1.000			
				80	1.000			
				85	1.000			
				90	1.000			

FIGURE 2.20 (continued)

ARM APPLICATION -- PROBLEM 1.		AUTOMATIC RELIABILITY MATH MODEL						PAGE	6
		TIME SCHEDULE						00000000, 1900	0000-00
INTERVAL ID	TIME	FUNCTION STATE CHANGES (- FOR OFF)							
1	0.	-35	-50	-55	-65	-85	-90		
2	720.000	-30	35	-80	85				
3	721.000	-35	50	55	65	-85	90		
-0	745.000								

FIGURE 2.20 (continued)

AUTOMATIC RELIABILITY MATH MODEL					PAGE	7
ARM APPLICATION -- PROBLEM 1.					00000000, 1900	0000-00
PROBABILITY OF MISSION SUCCESS PRIOR THIS INTERVAL = 0.10000000E 01						
COMPONENT FAILURE COMBINATIONS	TIME INTERVAL		1	P(F)	FUNCTION NO.	
				0.14399395E-03	5	
105				0.71848994E-02	10	
110				0.71848994E-02	10	
115				0.60371129E-05	-25	
120	130\$			0.51622778E-04	20	
120 125				0.60371129E-05	-25	
125	130\$			0.60169852E-04	-80	
135	155\$			0.15080222E-05	-80	
135	185\$			0.60169852E-04	-80	
135	190\$			0.60169852E-04	-80	
135	195\$					

FIGURE 2.20 (continued)

FIGURE 2.20 (continued)

165	1955							0.15080222E-05	-80
165	175							0.12957278E-06	30
175	1555							0.15080222E-05	-80
175	1855							0.37795139E-07	-80
175	1905							0.15080222E-05	-80
175	1955							0.15080222E-05	-80
200	205	210						0.29486140E-05	75
ACCUMULATIVE MISSION FAILURE THIS INTERVAL =								0.15080514E-01	

FIGURE 2.20 (continued)

ARM APPLICATION -- PROBLEM 1.			AUTOMATIC RELIABILITY MATH MODEL		PAGE	8
			TIME INTERVAL 1		00000000, 1900	0000-00
FUNCTION ID	FUNCTION NAME	PROBABILITY OF FUNCTION FAILURE	PERCENT OF SYSTEM FAILURE	RANK		
5	WATER TANK	0.14314760E-03	0.949	4		
10	SUPPLY VALVES	0.14285338E-01	94.727	1		
20	TRANSFORMERS	0.51319357E-04	0.340	5		
-25	BUS TIE	0.12003258E-04	0.080	6		
30	PUMPS, INT 1	0.21480929E-03	1.424	3		
75	HEADER VALVES	0.29312830E-05	0.019	7		
-80	STANDBY PUMP, INT 1	0.37096555E-03	2.460	2		
COMPONENT COMBINATIONS		MAJOR CONTRIBUTORS TO SYSTEM UNRELIABILITY PROBABILITY		PERCENT		
115		0.71848994E-02		47.3636		
110		0.71848994E-02		47.3636		
135 145		0.20562628E-03		1.3555		
105		0.14399395E-03		0.9492		
145 155		0.60169852E-04		0.3966		
135 190		0.60169852E-04		0.3966		
135 155		0.60169852E-04		0.3966		
145 190		0.60169852E-04		0.3966		
135 195		0.60169852E-04		0.3966		
145 195		0.60169852E-04		0.3966		

FIGURE 2.20 (continued)

AUTOMATIC RELIABILITY MATH MODEL

PAGE 9

ARM APPLICATION -- PROBLEM 1.

00000000, 1900 0000-00

TIME INTERVAL 1

COMPONENT CONTRIBUTIONS TO UNRELIABILITY

COMPONENT ID	NAME	FAILURE RATE*10**6	SERIAL PROBABILITY	SERIAL PERCENT	SERIAL RANK	SYSTEM PROBABILITY	SYSTEM PERCENT	SYSTEM RANK
105.00	TANK T	0.10	0.13980658E-03	0.1416	12	0.14314760E-03	0.9492	5
110.00	VALVE V-1	5.00	0.69903292E-02	7.0822	6	0.71426693E-02	47.3636	1
115.00	VALVE V-2	5.00	0.69903292E-02	7.0822	7	0.71426693E-02	47.3636	2
120.00	TRANSFORMER X-1	5.00	0.69903292E-02	7.0822	8	0.29946557E-04	0.1986	9
125.00	TRANSFORMER X-2	5.00	0.69903292E-02	7.0822	9	0.29946557E-04	0.1986	10
130.00	BUS TIE B-T	2.00	0.	0.	0	0.34295023E-05	0.0227	11
135.00	PUMP P-1	10.00	0.13980658E-01	14.1643	1	0.19840197E-03	1.3156	3
140.00	PUMP P'-1	5.00	0.	0.	0	0.	0.	0
145.00	PUMP P-2	10.00	0.13980658E-01	14.1643	2	0.19840197E-03	1.3156	4
150.00	PUMP P'-2	5.00	0.	0.	0	0.	0.	0
155.00	PUMP P-3	10.00	0.	0.	0	0.62741382E-04	0.4160	6
160.00	PUMP P'-3	5.00	0.	0.	0	0.	0.	0
165.00	CHECK VALVE C-1	0.25	0.34951646E-03	0.3541	10	0.31804278E-06	0.0021	15
170.00	CHECK VALVE C'-1	1.00	0.	0.	0	0.	0.	0
175.00	CHECK VALVE C-2	0.25	0.34951646E-03	0.3541	11	0.31804277E-06	0.0021	16
180.00	CHECK VALVE C'-2	1.00	0.	0.	0	0.	0.	0
185.00	CHECK VALVE C-3	0.25	0.	0.	0	0.11070268E-06	0.0007	17
190.00	VALVE V-3	10.00	0.	0.	0	0.62741382E-04	0.4160	7
195.00	VALVE V-4	10.00	0.	0.	0	0.62741382E-04	0.4160	8
200.00	VALVE V-5	10.00	0.13980658E-01	14.1643	3	0.97709436E-06	0.0065	12
205.00	VALVE V-6	10.00	0.13980658E-01	14.1643	4	0.97709436E-06	0.0065	13
210.00	VALVE V-7	10.00	0.13980658E-01	14.1643	5	0.97709436E-06	0.0065	14

FIGURE 2.20 (continued)

AUTOMATIC RELIABILITY MATH MODEL				PAGE	10
ARM APPLICATION -- PROBLEM 1.				00000C00, 1900	0000-00
PROBABILITY OF MISSION SUCCESS PRIOR THIS INTERVAL = 0.98491948E 00					
COMPONENT FAILURE COMBINATIONS	TIME INTERVAL		2	P(F)	FUNCTION NO.
105				0.19999998E-06	5
110				0.99999706E-05	10
115				0.99999706E-05	10
120				0.11660158E-10	-25
130				0.99999412E-10	20
120 125				0.11660158E-10	-25
125				0.99999412E-10	35
140 150				0.99999412E-10	-85
140 160				0.19999929E-10	-85
140 170				0.49999844E-11	35
140 175					

FIGURE 2.20 (continued)

FIGURE 2.20 (continued)

FIGURE 2.20 (continued)

ARMED APPLICATION -- PROBLEM 1.			AUTOMATIC RELIABILITY MATH MODEL		PAGE	11
			TIME INTERVAL	2	00000000, 1900	0000-00
FUNCTION ID	FUNCTION NAME	PROBABILITY OF FUNCTION FAILURE	PERCENT CF SYSTEM FAILURE	RANK		
5	WATER TANK	0.19698282E-06	0.990	2		
10	SUPPLY VALVES	0.19698226E-04	99.003	1		
20	TRANSFORMERS	0.98490843E-10	0.000	5		
-25	BUS TIE	0.22968511E-10	0.000	6		
35	PUMPS, INT 2	0.11843529E-09	0.001	4		
-85	STANDBY PUMP,INT 2	0.10740404E-08	0.005	3		
COMPONENT COMBINATIONS		MAJOR CONTRIBUTORS TO SYSTEM UNRELIABILITY PROBABILITY	PERCENT			
115		0.99999706E-05	49.5041			
110		0.99999706E-05	49.5041			
105		0.19999998E-06	0.9901			
140 190		0.19999824E-09	0.0010			
150 190		0.19999824E-09	0.0010			
140 195		0.19999824E-09	0.0010			
150 195		0.19999824E-09	0.0010			
140 160		0.99999412E-10	0.0005			
120 125		0.99999412E-10	0.0005			
140 150		0.99999412E-10	0.0005			

FIGURE 2.20 (continued)

AUTOMATIC RELIABILITY MATH MODEL						PAGE	12	
ARM APPLICATION -- PROBLEM 1.			TIME INTERVAL 2			00000000, 1900	0000-00	
COMPONENT CONTRIBUTIONS TO UNRELIABILITY								
COMPONENT ID	NAME	FAILURE RATE*10**6	SERIAL PROBABILITY	SERIAL PERCENT	SERIAL RANK	SYSTEM PROBABILITY	SYSTEM PERCENT	SYSTEM RANK
105.00	TANK T	0.10	0.18025006E-06	0.1138	18	0.19698283E-06	C.9900	3
110.00	VALVE V-1	5.00	0.90125034E-05	5.6915	6	0.98491137E-05	49.5017	1
115.00	VALVE V-2	5.00	0.90125034E-05	5.6915	7	0.98491137E-05	49.5017	2
120.00	TRANSFORMER X-1	5.00	0.90125034E-05	5.6915	8	0.57448462E-10	C.0003	9
125.00	TRANSFORMER X-2	5.00	0.90125034E-05	5.6915	9	0.57448462E-10	C.0003	10
130.00	BUS TIE B-T	2.00	0.	0.	0	0.65624319E-11	C.0000	11
135.00	PUMP P-1	10.00	0.	0.	0	0.	C.	0
140.00	PUMP P'-1	5.00	0.90125034E-05	5.6915	10	0.25560687E-09	C.C013	7
145.00	PUMP P-2	10.00	0.	0.	0	0.	C.	0
150.00	PUMP P'-2	5.00	0.90125034E-05	5.6915	11	0.25560688E-09	C.C013	6
155.00	PUMP P-3	10.00	0.	0.	0	0.	C.	0
160.00	PUMP P'-3	5.00	0.90125034E-05	5.6915	12	0.10787095E-09	C.0005	8
165.00	CHECK VALVE C-1	0.25	0.45062517E-06	0.2846	15	0.11956768E-11	C.0000	14
170.00	CHECK VALVE C'-1	1.00	0.18025007E-05	1.1383	13	0.32830358E-11	C.0000	12
175.00	CHECK VALVE C-2	0.25	0.45062517E-06	0.2846	16	0.11956768E-11	C.0000	15
180.00	CHECK VALVE C'-2	1.00	0.18025007E-05	1.1383	14	0.32830358E-11	C.0000	13
185.00	CHECK VALVE C-3	0.25	0.45062517E-06	0.2846	17	0.71523380E-12	C.0000	16
190.00	VALVE V-3	10.00	0.18025007E-04	11.3830	1	0.28185921E-09	C.C014	4
195.00	VALVE V-4	10.00	0.18025007E-04	11.3830	2	0.28185921E-09	C.C014	5
200.00	VALVE V-5	10.00	0.18025007E-04	11.3830	3	0.	C.	0
205.00	VALVE V-6	10.00	0.18025007E-04	11.3830	4	0.	C.	0
210.00	VALVE V-7	10.00	0.18025007E-04	11.3830	5	0.	C.	0

FIGURE 2.20 (continued)

AUTOMATIC RELIABILITY MATH MODEL					PAGE	13
ARM APPLICATION -- PROBLEM 1.					00000000, 1900	0000-00
PROBABILITY OF MISSION SUCCESS PRIOR THIS INTERVAL = 0.98489959E 00						
COMPONENT FAILURE COMBINATIONS	TIME INTERVAL		P(F)		FUNCTION NO.	
	3		0.47999931E-05		5	
105			0.23998320E-03		10	
110			0.23998320E-03		10	
115			0.67191320E-08		-25	
120	130\$		0.57591935E-07		20	
120 125			0.67191320E-08		-25	
125	130\$					

FIGURE 2.20 (continued)

FIGURE 2.20 (continued)

ARM APPLICATION -- PROBLEM 1.			AUTOMATIC RELIABILITY MATH MODEL		PAGE	14
			TIME INTERVAL	3	00000000, 1900	0000-00
FUNCTION	ID	FUNCTION NAME	PROBABILITY OF FUNCTION FAILURE	PERCENT OF SYSTEM FAILURE	RANK	
5		WATER TANK	0.47269262E-05	0.990	2	
10		SUPPLY VALVES	0.47266021E-03	98.991	1	
20		TRANSFORMERS	0.56715254E-07	0.012	3	
-25		BUS TIE	0.13233703E-07	0.003	4	
50		PUMPS, INT 3	0.68058066E-12	0.000	8	
-60		CHECK VALVE C'+1	0.11343686E-07	0.002	5	
-70		CHECK VALVE C'+2	0.11343686E-07	0.002	6	
-90		STANDBY PUMP, INT 3	0.71486471E-10	0.000	7	
COMPONENT COMBINATIONS			MAJOR CONTRIBUTORS TO SYSTEM UNRELIABILITY		PERCENT	
115			PROBABILITY			
110			0.23998320E-03		49.4954	
105			0.23998320E-03		49.4954	
120 125			0.47999931E-05		0.9900	
140 170			0.57591935E-07		0.0119	
150 180			0.11519032E-07		0.0024	
125 130			0.11519032E-07		0.0024	
120 130			0.67191320E-08		0.0014	
140 150 195			0.67191320E-08		0.0014	
140 150 190			0.27640258E-10		0.0000	
			0.27640258E-10		0.0000	

FIGURE 2.20 (continued)

AUTOMATIC RELIABILITY MATH MODEL						PAGE	15
ARMH APPLICATION - PROBLEM 1.						00000000, 1900	0000-00
TIME INTERVAL 3							
COMPONENT CONTRIBUTIONS TO UNRELIABILITY							
COMPONENT ID	NAME	FAILURE RATE*10**6	SERIAL PROBABILITY	SERIAL PERCENT	SERIAL SYSTEM RANK PROBABILITY	SYSTEM PERCENT	SYSTEM RANK
105.00	TANK T	0.10	0.43201473E-05	0.1138	18	0.47269262E-05	0.9900 3
110.00	VALVE V-1	5.00	0.21600737E-03	5.6915	6	0.23633011E-03	49.4953 1
115.00	VALVE V-2	5.00	0.21600737E-03	5.6915	7	0.23633011E-03	49.4953 2
120.00	TRANSFORMER X-1	5.00	0.21600737E-03	5.6915	8	0.33083949E-07	0.0069 4
125.00	TRANSFORMER X-2	5.00	0.21600737E-03	5.6915	9	0.33083949E-07	0.0069 5
130.00	BUS TIE B-T	2.00	0.	0.	0	0.37810580E-08	0.0008 8
135.00	PUMP P-1	10.00	0.	0.	0	0.	0. 0
140.00	PUMP P'-1	5.00	0.21600737E-03	5.6915	10	0.94728053E-08	0.0020 6
145.00	PUMP P-2	10.00	0.	0.	0	0.	0. 0
150.00	PUMP P'-2	5.00	0.21600737E-03	5.6915	11	0.94715501E-08	0.0020 7
155.00	PUMP P-3	10.00	0.	0.	0	0.	0. 0
160.00	PUMP P'-3	5.00	0.21600737E-03	5.6915	12	0.48688932E-11	0.0000 13
165.00	CHECK VALVE C-1	0.25	0.10800368E-04	0.2846	15	0.	0. 0
170.00	CHECK VALVE C'-1	1.00	0.43201474E-04	1.1383	13	0.18906142E-08	0.0004 9
175.00	CHECK VALVE C-2	0.25	0.10800368E-04	0.2846	16	0.62771520E-13	0.0000 14
180.00	CHECK VALVE C'-2	1.00	0.43201474E-04	1.1383	14	0.18906143E-08	0.0004 10
185.00	CHECK VALVE C-3	0.25	0.10800368E-04	0.2846	17	0.18146405E-13	0.0000 15
190.00	VALVE V-3	10.00	0.43201474E-03	11.3830	1	0.14502258E-10	0.0000 11
195.00	VALVE V-4	10.00	0.43201474E-03	11.3830	2	0.14502258E-10	0.0000 12
200.00	VALVE V-5	10.00	0.43201474E-03	11.3830	3	0.	0. 0
205.00	VALVE V-6	10.00	0.43201474E-03	11.3830	4	0.	0. 0
210.00	VALVE V-7	10.00	0.43201474E-03	11.3830	5	0.	0. 0

FIGURE 2.20 (continued)

AUTOMATIC RELIABILITY MATH MODEL				PAGE	16
ARM APPLICATION - PROBLEM 1.				00000000, 1900	0000-00
SUMMARY					
PROBABILITY OF SYSTEM FAILURE =				0.15577890E-01	
PROBABILITY OF SYSTEM SUCCESS =				0.98442210	
FUNCTION ID	FUNCTION NAME	PROBABILITY OF FUNCTION FAILURE	PERCENT OF SYSTEM FAILURE	RANK	
5	WATER TANK	0.14806921E-03	0.951	4	
10	SUPPLY VALVES	0.14777467E-01	94.863	1	
20	TRANSFORMERS	0.51376142E-04	0.330	5	
-25	BUS TIE	0.12016508E-04	0.077	6	
30	PUMPS, INT 1	0.21480929E-03	1.379	3	
35	PUMPS, INT 2	0.11843290E-09	0.000	11	
50	PUMPS, INT 3	0.68025071E-12	0.000	13	
-60	CHECK VALVE C'-1	0.11338187E-07	0.000	8	
-70	CHECK VALVE C'-2	0.11338187E-07	0.000	9	
75	HEADER VALVES	0.29312830E-05	0.019	7	
-80	STANDBY PUMP, INT 1	0.37096555E-03	2.381	2	
-85	STANDBY PUMP, INT 2	0.10740187E-08	0.000	10	
-90	STANDBY PUMP, INT 3	0.71451814E-10	0.000	12	

FIGURE 2.20 (continued)

ARM APPLICATION -- PROBLEM 1.

COMPONENT COMBINATIONS

115
110
135 145
105
135 155
145 190
135 190
135 195
145 155
145 195

AUTOMATIC RELIABILITY MATH MODEL

SUMMARY

MAJOR CONTRIBUTORS TO SYSTEM UNRELIABILITY
PROBABILITY

0.74348825E-02
0.74348825E-02
0.20562628E-03
0.14899394E-03
0.60169852E-04
0.60169852E-04
0.60169852E-04
0.60169852E-04
0.60169852E-04
0.60169852E-04

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00000000, 1900 0000-00

PERCENT

47.4323
47.4323
1.3118
0.9505
0.3839
0.3839
0.3839
0.3839
0.3839
0.3839

FIGURE 2.20 (continued)

AUTOMATIC RELIABILITY MATH MODEL						PAGE	18	
ARMN APPLICATION -- PROBLEM 1.		SUMMARY				00000000, 1900 0000-00		
COMPONENT CONTRIBUTIONS TO UNRELIABILITY								
COMPONENT ID	NAME	FAILURE RATE*10**6	SERIAL PROBABILITY	SERIAL PERCENT	SERIAL RANK	SYSTEM PROBABILITY	SYSTEM PERCENT	SYSTEM RANK
105.00	TANK T	0.10	0.14422407E-03	0.1405	17	0.14807151E-03	C.9505	5
110.00	VALVE V-1	5.00	0.72112036E-02	7.0246	6	0.73888485E-02	47.4316	1
115.00	VALVE V-2	5.00	0.72112036E-02	7.0246	7	0.73888485E-02	47.4316	2
120.00	TRANSFORMER X-1	5.00	0.72112036E-02	7.0246	8	0.29979698E-04	0.1925	9
125.00	TRANSFORMER X-2	5.00	0.72112036E-02	7.0246	9	0.29979698E-04	C.1925	10
130.00	BUS TIE B-T	2.00	0.	0.	0	0.34332899E-05	C.0220	11
135.00	PUMP P-1	10.00	0.13938434E-01	13.5777	4	0.19840197E-03	1.2736	3
140.00	PUMP P'-1	5.00	0.24198670E-03	0.2357	14	0.97284122E-08	C.0001	18
145.00	PUMP P-2	10.00	0.13938434E-01	13.5777	5	0.19840197E-03	1.2736	4
150.00	PUMP P'-2	5.00	0.24198670E-03	0.2357	15	0.97271570E-08	C.0001	19
155.00	PUMP P-3	10.00	0.	0.	0	0.62741382E-04	C.4028	8
160.00	PUMP P'-3	5.00	0.24198670E-03	0.2357	16	0.11273985E-09	C.0000	22
165.00	CHECK VALVE C-1	0.25	0.36056018E-03	0.3512	12	0.31804397E-06	C.0020	16
170.00	CHECK VALVE C'-1	1.00	0.48397340E-04	0.0471	18	0.18938973E-08	C.0000	20
175.00	CHECK VALVE C-2	0.25	0.36056018E-03	0.3512	13	0.31804403E-06	C.0020	15
180.00	CHECK VALVE C'-2	1.00	0.48397340E-04	0.0471	19	0.18938973E-08	C.0000	21
185.00	CHECK VALVE C-3	0.25	0.12099335E-04	0.0118	20	0.11070342E-06	C.0007	17
190.00	VALVE V-3	10.00	0.48397340E-03	0.4714	10	0.62741677E-04	C.4028	6
195.00	VALVE V-4	10.00	0.48397340E-03	0.4714	11	0.62741677E-04	C.4028	7
200.00	VALVE V-5	10.00	0.14422407E-01	14.0491	1	0.97709436E-06	C.0063	12
205.00	VALVE V-6	10.00	0.14422407E-01	14.0491	2	0.97709436E-06	C.0063	13
210.00	VALVE V-7	10.00	0.14422407E-01	14.0491	3	0.97709436E-06	C.0063	14
TOTAL SERIAL UNRELIABILITY			0.10265704E 00					

FIGURE 2.20 (continued)

ARM APPLICATION -- PROBLEM 1.

AUTOMATIC RELIABILITY MATH MODEL

PAGE

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00000000, 1900 0000-00

SUMMARY

INDEX

INPUT						1
OUTPUT						16
INTERVAL 1 (	0.	TO	720.000)			7
INTERVAL 2 (	720.000	TO	721.000)			10
INTERVAL 3 (	721.000	TO	745.000)			13

NUMBER OF COMBINATIONS CONSIDERED = 260

NUMBER OF FAILURE TERMS CALCULATED= 72

NUMBER OF COMBINATIONS WRITTEN 71

PHI = 0.15674735E-01

FIGURE 2.20 (continued)

AUTOMATIC RELIABILITY MATH MODEL			PAGE	1
ARM APPLICATION --	PROBLEM 2.		00000000, 1900	0000-00
		--ILLUSTRATION OF ARMM APPLICATION--		
	PROBLEM 1.	ARM APPLICATION TO A SAMPLE SYSTEM.		
	PROBLEM 2.	EXAMPLE USE OF PARTIAL DATA OPTION.		
NUMBER OF COMPONENTS	22	NUMBER OF TIME INTERVALS	3	LENGTH OF MISSION
				193.000
NUMBER OF FUNCTIONS	15	NUMBER OF INTEGRATION INTERVALS	2	PRINT-OUT INDICATOR
				1
MAXIMUM NUMBER OF COMPONENTS FAILED AT A TIME	2	REINITIALIZE INDICATOR	1	

FIGURE 2.21

COMPUTER OUTPUT SUMMARY

ARM APPLICATION -- PROBLEM 2.			AUTOMATIC RELIABILITY MATH MODEL		PAGE	17
			SUMMARY		00000000, 1900	0000-00
			PROBABILITY OF SYSTEM FAILURE =		0.11848346E-03	
			PROBABILITY OF SYSTEM SUCCESS =		0.99988151	
FUNCTION ID	FUNCTION NAME	PROBABILITY OF FUNCTION FAILURE	PERCENT OF SYSTEM FAILURE	RANK		
5	WATER TANK	0.38239574E-04	32.274	1		
10	SUPPLY VALVES	0.11377681E-04	9.603	5		
20	TRANSFORMERS	0.28471601E-05	2.403	6		
-25	BUS TIE	0.66470302E-06	0.561	7		
30	PUMPS, INT 1	0.11711839E-04	9.885	4		
35	PUMPS, INT 2	0.12023563E-09	0.000	11		
50	PUMPS, INT 3	0.69100285E-12	0.000	13		
-60	CHECK VALVE C'-1	0.11517400E-07	0.010	8		
-70	CHECK VALVE C'-2	0.11517400E-07	0.010	9		
75	HEADER VALVES	0.33440933E-04	28.224	2		
-80	STANDBY PUMP, INT 1	0.20177226E-04	17.030	3		
-85	STANDBY PUMP, INT 2	0.10903669E-08	0.001	10		
-90	STANDBY PUMP, INT 3	0.72581191E-10	0.000	12		

FIGURE 2.21 (continued)

ARM APPLICATION - PROBLEM 2.		AUTOMATIC RELIABILITY MATH MODEL.		PAGE	18
COMPONENT COMBINATIONS		SUMMARY		00000000, 1900	0000-00
105		MAJOR CONTRIBUTORS TO SYSTEM UNRELIABILITY		PERCENT	
110 115		0.38599662E-04		32.2450	
200 210		0.11498232E-04		9.6053	
200 205		0.11267496E-04		9.4125	
135 145		0.11267496E-04		9.4125	
205 210		0.11267496E-04		9.4125	
135 190		0.11267496E-04		9.4125	
135 195		0.32888511E-05		2.7474	
145 190		0.32888511E-05		2.7474	
135 155		0.32888511E-05		2.7474	
		0.32888511E-05		2.7474	

FIGURE 2.21 (continued)

AUTOMATIC RELIABILITY MATH MODEL						PAGE	19	
ARM APPLICATION — PROBLEM 2.						00000000, 1900	0000-CC	
SUMMARY								
COMPONENT CONTRIBUTIONS TO UNRELIABILITY								
COMPONENT ID	NAME	FAILURE RATE*10**6	SERIAL PROBABILITY	SERIAL PERCENT	SERIAL RANK	SYSTEM PROBABILITY	SYSTEM PERCENT	SYSTEM RANK
105.00	TANK T	0.10	0.38175661E-04	0.1207	19	0.3823960CE-04	32.2742	1
110.00	VALVE V-1	10.00	0.38175663E-02	12.0723	1	0.56888412E-05	4.8014	7
115.00	VALVE V-2	10.00	0.38175663E-02	12.0723	2	0.56888412E-05	4.8014	8
120.00	TRANSFORMER X-1	5.00	0.19087831E-02	6.0361	8	0.16609742E-05	1.4019	12
125.00	TRANSFORMER X-2	5.00	0.19087831E-02	6.0361	9	0.16609742E-05	1.4019	13
130.00	BUS TIE B-T	2.00	0.	0.	0	0.18991517E-06	0.1603	14
135.00	PUMP P-1	10.00	0.33230628E-02	10.5085	6	0.10805541E-04	9.1159	5
140.00	PUMP P'-1	5.00	0.24725170E-03	0.7819	12	0.98774133E-08	0.0083	17
145.00	PUMP P-2	10.00	0.33230628E-02	10.5085	7	0.10805541E-04	9.1159	6
150.00	PUMP P'-2	5.00	0.24725170E-03	0.7819	13	0.98761366E-08	0.0083	18
155.00	PUMP P-3	10.00	0.	0.	0	0.34124919E-05	2.8801	11
160.00	PUMP P'-3	5.00	0.24725170E-03	0.7819	14	0.11445421E-09	0.0001	22
165.00	CHECK VALVE C-1	0.25	0.95439156E-04	0.3018	15	0.17268023E-07	0.0146	16
170.00	CHECK VALVE C'-1	1.00	0.49450340E-04	0.1564	17	0.19229094E-08	0.0016	20
175.00	CHECK VALVE C-2	0.25	0.95439156E-04	0.3018	16	0.17268087E-07	0.0146	15
180.00	CHECK VALVE C'-2	1.00	0.49450340E-04	0.1564	18	0.19229094E-08	0.0016	21
185.00	CHECK VALVE C-3	0.25	0.12362585E-04	0.0391	20	0.60068835E-08	0.0051	19
190.00	VALVE V-3	10.00	0.49450340E-03	1.5638	10	0.34127927E-05	2.8804	9
195.00	VALVE V-4	10.00	0.49450340E-03	1.5638	11	0.34127927E-05	2.8804	10
200.00	VALVE V-5	10.00	0.38175663E-02	12.0723	3	0.11146978E-04	9.4080	2
205.00	VALVE V-6	10.00	0.38175663E-02	12.0723	4	0.11146978E-04	9.4080	3
210.00	VALVE V-7	10.00	0.38175663E-02	12.0723	5	0.11146978E-04	9.4080	4
TOTAL SERIAL UNRELIABILITY			0.31622601E-01					

FIGURE 2.21 (continued)

FIGURE 2.22

$P(\lambda T)$ AS A FUNCTION OF λT FOR SEVERAL VALUES OF A .
THE MODEL IS A TWO-OUT-OF-THREE SYSTEM WITH IDENTICAL
COMPONENTS AND NO REPAIR.

LEGEND

T = TRANSFORMERS
 BAB = BUS AIR CIRCUIT BREAKERS

FIGURE 2.23
 SCHEMATIC OF DRESDEN-3 EMERGENCY A-C POWER SYSTEM⁽⁴⁾

FIGURE 2.24
 FAULT TREE FOR DRESDEN-3 EMERGENCY A-C POWER SYSTEM

```

3000    57    250      1      1
4.20000E 04 1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00
1.00000E 06 1.00000E 07 1.11000E 05 1.11000E 05 1.00000E 04 1.00000E 06
1.00000E 06 1.11000E 05 1.11000E 05 1.00000E 06 1.00000E 06 2.00000E 05
1.00000E 06 1.11000E 05 1.11000E 05 1.00000E 06 2.00000E 05 1.00000E 06
2.00000E 05 2.00000E 05 2.00000E 05 1.00000E 05 1.00000E 05 1.00000E 06
1.00000E 05 2.00000E 05 1.11000E 05 1.11000E 05 1.00000E 06 2.00000E 05
1.00000E 05 2.00000E 05 1.00000E 05 2.00000E 05 2.00000E 05 2.00000E 06
1.00000E 05 1.00000E 06 1.00000E 05 2.00000E 05 1.00000E 05 2.00000E 05
1.00000E 05 1.00000E 06 1.11000E 05 1.11000E 05 1.00000E 06 2.00000E 05
1.00000E 05 2.00000E 05 1.00000E 05 1.00000E 06 1.11000E 05 1.11000E 05
1.00000E 06 2.00000E 05 1.00000E 05
1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05
1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05
1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05
1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05
1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05
1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05
1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05
1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05
1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05 1.00000E 05
1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01
1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01
1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01
1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01
1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01
1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01
1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01
1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01 1.00000E-01
1.00000E 00
      0      0      0

```

FIGURE 2.25

INPUT DATA CARD LISTING FOR SAMPLE CALCULATION (ANALOG)

NTRIAL= 3000
IMX= 57
NOINT= 250
NCONS= 1
NO. OF CRITICAL PATHS= 1
TMAX= 0.42000E 05
AA= 0.10000E 01
BB= 0.10000E 01
CC= 0.10000E 01

FIGURE 2.26A
SAFTE-I SAMPLE CALCULATION OUTPUT

MTTF		MTTR	
0.10000E 07		0.10000E 06	
0.10000E 08		0.10000E 06	
0.11100E 06		0.10000E 06	
0.11100E 06		0.10000E 06	
0.10000E 05		0.10000E 06	
0.10000E 07		0.10000E 06	
0.10000E 07		0.10000E 06	
0.11100E 06		0.10000E 06	
0.11100E 06		0.10000E 06	
0.10000E 07		0.10000E 06	
0.10000E 07		0.10000E 06	
0.20000E 06		0.10000E 06	
0.10000E 07		0.10000E 06	
0.11100E 06		0.10000E 06	
0.11100E 06		0.10000E 06	
0.10000E 07		0.10000E 06	
0.20000E 06		0.10000E 06	
0.10000E 07		0.10000E 06	
0.20000E 06		0.10000E 06	
0.20000E 06		0.10000E 06	
0.20000E 06		0.10000E 06	
0.10000E 06		0.10000E 06	
0.10000E 06		0.10000E 06	
0.10000E 07		0.10000E 06	
0.10000E 06		0.10000E 06	
0.20000E 06		0.10000E 06	
0.11100E 06		0.10000E 06	
0.11100E 06		0.10000E 06	
0.10000E 07		0.10000E 06	
0.20000E 06		0.10000E 06	
0.10000E 06		0.10000E 06	
0.20000E 06		0.10000E 06	
0.20000E 06		0.10000E 06	
0.20000E 06		0.10000E 06	
0.20000E 07		0.10000E 06	
0.10000E 06		0.10000E 06	
0.10000E 07		0.10000E 06	
0.10000E 06		0.10000E 06	
0.20000E 06		0.10000E 06	
0.10000E 06		0.10000E 06	
0.10000E 06		0.10000E 06	
0.20000E 06		0.10000E 06	
0.10000E 06		0.10000E 06	
0.10000E 07		0.10000E 06	
0.11100E 06		0.10000E 06	
0.11100E 06		0.10000E 06	
0.10000E 07		0.10000E 06	
0.20000E 06		0.10000E 06	
0.10000E 06		0.10000E 06	
0.20000E 06		0.10000E 06	
0.10000E 06		0.10000E 06	
0.10000E 07		0.10000E 06	
0.11100E 06		0.10000E 06	
0.11100E 06		0.10000E 06	
0.10000E 07		0.10000E 06	
0.20000E 06		0.10000E 06	
0.10000E 06		0.10000E 06	

FIGURE 2.26B

SAFTE-I SAMPLE CALCULATION OUTPUT

PROBABILITY OF SYSTEM FAILURE BEFORE TMAX= 0.25467E 00

SYSTEM FAILURE FREQUENCY

0.	0.	0.	0.	0.
0.	0.	0.	0.	0.
0.	0.	0.	0.	0.
0.	0.	0.	0.	0.
0.	0.	0.	0.	0.
0.	0.	0.19841E-05	0.	0.
0.	0.	0.	0.	0.
0.39683E-05	0.	0.	0.	0.19841E-05
0.	0.	0.	0.19841E-05	0.
0.19841E-05	0.19841E-05	0.	0.	0.39683E-05
0.	0.19841E-05	0.	0.	0.
0.19841E-05	0.19841E-05	0.19841E-05	0.79365E-05	0.19841E-05
0.39683E-05	0.39683E-05	0.	0.	0.
0.39683E-05	0.19841E-05	0.	0.	0.39683E-05
0.	0.19841E-05	0.	0.	0.19841E-05
0.59524E-05	0.19841E-05	0.	0.	0.19841E-05
0.39683E-05	0.39683E-05	0.59524E-05	0.59524E-05	0.39683E-05
0.19841E-05	0.	0.39683E-05	0.	0.
0.39683E-05	0.59524E-05	0.39683E-05	0.99206E-05	0.99206E-05
0.79365E-05	0.19841E-05	0.59524E-05	0.19841E-05	0.59524E-05
0.	0.39683E-05	0.79365E-05	0.59524E-05	0.19841E-05
0.79365E-05	0.79365E-05	0.59524E-05	0.59524E-05	0.99206E-05
0.19841E-05	0.39683E-05	0.59524E-05	0.39683E-05	0.39683E-05
0.39683E-05	0.79365E-05	0.19841E-05	0.59524E-05	0.99206E-05
0.19841E-05	0.19841E-05	0.99206E-05	0.59524E-05	0.99206E-05
0.39683E-05	0.59524E-05	0.39683E-05	0.11905E-04	0.59524E-05
0.39683E-05	0.39683E-05	0.39683E-05	0.79365E-05	0.79365E-05
0.	0.17857E-04	0.99206E-05	0.19841E-05	0.99206E-05
0.99206E-05	0.59524E-05	0.19841E-05	0.19841E-05	0.39683E-05
0.19841E-05	0.79365E-05	0.99206E-05	0.39683E-05	0.79365E-05
0.79365E-05	0.99206E-05	0.11905E-04	0.39683E-05	0.15873E-04
0.15873E-04	0.11905E-04	0.59524E-05	0.99206E-05	0.79365E-05
0.99206E-05	0.11905E-04	0.17857E-04	0.15873E-04	0.79365E-05
0.11905E-04	0.79365E-05	0.79365E-05	0.11905E-04	0.39683E-05
0.11905E-04	0.11905E-04	0.79365E-05	0.59524E-05	0.11905E-04
0.15873E-04	0.13889E-04	0.59524E-05	0.99206E-05	0.13889E-04
0.79365E-05	0.39683E-05	0.79365E-05	0.99206E-05	0.19841E-05
0.99206E-05	0.79365E-05	0.79365E-05	0.59524E-05	0.39683E-05
0.79365E-05	0.11905E-04	0.99206E-05	0.79365E-05	0.99206E-05
0.11905E-04	0.13889E-04	0.13889E-04	0.13889E-04	0.39683E-05
0.79365E-05	0.11905E-04	0.13889E-04	0.11905E-04	0.11905E-04
0.59524E-05	0.79365E-05	0.11905E-04	0.19841E-05	0.11905E-04
0.15873E-04	0.79365E-05	0.11905E-04	0.11905E-04	0.13889E-04
0.17857E-04	0.79365E-05	0.39683E-05	0.17857E-04	0.15873E-04
0.11905E-04	0.15873E-04	0.99206E-05	0.11905E-04	0.59524E-05
0.39683E-05	0.19841E-04	0.15873E-04	0.11905E-04	0.99206E-05
0.79365E-05	0.15873E-04	0.13889E-04	0.79365E-05	0.13889E-04
0.79365E-05	0.99206E-05	0.99206E-05	0.17857E-04	0.11905E-04
0.79365E-05	0.11905E-04	0.99206E-05	0.99206E-05	0.17857E-04
0.59524E-05	0.59524E-05	0.29762E-04	0.99206E-05	0.13889E-04

FIGURE 2.26D

SAFTE-I SAMPLE CALCULATION OUTPUT

CUMULATIVE FAILURE DIST.

0.	0.	0.	0.	0.
0.	0.	0.	0.	0.
0.	0.	0.	0.	0.
0.	0.	0.	0.	0.
0.	0.	0.	0.	0.
0.	0.	0.33333E-03	0.33333E-03	0.33333E-03
0.33333E-03	0.33333E-03	0.33333E-03	0.33333E-03	0.33333E-03
0.10000E-02	0.10000E-02	0.10000E-02	0.10000E-02	0.13333E-02
0.13333E-02	0.13333E-02	0.13333E-02	0.16667E-02	0.16667E-02
0.20000E-02	0.23333E-02	0.23333E-02	0.23333E-02	0.30000E-02
0.30000E-02	0.33333E-02	0.33333E-02	0.33333E-02	0.33333E-02
0.36667E-02	0.40000E-02	0.43333E-02	0.56667E-02	0.60000E-02
0.66667E-02	0.73333E-02	0.73333E-02	0.73333E-02	0.73333E-02
0.80000E-02	0.83333E-02	0.83333E-02	0.83333E-02	0.90000E-02
0.90000E-02	0.93333E-02	0.93333E-02	0.93333E-02	0.96667E-02
0.10667E-01	0.11000E-01	0.11000E-01	0.11000E-01	0.11333E-01
0.12000E-01	0.12667E-01	0.13667E-01	0.14667E-01	0.15333E-01
0.15667E-01	0.15667E-01	0.16333E-01	0.16333E-01	0.16333E-01
0.17000E-01	0.18000E-01	0.18667E-01	0.20333E-01	0.22000E-01
0.23333E-01	0.23667E-01	0.24667E-01	0.25000E-01	0.26000E-01
0.26000E-01	0.26667E-01	0.28000E-01	0.29000E-01	0.29333E-01
0.30667E-01	0.32000E-01	0.33000E-01	0.34000E-01	0.35667E-01
0.36000E-01	0.36667E-01	0.37667E-01	0.38333E-01	0.39000E-01
0.39667E-01	0.41000E-01	0.41333E-01	0.42333E-01	0.44000E-01
0.44333E-01	0.44667E-01	0.46333E-01	0.47333E-01	0.49000E-01
0.49667E-01	0.50667E-01	0.51333E-01	0.53333E-01	0.54333E-01
0.55000E-01	0.55667E-01	0.56333E-01	0.57667E-01	0.59000E-01
0.59000E-01	0.62000E-01	0.63667E-01	0.64000E-01	0.65667E-01
0.67333E-01	0.68333E-01	0.68667E-01	0.69000E-01	0.69667E-01
0.70000E-01	0.71333E-01	0.73000E-01	0.73667E-01	0.75000E-01
0.76333E-01	0.78000E-01	0.80000E-01	0.80667E-01	0.83333E-01
0.86000E-01	0.88000E-01	0.89000E-01	0.90667E-01	0.92000E-01
0.93667E-01	0.95667E-01	0.98667E-01	0.10133E 00	0.10267E 00
0.10467E 00	0.10600E 00	0.10733E 00	0.10933E 00	0.11000E 00
0.11200E 00	0.11400E 00	0.11533E 00	0.11633E 00	0.11833E 00
0.12100E 00	0.12333E 00	0.12433E 00	0.12600E 00	0.12833E 00
0.12967E 00	0.13033E 00	0.13167E 00	0.13333E 00	0.13367E 00
0.13533E 00	0.13667E 00	0.13800E 00	0.13900E 00	0.13967E 00
0.14100E 00	0.14300E 00	0.14467E 00	0.14600E 00	0.14767E 00
0.14967E 00	0.15200E 00	0.15433E 00	0.15667E 00	0.15733E 00
0.15867E 00	0.16067E 00	0.16300E 00	0.16500E 00	0.16700E 00
0.16800E 00	0.16933E 00	0.17133E 00	0.17167E 00	0.17367E 00
0.17633E 00	0.17767E 00	0.17967E 00	0.18167E 00	0.18400E 00
0.18700E 00	0.18833E 00	0.18900E 00	0.19200E 00	0.19467E 00
0.19667E 00	0.19933E 00	0.20100E 00	0.20300E 00	0.20400E 00
0.20467E 00	0.20800E 00	0.21067E 00	0.21267E 00	0.21433E 00
0.21567E 00	0.21833E 00	0.22067E 00	0.22200E 00	0.22433E 00
0.22567E 00	0.22733E 00	0.22900E 00	0.23200E 00	0.23400E 00
0.23533E 00	0.23733E 00	0.23900E 00	0.24067E 00	0.24367E 00
0.24467E 00	0.24567E 00	0.25067E 00	0.25233E 00	0.25467E 00

FIGURE 2.26E

SAFTE-I SAMPLE CALCULATION OUTPUT

COMP. ID	NO. OF FAILURES
1	0.
2	0.33333E-03
3	0.
4	0.66667E-03
5	0.70000E-02
6	0.
7	0.13333E-02
8	0.22667E-01
9	0.27333E-01
10	0.16667E-02
11	0.16667E-02
12	0.70000E-02
13	0.33333E-03
14	0.10000E-02
15	0.33333E-03
16	0.
17	0.
18	0.
19	0.56667E-02
20	0.40000E-02
21	0.63333E-02
22	0.73333E-02
23	0.61667E-01
24	0.70000E-02
25	0.36667E-02
26	0.23333E-02
27	0.13667E-01
28	0.16333E-01
29	0.13333E-02
30	0.
31	0.33333E-03
32	0.26667E-02
33	0.56667E-02
34	0.30000E-02
35	0.20000E-02
36	0.66667E-03
37	0.18000E-01
38	0.23333E-02
39	0.14000E-01
40	0.23333E-02
41	0.30000E-02
42	0.
43	0.
44	0.
45	0.
46	0.
47	0.
48	0.
49	0.
50	0.
51	0.
52	0.
53	0.
54	0.
55	0.
56	0.
57	0.

FIGURE 2.26F

SAFTE-I SAMPLE CALCULATION OUTPUT

FIGURE 2.27
 $P(T)$ AS A FUNCTION OF OPERATING TIME (WEEKS) FOR
 THE DRESDEN-3 EMERGENCY A-C POWER SYSTEM

CHAPTER 3

EXAMPLE APPLICATIONS OF RELIABILITY ANALYSIS

CHAPTER 3

EXAMPLE APPLICATIONS OF RELIABILITY ANALYSIS

A system for collection and generation of reliability data has been defined and two methods of performing the quantitative aspects of reliability analysis have been described. This chapter illustrates the steps required in using these tools in reliability analyses for engineered safeguard systems. The intent is to indicate the steps involved in an analysis by example applications to selected PWR and BWR safeguard systems. The examples are not meant to be critical evaluations of the safeguard design. Specific systems for which brief, example reliability applications have been given in following sections are the Dresden-3 primary containment, the Connecticut Yankee safety injection system, the Connecticut Yankee containment cooling system, and the San Onofre safety injection system.

Briefly, the steps involved in a reliability analysis are:

1. Define the system to be analyzed including specific equipment items and their required operating patterns.
2. Define the performance goals for which the probability of success is desired or, conversely, the undesired events for which the probability of occurrence is to be determined.
3. Describe the methods of testing, checking, and maintaining the system, including the time intervals between these activities.
4. Perform an analysis of failure modes and effects for each equipment item in the system identifying the cause of each failure and its importance to system performance goals, and indicating conditions or practices which may eliminate or reduce critical failures.
5. Construct system reliability block diagrams reflecting the knowledge gained in the preceding steps. It is important that this diagram include all critical components. All time intervals of interest should be considered.
6. Obtain failure rate estimates for all components in each failure mode of interest.

7. Perform numerical reliability evaluations using block diagram logic and appropriate failure rates. These evaluations may include machine or hand calculations or a combination of both.
8. Summarize results of reliability evaluation, identifying the relative importance of various components, the effect of simplifying assumptions and redundancies and the critical phases or intervals in system operation.
9. Identify corrective actions which may be taken to improve system reliability or, conversely, reduce the probability of system failure. These actions may include further investigation of failure rate assumptions, identification of areas for potential use of redundancy or for equipment redesign, modification of operating or maintenance procedures or altered test procedures and frequencies.

The preceding pattern of reliability analysis has been used in each of the following examples.

In following the applications it should be noted that while the goal is a quantitative evaluation, the qualitative information developed in the intermediate steps sheds much light on the potential trouble spots in a system. This is particularly true with respect to performing the failure mode and effect analysis and construction of the appropriate reliability block diagrams. At this stage of the analysis, the potential culprits in a system frequently are obvious to the analyst. Further steps leading to a quantitative result tend to confirm the qualitative evaluation and point out the relative contributions to system unreliability which can be expected from the various components. Thus, numerical reliability estimates provide a means for qualifying the effectiveness of a system and any modifications which may be made in its operation, testing or equipment. In this regard, it should be noted that while corrective actions will be most beneficial if applied to prime contributors to unreliability, the lesser contributors must not be overlooked for Murphy's law* tends to prevail in all cases. Consideration of lesser contributors is particularly important if it identifies ways in which these components can be eliminated or the effect of their failures can be made inconsequential to system success.

* If a device can fail, it will fail, (eventually).

DRESDEN UNIT 3 PRIMARY CONTAINMENT

A preliminary investigation of the reliability of the Dresden-3 containment has been performed. This analysis is based on system descriptions and functional designs indicated in the Unit 3 Plant Design and Analysis Report (PDAR), dated February 1966, and its first three amendments.

SYSTEM DESCRIPTION

As described in the preceding documents, the Unit 3 containment can be considered as consisting of two major subsystems--a primary containment and a secondary containment. Within each of these subsystems are assemblies of components designed to perform various functions necessary for the maintenance of overall containment integrity under normal and accident conditions. A schematic crosssection of the overall facility is shown in Figure 3.1 In the Unit 3 PDAR seven containment barriers to fission product release are cited. They are: (1) the high density ceramic UO_2 fuel; (2) the high integrity zirconium cladding; (3) the reactor vessel and its connected piping and isolation valves; (4) the drywell suppression chamber primary containment; (5) the reactor building; (6) the reactor building standby gas treatment system utilizing high efficiency and charcoal filters; and (7) elevated discharge of gaseous effluents from a stack. In this discussion, the isolation valves in barrier 3 and all of barrier 4 are considered the primary containment while barriers 5, 6, and 7 are classed as the secondary containment.

The primary containment is designed to provide a low leakage barrier to the release of radioactivity (0.5 percent contained air at 62 psig internal pressure), and the secondary containment is provided for controlled release of any primary containment leakage to a 310-foot stack. The Unit 3 secondary containment also serves as the secondary containment for Dresden Unit 2.

The primary containment houses the reactor vessel, the reactor coolant and recirculating loops, and other service loops connected to the reactor. It consists of a drywell, a pressure suppression chamber which stores a large volume of water, a connecting vent system between the drywell and the water pool, isolation valves, containment cooling systems, and other service equipment. If piping containing reactor coolant or steam fails in the drywell, reactor water and steam would be released into the drywell air space. The resulting increase in drywell pressure would then force a

mixture of air, steam, and water through the vent system and into the water stored in the suppression chamber. Appropriate isolation valves are actuated during this period to complete the primary containment. Cooling systems are provided to remove heat from the reactor core, the drywell, and from the water in the suppression chamber; and, thus provide continuous cooling of the primary containment under accident conditions.

A reactor building completely encloses the Unit 2 and Unit 3 primary containments. This structure provides secondary containment when the primary containment is in service, and provides primary containment during periods when the pressure suppression containment system (primary containment) is open. The principal function of the secondary containment is to minimize ground level release of airborne radioactive materials and to provide for controlled, decontaminated, release of the building atmosphere through a stack under accident conditions. This is accomplished by (1) directing leakage from the primary containment to the secondary containment, (2) maintaining the secondary containment at a negative pressure with respect to the outside atmosphere during accident conditions, (3) designing the building for a specified inleakage rate, and (4) discharging the ventilation gases through the 310-foot stack after they have passed through a series of high efficiency particulate and halogen filters.

Although the Unit 3 containment includes both a primary and a secondary containment, only the primary containment has been considered. The reliability analyses techniques used on the primary containment will apply equally well to the secondary containment.

The most important function of the primary containment and its associated isolation and protective systems is to mitigate rapidly the consequences of postulated accidents involving the reactor primary system. The major assemblies in this containment subsystem were previously listed and are shown functionally in Figure 3.2. Parameters used in developing the primary containment design are listed in Table 3.1. The design requirements and features of the primary containment components are described briefly in the following sections. More extensive discussion of design considerations is provided in the Unit 3 PDAR, as amended.

Drywell

As shown in Figure 3.1, the drywell is a steel pressure vessel with a spherical lower portion, 66 feet in diameter and a cylindrical upper portion, 37 feet in diameter. The overall height is approximately 113 feet.

The drywell is enclosed in the reinforced concrete structure of the reactor building for shielding purposes and to provide additional resistance to deformation and buckling of the drywell over areas where the concrete backs up the steel shell. Shielding at the top of the drywell is provided by a removable, segmented, reinforced concrete plug.

Access to the drywell is provided by the drywell head, one double door airlock, and two equipment hatches. The drywell head and hatch covers are bolted in place and sealed with gaskets. The locking mechanisms on each airlock door are designed so that a tight seal will be maintained when the doors are subjected to either internal or external pressure. The doors are mechanically interlocked so that one door cannot be operated unless the other door is closed and locked. The seals on the doors and the hatches are capable of being tested for leakage.

The drywell will not be entered during power operation, but access is permissible during hot standby operation with the reactor subcritical. The normal operating environment in the drywell is an atmosphere containing less than normal concentrations of oxygen at essentially 0 psig and 135°F. Temperature control is provided by recirculating the drywell air through cooling units which, in turn, are cooled by a closed loop cooling water system. A functional diagram of the drywell assembly is shown in Figure 3.3.

Pressure Suppression Chamber and Vent System

The functions of these assemblies are as follows:

1. The vent system will conduct flow of vapors and liquids from the drywell to the suppression chamber, distribute this flow uniformly throughout the pool following a postulated rupture in equipment contained in the drywell, and limit the pressure differentials between the drywell and suppression chamber by use of chamber-to-drywell vacuum breakers.
2. The suppression chamber will receive vapor-liquid flow from the vent system, condense the steam portion of this flow, contain the noncondensable gases and fission products that may be driven into the chamber during the postulated rupture sequence, and provide a source of water for cooling the reactor core and primary containment.

The vent system consists of eight 8-foot diameter circular vent pipes connecting the drywell to the suppression chamber. The vent pipes open directly into the drywell and terminate in a 4-foot, 10-inch toroidal vent header in the air-space of the suppression chamber. Jet deflectors are provided in the drywell at the entrance of each vent pipe to prevent possible damage to the vent pipes from jet forces which might accompany a pipe break in the drywell. The pipes are enclosed with sleeves and are provided with expansion joints to accommodate differential motion between the drywell and suppression chamber. Projecting downward from the vent header are 96 downcomer pipes, 24 inches in diameter and terminating 4 feet below the water surface of the suppression chamber pool. Baffles are provided in the suppression chamber to ensure proper interaction of the vent pipe discharge with the suppression pool water.

Six vacuum breakers, which discharge from the suppression pool into the drywell, prevent a backflow of water from the suppression pool into the vent header system. Operation of two of the vacuum breakers is calculated to be adequate for pressure differential control.

The pressure suppression chamber, located below the drywell, is a steel pressure vessel in the shape of a torus with a major diameter of approximately 109 feet and a cross-sectional diameter of 30 feet. It contains approximately 106,000 cubic feet of water and has a net air-space volume above the water pool of approximately 119,500 cubic feet. The suppression chamber is held on supports which transmit vertical and seismic loading to the reinforced concrete foundation slab of the reactor building. Space is provided outside of the chamber for inspection and maintenance.

Sufficient water is provided in the suppression pool to absorb the initial energy release into the drywell from any postulated pipe failure. The suppression chamber is sized to contain this water, plus the water displaced from the reactor primary system together with the free air initially contained in the drywell.

Access to the pressure suppression chamber for inspection is provided by two 3-foot diameter manhole entrances with double-gasketed, bolted covers. These access ports will normally be bolted closed and will be opened only when the reactor primary coolant temperature is below 212°F and the pressure suppression system is not required to be operational. A functional diagram of the suppression chamber and vent system assemblies is shown in Figure 3.4.

Penetrations

Openings in the primary containment which permit the entry of pipes, ducts, electrical cable, and the traveling in-core probe (TIP) guide tubes are designed to:

1. Withstand the peak transient pressure which could occur due to the postulated rupture of any reactor primary system pipe inside the drywell.
2. Withstand jet forces equal to that associated with flow from the largest local pipe or connection without failure.
3. Accommodate thermal stresses which may be encountered during all modes of operation without failure.
4. Allow individual leak testing to the extent practical and necessary.

Two general types of pipe penetrations are provided -- those which must accommodate thermal movement, and those which experience relatively little thermal stress. Piping penetrations which provide for movement consist of a penetration sleeve which passes through the concrete and is welded to the primary containment vessel; a process line which passes through the penetration and is connected at one end by a bellows expansion joint to accommodate axial movement; and a guard pipe around the process line to protect the bellows and maintain the penetration seal should the process line fail within the penetration.

The cold piping and ventilation duct penetrations are welded directly to the penetration sleeves. Bellows and guard pipes are not necessary in this design, since the thermal stresses are small and are accounted for in the design of the weld joints.

With the exception of the pipe penetrations which are welded directly to the primary containment shell, it will be possible to leak test individual containment penetrations without pressurizing the entire containment system. Testing may be accomplished by pressurizing the penetration between the double seals utilizing the pressure tap. Leak detection may then be accomplished either by the use of soap suds or by pressure decay techniques.

Leakage through valves installed in pipelines which open into the containment can be detected by pressurizing between pairs of containment isolation valves. Leakage through valves installed in pipelines that connect to the reactor primary system may be determined when the reactor primary system is pressurized with the containment isolation valves closed.

The electrical penetrations are for electrical power, signal, and instrument leads. Depending on the number of lines for which access is provided two types of electrical penetration cartridges are used. In each case, the penetrating sleeve is welded to the primary containment vessel, and the flanged ends are bolted and sealed with a soft gasket material. A bonding resin is utilized in the seals where the cable emerges from the flange. This arrangement provides a leak-tight configuration which is leak-tested after installation and provides a means for periodic leakage testing.

Isolation valves on the reactor primary system pipe and other ducts or pipes, which penetrate the primary containment, provide a containment barrier in these lines which is considered to be as effective as the primary containment shell.

The criteria on number, type, operation, testing, and location of valves for the various categories of penetrations are as follows:

1. Process pipes which connect to the reactor primary system, and pipes or ducts which penetrate the primary containment and are open to the drywell free air space, shall be provided with at least two isolation valves in series.

Valves in this category shall be designed to close automatically from selected signals, and shall be capable of remote manual actuation from the control room.

2. The valves will be physically separated. On lines connecting to the reactor primary system, one valve shall be located inside the primary containment and the second outside the primary containment as close to the primary containment wall as practical.
3. Lines which penetrate the primary containment and which neither connect to the reactor primary system nor open into the primary containment shall be provided with at least one valve which may be located outside the primary containment.

Valves in this category shall be capable of manual actuation from the control room.

4. Motive power for the valves on process lines which require two valves shall be physically independent sources to prevent a single accident from interrupting motive power to both closure devices.
5. Upon loss of motive power and when containment closure action of the valve is called for, the valve shall fail closed or shall fail in its existing position.
6. Valve actuation power failure shall be detected and annunciated.
7. The functional performance of valves, sensors, and other automatic devices essential to the isolation of the containment will be periodically tested to demonstrate proper function, correct setpoint of sensors, proper speed of response, and operability of fail-safe features.

The following are exceptions to the above isolation valve criteria:

1. Automatic isolation valves will not be used on the inlet or outlet lines of the core spray, containment spray, and feedwater supply systems, since operation of these systems is essential following a loss-of-coolant accident. Check valves located on these lines, inside the drywell, will provide automatic isolation when necessary on inlet lines.
2. One automatic isolation ball valve is provided on each TIP system guide tube outside the primary containment. A second shear isolation valve is provided inside the containment and requires manual actuation.
3. No automatic isolation valves are provided on the control rod drive hydraulic system lines. These lines are isolated by means of the normally closed hydraulic system control valves located in the reactor building and by means of check valves comprising a part of the drive mechanism.
4. Small diameter instrument lines are provided with one manually operated shut-off valve, operable from the reactor building.

The preceding exceptions are made only in the cases where normal criteria lead to a less desirable situation because of required operation or maintenance of the system in which the valves are located. In these cases, special attention is given to assure that the piping to the isolation valves has an integrity at least equal to the containment.

Table 3.2 is a listing of the principal isolation valves to be used in the piping which penetrates the primary containment. The table indicates the number and service of the valves, location of the valves with respect to the primary containment, the signal which actuates the valves, the motive power which actuates the valve, and the closure time of the valve. Approximate valve locations and arrangements are also shown on Figure 3.5. There are approximately 550 penetrations in the primary containment.

Containment Spray Cooling

Two containment spray cooling systems are provided to remove heat from the primary containment system following a blowdown accident. Each system is capable of removing the fission product decay heat at the maximum anticipated rate. This cooling is provided (1) to remove heat from the primary containment and thereby assure that the containment does not become overpressurized and fail; and (2) to reduce rapidly the pressure of the primary containment and hence, the containment leakage rate.

The containment spray cooling system consists of two independent loops each provided with two full-capacity pumps (one a spare), a heat exchanger rejecting heat to the containment cooling service water system, piping and valves, and a containment spray header. One of the loops is shared with Unit 2 as shown in Figure 3.6. The shared loop is on standby and would start automatically if the independent Unit 3 loop failed to start on demand. Both loops can be operated simultaneously. Automatic start is initiated by concurrent trips from drywell high pressure and the low reactor water level.

When operating, this system pump water from the suppression chamber through the heat exchanger and the spray header. The water then flows by gravity back into the suppression chamber. A bypass flow path directly from the heat exchanger discharge line to the suppression chamber air space is provided for test purposes.

Core Spray Cooling

Redundant, full capacity, core spray loops and a core flooding capability are provided to remove decay heat following a blowdown accident. Each of the core spray loops has sufficient capacity to rapidly immerse the fuel assemblies. To continue core cooling following restoration of a water level in the core requires a supply of water from either one or both of the loops, the reactor feedwater system, or the control rod drive feed system.

The core spray system is designed to pump water directly from the suppression chamber into the reactor vessel. Core spray piping from the suppression chamber to the outer isolation valve is fabricated of carbon steel. Safety valves are provided for pressure protection of this piping. Stainless steel piping having a design pressure of 1,250 psig is used from the outer isolation valve to the reactor.

A separate ring header for each of the two loops is located inside the reactor vessel directly above the core and sprays water directly onto the fuel bundles. A strainer is placed ahead of the core spray pump suction to screen out particulates which could interfere with a discharge of water from the nozzles.

Upon receipt of the actuating signal, the pumps in one loop are started automatically and the isolation valve opens. When the reactor pressure drops to approximately 160 psig, the check valve opens and water is sprayed onto the top of the fuel bundles.

This system is also designed so that if the pumps in one loop fail to start, the pumps in the other loop are automatically switched into operation. Both the pumps and isolation valves may be actuated from the control room. The electrical loads associated with these systems are considered in the standby diesel generator size.

Provisions are made for periodically testing the components in the core and containment cooling systems. These tests include:

1. Flow rate measurement in the core spray system. Preoperational testing of the core spray system will demonstrate the core flooding capability of the system. After preoperation testing, no special testing of this feature is planned.

2. Flow rate measurement in the containment cooling system. In test 1 and 2 each pump of each system can be started individually and water pumped from the suppression chamber through the appropriate supply lines to the outer isolation valve, then returned to the suppression chamber.
3. Exercising and demonstrating operability of all motor operated valves.
4. Blowing air into the containment spray headers and inspecting individual nozzles.
5. Continuous indication in the control room of water level in the suppression chamber.
6. Removal and setpoint testing of safety valves in the low pressure carbon steel lines of the core spray system.

Electrical Power

For purposes of this example application the Dresden-3 a-c electrical power system is assumed to be that shown in the single line schematic drawing of Figure 3.7. When completed, Dresden-3, as well as Dresden-2, will be tied to the Commonwealth Edison 345 kv network through five 345 kv circuits. At Dresden-3 auxiliary a-c power can be supplied from five separate and independent sources: Units 2 and 3, the 345 kv network via the 345 kv bus, a standby diesel generator* and a 34.5 kv line. Normal auxiliary power for Dresden-3 is split between the unit auxiliary power transformer, T-2, which is connected to the unit generator and the reserve auxiliary transformer, T-3, which is connected to the 345 kv bus. Each auxiliary transformer can carry the full auxiliary load for Dresden-3.

Should the 345 kv bus and the unit generator fail, auxiliary power can be supplied by the standby diesel generator or the 34.5 kv line through auxiliary transformer, T-8. Either of these sources is capable of operating all systems required to shut down and maintain the unit in a safe condition. The general design requirement is to supply duplicate services from different buses. As shown in Figure 3.7, it has been assumed that power for critical loads in the primary containment system is supplied from 4160 v buses 5 and 6 and from 480 v buses subsidiary to buses 5 and 6. The diesel generator and the 34.5 kv line may be connected to either or both bus 5 and 6 and through them to buses 3 and 4. Switchgear for the 4160 v buses is metal-clad, indoor type

*There are now three standby diesel generators planned for Dresden Units 2 and 3, one for each unit and one as a standby spare to either unit. This example considers the original condition of only the standby generator available to Unit 3.

with circuit breakers operated by a 125-volt d-c, stored/energy mechanism. Transformers and switchgear for the 480 v buses are located in the turbine building.

With loss of normal auxiliary power, the diesel generator starts automatically. As soon as generator voltage is normal, the generator connects to the appropriate low voltage buses to supply essential loads after incoming breakers and nonessential loads are tripped. Other loads may be dispatched by the operator if the system power interruption persists. If the diesel generator is not available, the 34.5 kv supply can be selected as the alternate source. Fuel for the generator is contained in a day tank and a larger tank for prolonged operation.

To protect against environmental conditions which could cause loss of outside power the diesel generator is housed in a concrete block cell in the turbine building and equipment connecting the diesel generator and 34.5 kv line to critical loads is protected by metal enclosure and underground location. The generator is air started and sized to support the loads listed in Table 3.3. Automatically connected loads listed in Table 3.3 will start without operator intervention when normal bus voltage has been restored by the diesel generator. Other loads required for shutdown will be manually connected by the operator in accordance with overload restrictions. To assure operability, this unit will be periodically started and operated under load for sufficient time to assure adequate performance during extended periods of operation.

Direct current loads in the primary containment will be supplied by a 125-volt, station battery, capable of carrying its required connected load for eight hours without recharging. All of the loads connected to the 125-volt d-c system, except heavy duty loads, also can be supplied by one of two battery chargers. The chargers will be powered from separate a-c buses which are operable from any auxiliary power source.

The battery is located in a ventilated battery room having concrete block walls. The 125-volt d-c system operates ungrounded with a ground detector alarm set to annunciate the first ground. Thus, multiple grounding, as a possible mode of failure, is extremely unlikely. The normal mode of battery failure is a single cell deterioration which is signalled well in advance by the routine of tests which will be performed regularly on the battery. Typical tests and servicings include visual inspection for leaks and corrosion, and checking voltage, and the specific gravity and level of the electrolyte.

RELIABILITY CONSIDERATIONS

The reliability of the Unit 3 primary containment must be evaluated with respect to a specific performance requirement. That is, the number of assemblies and components required for successful containment will vary, depending on the type of radioactivity release occurring in this containment subsystem. If the type of release is unspecified, it is probably best to consider the most severe release conditions that can develop in the primary containment. In this example, a major rupture of the reactor coolant system is assumed, i. e., a blowdown accident.

Once a release conditions has been identified, the design basis requirements for operation of various parts of the primary containment must be determined from the descriptive materials and available accident analyses. In the February 1966 edition of the Unit 3 PDAR, the blowdown accident was analyzed for a number of different containment operability conditions. The results of these analyses are shown as pressure-time curves in Figure 3.8 and as operational assumptions in Table 3.4. As indicated in Table 3.3, the variables in operational assumptions for the analyses were the number of core spray and containment spray systems in operation and the extent of metal-water reaction.

The design basis accident is characterized by the curve given for Case f which assumes operation of one containment spray loop, no core spray, and the maximum metal-water reaction of 27.5 percent. Case f has been used as the basis for the initial reliability analysis for the Unit 3 primary containment. That is, the primary containment reliability has been evaluated on the basis that at least one containment spray functions satisfactorily, and the primary containment achieves and maintains a status which allows only a minimal leakage. This reliability analysis includes all equipment combinations which can be expected to maintain containment pressure below the design pressure. Conversely, it can be used to estimate the probability of a containment pressure greater than design given a blowdown accident.

An additional analysis has been made for the condition of at least one containment spray and one core spray operating. This is approximately equivalent to estimating the probability of Case b, i. e., one containment spray loop and one core spray loop operable in addition to an adequate isolation condition. To illustrate the value of assuming redundancy, a subsidiary analysis has been run for the core spray alone in which both core spray loops are required to function. In each of the preceding analyses emergency a-c power has been included as an operational requirement by the assumption that either bus 5 or bus 6 and their respective subsidiary 480 v buses, bus 2A or bus 2B, must operate.

RELIABILITY EVALUATION

The reliability model has been developed in a number of steps intended to define all systems and components critical to operation of the primary containment and to identify the time dependent status of this equipment. These steps can be summarized as follows:

1. Review design
2. Review accident analysis and characterize accident sequence
3. Perform failure mode and effect analysis
4. Identify critical components
5. Construct reliability block diagram
6. Identify reliability evaluation intervals
7. Identify component requirements for each interval

Step 1 was accomplished by way of the preceding primary containment description. A description of the accident analyses is given in the Unit 3 PDAR. This description is general with respect to characterizing the component operation and sequence of events. It may be briefly summarized as follows:

The reactor is operating at the design thermal output and the outlet leg of a recirculation loop is assumed to be instantly severed in a circumferential break. Flow at critical velocity occurs at the break. Immediately following the break, the large increase in core void fraction due to depressurization sharply decreases reactor power. Scram will be initiated in less than a second by high drywell pressure.

In about four seconds, the subcooled liquid mass below the core will begin flashing vigorously because of depressurization. This will tend to force a steam-water mixture up through the core, as well as backward through the jet pump diffuser pipes.

Calculations indicate that it will take nearly 24 seconds to depressurize the vessel. During a fraction of this time, the bulk of the core will be cooled by a boiling two phase mixture. The recirculation pump in the other leg will continue to inject fluid into the vessel for approximately 4 seconds or at least until the subcooled fluid begins to flash. Low water level in the reactor vessel will initiate actuation of the independent core spray loops about one minute after rupture.

These loops will begin injecting water into the core when the reactor pressure falls below 150 psig.

The drywell pressure will rise to about 39 psig in approximately three seconds. In less than 30 seconds after the break, the pressure in the pressure suppression chamber and drywell will have equalized to about 21 psig, as shown in Figure 3.8. The containment cooling systems are designed so that either of the full capacity independent systems will maintain the pressure of the suppression chamber below the 62 psig design pressure. This analysis assumes that only one of the two independent containment spray systems operates.

For the case in which no core cooling is assumed the core continues to heat up and subsequently undergoes a complete meltdown. The maximum extent of metal-water reaction resulting from the meltdown is estimated to be approximately 27.5 percent of all the available metal (channel boxes and cladding) within the core region. It is assumed that there is an unlimited amount of steam available to support the metal-water reaction. The total duration of the reactor core meltdown is approximately one hour. However, the reactor core is effectively melted (90 percent) in about half an hour. Table 3.5 indicates the time for various stages of meltdown and metal-water reaction.

On the basis of the preceding accident sequence, the initial reliability model will consider two time intervals. The first interval will evaluate the probability of achieving containment isolation and startup of at least one containment cooling system. The second interval will consider operation of the containment cooling system until primary containment pressure has decayed to essentially atmospheric pressure. The second reliability model is the same as the first with the added requirement that one of the core spray loops also operates. The third, subsidiary model evaluates the probability that both core spray loops will operate.

Since test frequencies have not been defined, it will be assumed for each of the preceding models that the length of the first interval is one month or 720 hours. This is equivalent to assuming that the critical components, which will be subsequently identified, may be assumed to be unmonitored with respect to operability for as long as 720 hours.

The second time interval has been estimated from the pressure-time history for the blowdown accident. Since the time at which the Case f curve in Figure 3.8 decays to 0 psig is not given, the length of the second interval

has been assumed to be approximately 300 hours. The existing curve indicates a pressure of approximately 17 psig at 278 hours after rupture and; therefore, the 300-hour interval may be somewhat optimistic.

Examples of failure mode and effect analyses on primary containment components are given in Figure 3.9. Based on these analyses and discussions of design, construction, and testing practices contained in the PDAR, it is assumed that the structural integrity of the containment vessels and connecting lines will be high relative to components such as drywell and suppression chamber closure seals, isolation valves in lines open to the containment atmosphere or the primary system and equipment in the containment cooling systems. These latter components will be taken to be the critical components at this time. Reliability block diagrams defining the logical operating requirements for the critical components are given in Figures 3.10 through 3.15.

The isolation valve requirements were developed on the basis of the guidelines given in Appendix F of this report, the reactor protection system trip functions, and the isolation valve summary in Table 3.2. The reliability evaluation intervals were previously defined. Referring to the reliability block diagrams the functional requirements for the reliability analysis cases in each of these intervals are as follows.

Operable Function Requirements

Interval 1

- Case 1 - All drywell and suppression chamber closure seals function; all isolation valves actuated by containment isolation protection system trip; operating mode status achieved in one loop of containment cooling system; and emergency a-c power supplied to operable cooling loop.
- Case 2 - Same as Case 1 with added requirement that operating mode status achieved in one loop of core spray system.
- Case 3 - One of two core spray loops achieves operating mode status along with appropriate emergency a-c power train.
- Case 4 - Both core spray loops achieve operating mode status and emergency a-c power trains on.

Interval 2

- Case 1 - Operating mode status continued in one loop of containment cooling system and appropriate emergency a-c power train.
- Case 2 - Same as Case 1 with added requirement that operating mode status continued in one loop of core spray system.
- Case 3 - One of two core spray loops continues operation along with appropriate emergency a-c power train.
- Case 4 - Both core spray loops and emergency power trains continue operation.

An important and final step in preparing for the mathematical reliability evaluation is the selection of appropriate failure rates for each component included in the model. In selecting failure rates one must consider the operating environment for each component and the failure mode(s) of importance in each interval. If appropriate failure rates cannot be identified from available reliability data sources such as those listed in Appendix D or from operating experience summaries such as HN-185, then it becomes necessary to assume failure rates and later test the assumption. Limits should be established on assumed failure rate values to evaluate the sensitivity of system reliability to changes in failure rate.

For the present all failure rates have been assumed, as shown in Table 3.6, in order to complete the reliability evaluation illustration. Thus, the reliability analysis presented here is preliminary with respect to component failure rates. While the failure rates are assumed, they do reflect some consideration of the component status, the appropriate failure mode, and past experience.

Although not a consideration in this example, it should be noted that not all unmonitored components will be tested on the same interval. As a result some failure rate adjustment will be necessary when performing a reliability analysis using a program such as ARMM, which computes success and failure probabilities at the end of fixed intervals for all components. That is, the program computes the reliability of all components under consideration in a time interval on the basis that the component is unmonitored during the time interval with respect to the failure mode of concern. To compensate for the fact that components are tested at different frequencies, the component failure rates should

be multiplied by a factor equivalent to the ratio of component test interval to reliability evaluation interval.

RESULTS OF ANALYSIS

Each of the previously listed reliability analysis cases, Cases 1 through 4, has been evaluated by the ARMM computer program. The results of these evaluations are summarized in Table 3.7. In this summary, Case 1 corresponds to Case f of the Dresden-3 PDAR. Case 2 is a slightly less restrictive version of Case b in the PDAR; only one of the core spray loops is required to operate. Cases 3 and 4 provide insight into the effect of requiring both core spray loops to operate.

As shown in Table 3.7, the probability of achieving adequate isolation and operation of one of the two containment cooling loops (Case 1) is 0.99981. If one of the core spray loops is required to operate as well (Case 2), the probability of success is decreased to 0.99970. The difference between Case 1 and Case 2 represents an increase in the probability of failure of approximately 60 percent.

In both Case 1 and Case 2, the probability failure in the first interval is approximately three orders of magnitude greater than that for the second interval. Thus, if the reliability model and failure rate assumptions are considered adequate, the most difficult aspect of containment operation in a blowdown accident would be associated with initiating the containment functions. This result derives primarily from the reduction in the number of operating components in the second interval, 162 to 23 in Case 1 and 204 to 31 in Case 2. Requiring a longer period of containment cooling (e.g., 720 instead of 300 hours) in Interval 2 would not significantly effect this estimate. Of course, these results reflect a preliminary analysis and do not consider the effect of the accident induced environment on component failure rates. Data of this type is currently unavailable.

Cases 3 and 4 provide an indication of the effect of assuming redundancy in the core spray system operation. If such redundancy is not allowed, then it is estimated that the reliability of the containment with core spray required would be reduced rather strongly from 0.9997 to approximately 0.9570. Conversely, the unreliability would be ~~expected~~ to increase by a factor of approximately 200. If Case b were selected as the design basis for the primary containment, the preceding results indicate that it would be desirable to design the core spray system and the containment spray cooling system so that only one loop in each is required for satisfactory operation.

Further insight on the primary containment reliability can be obtained by considering individual component contributions to system failure. Table 3.8 lists the 20 largest contributors to containment failure in Cases 1 and 2. Contributions from the remaining components are illustrated by the ARMM output in Figure 3.16. Several important conclusions are implied by this data. First, most of the components listed in Table 3.8 are associated with the supply of emergency a-c power, particularly at the 480 volt level. This may be attributed partly to relative difference between the failure rates for electrical and nonelectrical components. It also results from the serial arrangement of these components in the containment and core spray loops where they provide motive power for proper alignment of these loops. As indicated in Table 3.8, the six largest contributors are the same in both Cases 1 and 2. These components provide 480 volt power to Buses 2A and 2B. In these analyses it has been assumed that these components independently operate the respective buses; components 150, 152, and 154 for Bus 2A, and components 238, 240, and 242 for Bus 2B. If the system was arranged so that either set of the preceding components could power either bus, then the system unreliability could be reduced by approximately 67 percent for Case 2 and 78 percent for Case 1. This conclusion assumes that the equipment used to achieve the redundancy would have an unreliability of the order of 1×10^{-5} or less in these reliability models.

The six major contributors cited in the previous paragraph were also found to contribute to approximately 62 percent of the system failure probability for Case 4, both core spray loops in operation. If an actual design review were being conducted, this result would give additional emphasis to the need for improving the reliability of the 480 volt power supply for checking the analysis for overly conservative estimates of failure rates or for adding redundancy.

Additional information which can be used to scope reliability improvement or monitoring efforts is provided by the ARMM analysis summary given in Table 3.9. This table shows that in Case 1 approximately 92 percent of system failure may be attributed to 8 out of 162 components. Similarly, in Case 2 fourteen out of 204 components contribute to approximately 93 percent of system failure. These components are the first 8 and the first 14 components for Cases 1 and 2, respectively, in Table 3.8. If it was desired to concentrate on achieving an order of magnitude reduction in system failure probability, the group contributions to system failure given in Table 3.9 could be used as a guide. For example, an order of magnitude reduction in Case 1 would require concentration of reliability improvement effort largely on 28 of the 162 components. Twenty of these latter components are listed in Table 3.8.

In conclusion, this example application outlines means whereby potentially troublesome design and equipment can be identified by reliability analysis of an engineered safeguard system. This information can be used in turn to make changes in system design, to set reliability improvement goals for specific equipment, or to suggest altered testing and operational practices; and thereby minimize the time during which component failures may exist.

CONNECTICUT YANKEE SAFETY INJECTION SYSTEM

Reliability analysis of the Connecticut Yankee safety injection system has been performed based on system descriptions and the loss of coolant incident analysis provided in the Facility Description and Safety Analysis (FDSA) for the Haddam Neck Plant, Topical Report No. NYO-3250-5, dated May 1966. This system is one of several systems which might be used to provide emergency core cooling with occurrence of a loss-of-coolant incident.

A loss-of-coolant incident could be caused by rupture of any line or nozzle connected to the reactor coolant system by improper opening of a valve or series of valves, by allowing uncontrolled discharge from the high pressure coolant system, or by material failure in a pipe or component of the reactor coolant system.

For small leaks in the reactor coolant system, the pressurizer level control adjusts the charging rate to maintain a minimum level in the pressurizer. Depletion of coolant in the volume control tank is compensated by automatic makeup control in the chemical and volume control system. Should the automatic makeup malfunction, a low-level signal from the volume control tank-level instrumentation would cause the charge pumps to take suction from the refueling water storage tank instead of the volume control tank.

For larger breaks, in which the discharge rate exceeds the delivery rate of the charge pumps for a prolonged period of time, the level in the pressurizer continues to decrease, eventually exceeding the low-level trip point for safety injection. Coincidentally, change in the pressurizer steam volume will cause an accompanying decrease in system pressure. Reactor trip and turbine trip will occur due to low pressurizer pressure. The coincidence of low pressurizer pressure with low pressurizer level, requiring signals from two out of three channels monitoring each parameter, actuates the safety injection system, which automatically delivers borated water to the reactor vessel for cooling the core. With normal incoming electrical power available, the system will prevent melting of the fuel cladding for loss-of-coolant incidents up to and including circumferential failure of the largest reactor coolant line, with only one of the two safety injection pumps, one of two charging pumps, and one of two residual heat removal pumps in operation.

If all outside power sources fail, emergency power will be provided by diesel generators in sufficient numbers to operate at least one residual

heat removal pump (core deluge) and one of four service water pumps (for recirculation cooling) along with other equipment deemed essential for a loss-of-coolant incident. The system's path of access, mode of cooling water delivery, and design characteristics are such as to assure core cladding immersion in steam and cascading water so that core meltdown and metal-water reactions are highly unlikely.

A summary of safety injection system operation in relation to the type of loss-of-coolant incident is shown in Table 3.10.

SYSTEM DESCRIPTION

Equipment

The primary side of the safety injection system consists of one refueling water storage tank, three pumping trains, and associated valves to properly align the system as shown in Figure 3.17. Pumps are provided with one out of two redundancies in each pumping train, and the isolation valves in all loops entering the reactor vessel are also arranged with various degrees of redundancy. The rated capacities of the safety injection and charge pumps are 1,750 gpm at 1,500 psig and 360 gpm at 2,300 psig, respectively. These pumps are capable of injecting borated water directly into the reactor vessel. The residual heat removal pumps have rated capacity of 2,250 gpm at 500 psig. Thus the deluge cooling of the reactor core through the vessel head can be provided only when the pressure in the reactor vessel is below the discharge pressure of the residual heat removal pumps.

Piping and motor-operated valves are provided to supply water from the refueling water storage tank to each pump, and from the containment sump to the residual heat removal pumps. Check valves are provided throughout the system to prevent backflow which might adversely affect system operation. All stop valves provided for removal of pumps and other equipment for maintenance purposes are locked-open.

Heat removal from the recirculating water returned from the containment sump is provided by a pair of residual heat exchangers. On the secondary side, the heat exchangers are connected to a service water system through motor-operated valves as shown in Figure 3.18. The system uses four service water pumps, each capable of delivering 6,000 gpm, to circulate river water to plant cooling loads.

Power for the safety injection system is normally supplied by two transmission lines one connecting with the Connecticut Light and Power Company system at the Montville generating station and Haddam substation (line 12500) and the other with the Hartford Electric Light Company system at the Middletown generating station (line 772). These lines along with the 115 kv/4,160 v transformers and 4,160 v buses they serve are shown schematically in Figure 3.19. One safety injection pump, one charge pump, and four 4,160/480 v station service transformers are served by each of the two 4,160 v buses. Loss of normal supply to either bus section will automatically transfer the dead bus load to the other bus by closing bus tie breaker 2T3.

The four station service transformers in turn supply power to four 480 v buses as shown in Figure 3.20. One service water pump is served by each of the four 480 v buses. One residual heat removal pump is served by each of two 480 v buses as are the two sub-buses (No. 5-5 and 5-6) which serve all motor-operated valves and semi-vital buses for controls and instrumentation. Tie breakers between 480 v bus sections permit manual transfer of supplies to adjacent bus sections. They are automatically closed to establish a single bus during an emergency with a total loss of normal 480 v a-c power.

On-site, emergency power is provided by three emergency generators which start automatically if all normal 480 v a-c power is lost. Each generator has a rated capacity of 400 kw. These synchronous generators are driven by diesel engines which are equipped with d-c starting motors. Each generator is connected to a section of the 480 v bus by an electrically operated circuit breaker.

Operation

Components which have been considered initially in evaluating system operation from a reliability viewpoint, are shown in Figure 3.21.

Operation of the safety injection system is initiated by an actuation signal generated as a result of two out of three low pressurizer water level signals coincident with two out of three low pressurizer pressure signals. This actuation is fully automatic and consists of:

1. Opening the refueling water storage tank supply valve.
2. Opening the safety injection isolation valves.

3. Opening the residual heat exchanger bypass valve and throttling valve, and the core deluge isolation valves.
4. Opening the control valve and the isolation valves in the charge lines to the reactor coolant loops.
5. Opening the valve in the charge pump suction from the refueling water storage tank, and closing the valve in the normal suction line from the volume control tank.
6. Starting the safety injection pumps, charge pumps, and residual heat removal pumps.

The system may also be actuated manually from the main control room. To prevent automatic operation while the reactor is cold and depressurized, the actuation signal is blocked manually when reactor coolant system pressure is below 1,700 psig. The signal is unblocked automatically when reactor coolant system pressure rises above 1,700 psig.

Within 10 seconds after the initiation signal is generated, the two safety injection pumps can deliver borated refueling water at full rated flow to a header supplying four independent injection lines, one to the cold leg of each reactor coolant loop. Suction of the two centrifugal charge pumps is automatically transferred from the volume control tank to the refueling water storage tank, and borated refueling water is delivered through the charge lines to the cold leg of loop 2 and the hot leg of loop 4.

Continued operation of the safety injection will depend upon the leak size and hence the reactor coolant pressure. For small breaks, the system may maintain the reactor coolant pressure at a level sufficiently high to preclude core deluge flow. In this case, the core deluge pumps will be secured and the residual heat removal loop will be realigned to provide high pressure recirculation via the safety injection pumps and charge pumps.

For larger breaks there may be no reliable indication that the core has been covered with water. In this situation the operator will terminate safety injection and begin low pressure recirculation via the core deluge piping from 150,000 gallons of borated water have been pumped from the refueling water storage tank. This quantity insures that the core has been covered for any rupture up to and including a double-ended break of a reactor coolant line.

High pressure recirculation via the safety injection pumps and charge pumps provides a means of using the spilled reactor coolant to keep the reactor core covered with water after small leaks or ruptures occur. The borated water draining from a system rupture is collected in a sump located at the lowest point of the reactor containment lower operating level. After several minutes of safety injection operation, sufficient borated water will have collected in the sump to permit initiation of recirculation operation. Recirculation flow and cooling is accomplished by the residual heat removal pumps and heat exchangers. Remote operated valves provide the means for (1) transferring the residual heat removal pumps suction from the refueling water storage tank to the reactor containment sump, (2) directing the resulting flow through the heat exchangers, (3) providing service water cooling to the heat exchanger, and (4) transferring discharge from the core deluge header to the combined safety injection and charging pump suction header. The cooled borated water is then returned to the reactor coolant system via the safety injection pumps and charge pumps.

If a large rupture occurs, low pressure recirculation to the reactor vessel via the core deluge lines is established remotely in the same manner as the high pressure recirculation except that the residual heat pump discharge flow is directed to the core deluge line rather than to the suction of the safety injection pumps and charging pumps.

Testing

The safety injection system may be tested at any time the reactor coolant system is pressurized above the shutoff head of the safety injection pumps (1,400 psig). Water in the safety injection lines is circulated from the refueling water storage tank to the injection system lines during pump testing by using the recirculation lines from each safety injection branch line. Recirculation of water in the safety injection lines insures the proper boron concentration in the lines.

Motor operated isolation valves are tested by manual operation of each valve from the main control room. Remote position indicators in the main control room permit a check of valve operation.

Periodic testing of the core deluge including operation of the residual heat removal pump with emergency power is required, and is a part of the periodic test of the safety injection system.

RELIABILITY CONSIDERATIONS

The analysis of the loss-of-coolant incident is presented in the FDSEA and summarized in Table 3.11 for break sizes corresponding to single ended rupture of 1-1/2, 3, 4, 6, and 10-inch lines, a 2 square foot rupture, and the hypothetical doubled ended rupture of a reactor coolant loop. In addition, a rupture of a charge line at the connection to the reactor coolant system and a similar rupture of a safety injection line are analyzed. The charge line rupture, in effect, allows all charge flow to spill on the containment floor. The safety injection line break impairs the delivery curve of the injection system. For this special break, delivery to the reactor through the intact lines does not begin until reactor pressure has reduced to a value equal to the pressure drop in the broken line.

In all cases the rupture is assumed to be near a safety injection connection and a charge line connection to the reactor coolant system. Conservatively, 1/3 of the safety injection flow and 1/2 of the charge flow is assumed to be released through the rupture. Delivery curves are adjusted to take this into account. Calculations were made of pressure and volume histories for the various break sizes, and cladding hot spot temperature transients for those cases in which significant core uncovering occurs. The clad hot spot temperature is less than the 2,550°F. melting temperature in all cases. A typical pressure and volume curve is shown in Figure 3.22 for a 3-inch charge line break. One of the two safety injection pumps, one of two deluge pumps, and one of two centrifugal charging pumps are assumed to be operating.

Failure Mode and Effect Analysis

Based on the assumptions and the system description given in the FDSEA, a failure mode and effect analysis was made as shown in Figure 3.23 on components considered essential to the system reliability.

The refueling water storage tank is equipped with an externally-mounted thermosiphon reboiler-type heat exchangers as shown in Figure 3.17 designed to maintain a refueling water temperature of 55°F. with an outdoor temperature of -15°F. The heating steam is provided by the building service heating system through the auxiliary steam system. Since adequate time can be expected to exist to correct a tank heating failure before the freezing of 250,000 gallons of borated water takes place, the failure rate assigned to the tank was selected with this assumption in mind.

As for the outside power sources, the possibility of failure of any particular combination of interconnected transmission systems is very remote. For this reason a representative value for their failure rate was chosen.

Pumps have different failure modes, fail to start and fail to continue running, and as such different failure rates were chosen accordingly. As for valves, assigned failure rates are those associated with the failure to open or failure to close modes of operation. Other types of valve failure modes, such as failure to stay open or failure to stay closed, are considered to occur at a rate at least one order of magnitude lower than the first mode. Typical failure rates of all components are listed in Table 3.12.

Reliability Model

The reliability model for this analysis has been developed, as shown in Figures 3.24 and 3.25 to include all components critical to operation of the safety injection system under all types of loss-of-coolant incident.

Since motor-operated valves, instrumentation and controls for the safety injection system as well as for other vital systems require Buses No. 5 and 6 to be energized at all times, the reliability block diagram was considerably simplified by isolating components which are fed through these buses from the power network reliability model. The only exceptions to this approach were two service water pumps, since these were in redundancy with two other pumps connected to Buses No. 4 and 7.

RELIABILITY EVALUATION

Based on the failure mode and effect analysis and the reliability model, loadsheets for an ARMM calculation were prepared as shown in Figure 3.26. As far as the system reliability is concerned, a case which requires longer time to initiate low pressure recirculation will yield slightly lower reliability values. Thus, the case of a charge line rupture shown in Figure 3.22 is demonstrated in the calculation. All other cases will yield a better reliability even though the severity of an incident may be more or less.

Time intervals chosen were based on information in the FDSA and Figure 3.22, and the functions are turned on and off accordingly. The intervals were:

- Interval 1 - Since test frequencies have not been defined in the FDSA, it will be assumed that the length of the first interval is one month or 720 hours. This is equivalent to assuming that all components are unmonitored and that if a component fails it will remain in a failed state until detected during a safety injection test.

- Interval 2 - Safety injection is initiated, and after several minutes (assumed 0.1 hour) of operation sufficient borated water will have collected in the sump to permit initiation of high pressure recirculation.
- Interval 3 - High pressure recirculation is initiated and approximately 1,400 seconds (~ 0.4 hours) after initiating safety injection, the reactor coolant pressure will have dropped sufficiently to permit low pressure recirculation through the reactor vessel head.
- Interval 4 - Low pressure recirculation is initiated and continues for 24 hours.

As shown in the block diagram in Figure 3.24, there are a number of nonredundant valves, any one of which would contribute significantly to system unreliability if their failure rates were not substantially smaller than other components which are redundantly arranged. In order to improve system reliability, one-out-of-two redundancies were added to these nonredundant components in a second case by using the ARMM program capability for handling a limited number of partial data* changes without changing the basic input. To make this partial data change possible in a single run, additional load sheets were prepared as shown in Figure 3.27, to accomodate those nonredundant components listed in the load sheets shown in Figure 3.26.

In addition, a third case was investigated whereby Interval 1 was shortened to one week (168 hours) simulating a shorter testing interval or shorter interval in which failures could exist. The partial data change is noted in the second half of data entries in Forms A and G of Figure 3.27.

RESULTS OF ANALYSIS

Table 3.13 presents results of the analysis for three cases and four different time intervals. The overall system unreliability of 0.388×10^{-1} (Case 1) for the system described in the FDSA was reduced by 97.9 percent to 0.831×10^{-3} (Case 2) for the improved version with all critical in-series valves placed in one-out-of-two redundancies, and by 76.6 percent to 0.908×10^{-2} (Case 3) for the system with shorter testing interval. Considering the different time intervals, the analysis shows that the chance of failure at the end of the starting interval is roughly three orders

*See section on ARMM input data Field 10A, Partial Data.

of magnitude greater than the change of failure of the subsequent safety injection period of 24 hours. Thus, if the system initiates safety injection, the chance of subsequent failure to continue injection is remote.

A summary of component contributions to system unreliability is shown in Figure 3.28 for Cases 1, 2, and 3. Components found least reliable and contributing up to 99 percent of overall system failure in Case 1 are listed in Table 3.14. In Figure 3.29, nonredundant valves were represented by two fictitious valves with only one-half of the true failure rate. Since each of these two valves belonged to a single function, the probability of function failure as shown in Figure 3.29 corresponds to that of a real valve. When these in-series valves were placed in-parallel with one-out-of-two redundancies as in Case 2, their contributions to system failure dropped to as little as 1/3 to 1/10 of those in Case 1. In Case 3 their relative contributions to overall system failure have not changed substantially since the only change was in the initial time interval.

CONNECTICUT YANKEE CONTAINMENT COOLING

The Connecticut Yankee plant contains two engineered safeguard systems designed to provide a sufficiently large heat sink to prevent the containment atmosphere pressure buildup resulting from the maximum credible accident from exceeding design limits. These safeguard systems are the air recirculation system and the containment spray system. The following discussion presents a preliminary reliability analysis for these systems.

The analysis is carried to the limit; that is, a reliability model is constructed for the containment cooling system. This model is then used to arrive at a quantitative statement for the probability that, in the event of the maximum credible accident (circumferential failure of the 27.5 inch primary coolant line), the containment design pressure will not be exceeded.

SYSTEM DESCRIPTION

Air Recirculation System

The air recirculation system consists of four (4) 65,000 cfm fan-cooling coil units and a system of distribution duct work (including inlet and outlet dampers), instrumentation, and controls. A typical unit is shown in Figure 3.30. The fans are direct driven, centrifugal type, and the cooling coils are transverse flow, finned coil banks. The fans take suction from the containment atmosphere and discharge into the system duct work. The duct work distributes the cooled air to the individual reactor coolant loop areas, the refueling cavity area, and the containment dome area. All four fans are normally in operation when the reactor coolant system is above 200° F. and 300 psig.

Two sets of inlet dampers are provided on each air recirculation unit. One set is located on the face of the filters while the other set controls bypass flow directly to the inlet of the cooling coils as shown in Figure 3.30.

During normal operation, the dampers on the face of the filters (incident dampers) are closed, while those leading directly from the containment to the cooling coils are open. A high pressure signal from the containment reverses the damper positions, sending 50,000 cfm through the filter bank. In the normal operating position, each set of dampers is

held against a spring by an energized electrical clutch. Loss of power de-energizes the clutch and the spring forces the dampers into the incident position, i. e., the incident dampers open and the normal dampers close.

The reliability block diagram constructed for a single fan unit is shown in Figure 3.31A. Here it was assumed that in the event of failure of the incident flow path, the plant operator has the option of reversing the damper positions, thereby achieving full cooling effectiveness via the normal flow path. Hence, the normal flow path is shown as redundant to the incident flow path in Figure 3.31A. A failure mode and effect analysis for a fan unit is shown in Figure 3.34A.

Containment Spray System

The containment spray system utilizes the residual heat pumps, the residual heat exchangers, and a spray header just inside the containment liner to distribute water throughout the containment. Spray water may be drawn either from the refueling cavity water storage tank or from the containment sump.

Containment spray is not automatically initiated in the event of a loss-of-coolant incident. The residual heat removal pumps would normally deliver water to the reactor vessel in such an incident. To initiate spray, the operator must close a valve in the line leading from the residual heat removal pumps to the reactor vessel and open a valve in the line leading to the spray headers. The path taken by spray water when the residual heat removal system is in this configuration is shown in Figure 3.32. The reliability block diagram constructed for the spray system is shown in Figure 3.31B and the failure mode and effect analysis in Figure 3.34B.

Electrical Power and Service Water Supply Systems

Electrical power for the fan motors, service water and residual heat removal pumps and motor operated valves is normally available through the station service supply system. In the event of loss of outside power, three (3) diesel generators are available in the plant to supply power.

Cooling water for the air recirculation system and residual heat exchangers is provided by the plant service water system. The capacity of any one of the four (4) service water pumps is assumed to be sufficient for this purpose. Figure 3.31C shows the reliability block diagram constructed for these systems.

RELIABILITY CONSIDERATIONS

Air Recirculation System

Figure 3.33 (extracted from NYO-3250-5) shows the calculated pressure transient in the containment following circumferential failure of a 27.5-inch reactor coolant line. It appears that the heat sinks provided by the safety injection and core deluge systems are of small efficacy and that the major burden in controlling the peak pressure is placed on the air recirculation system. Further, as far as the peak pressure is concerned, three (3) fans in operation are seen to be as effective as all four (4) fans in operation. From the point of view of a reliability analysis, it would be desirable to see similar curves for 1 and 2 fans in operation. Lacking this information, a major (conservative) assumption regarding the effectiveness of the air recirculation system was made in the reliability analysis. It was assumed that operation of at least three fan units is required to maintain the pressure transient within design pressure.

Containment Spray System

The containment spray system is installed as a backup for the air recirculation system for depressurization of the containment following a loss-of-coolant accident.

The spray system is not considered in the calculation of the containment pressure transient. To quote from the Plant Design and Analysis Report (NYO-3250-5), "No quantitative credit is taken for the spray system in the analysis of the hypothetical accident because the experimental work done to date is not considered extensive enough to assess accurately the effect of the spray under the conditions which would exist in the containment after such an accident." Nevertheless, in this study it was assumed that the spray system is an effective standby system for the air recirculation system and would be started in the event of failure of more than one fan unit.

RELIABILITY EVALUATION

Overall Reliability Block Diagram

Based on the above discussion of system effectiveness, the reliability block diagram for the complete containment cooling system takes the form shown in Figure 3.31D.

Reliability Calculation

Two separate reliability calculations were made using the ARMM program, one for the combined power supply and service water supply systems and one for the combined air recirculation and containment spray systems. The components were "aged" for a period of 1,020 hours. This assumes that there is a component testing interval of 1 month (720 hours) and that coolant system operation is required for a period of 300 hours following an incident.

Failure rates assumed for the components of Figures 3.31A, B, and C are shown in Table 3.15.

The criteria used for grouping of components into functions as shown in Figures 3.31A, B, and C was such as to lead to the minimum number of functions necessary for system description in the ARMM input. All components to the right of a function number (F. ____) belong to that function. For example, in Figure 3.31B components 56, 57, 58, 59, 60, and 61 belong to function F. -51, (the minus indicates that the function is listed in standby capacity).

RESULTS OF ANALYSIS

Power Supply

As seen on Figure 3.31C, there are seven paths, not all independent, by which 480-volt power may be supplied. Failure of components 60, 90 (common to five of the paths) and 130 lead to system failure. All other component failure combinations resulting in system failure are of higher order,* i. e., they require four or more component failures. Since the probability of failure of a typical single component is of the order of 10^{-2} , it may be anticipated that the lowest order failure combination contributes most of the total system failure probability. This is clearly evident in the results obtained in the present case, as shown in Table 3.16.

Service Water Supply System

The reliability, or conversely the unreliability, of the service water supply system has been evaluated on the basis that the critical components are the four service water pumps. Other components in the system were assumed

*The order of a component failure combination has been defined as the number of components failed in order to achieve system failure; e. g., a third order combination is a unique combination of three failed components which will cause system failure.

to contribute negligibly to the system unreliability. System failure was assumed to require failure of all four pumps (i. e. , one service water pump was assumed to supply adequate cooling capacity to the tube sides of the air recirculation unit cooling coils and the residual heat exchangers). The probability of all four service water pumps failing is calculated to be 0.21×10^{-6} .

Air Recirculation and Containment Spray Systems

This system incorporates a high degree of redundancy. The three out of four fan units operating condition on the air recirculation system with the containment spray system in standby (See Figure 3.31D) implies that a minimum of 3 components must fail to result in system failure.

The failure probability of the combined system was calculated in two ways. First, a complete ARMM run was made with the containment spray system described in standby capacity to three out of four air recirculation units. As anticipated, the run time was high due to the large number of component failure combinations that contribute to system failure (in this system, 270 third order and 3,222 fourth order combinations).

The results of the ARMM run are shown in Table 3.17A. The seventeen components listed are those involved in third order failure combinations. They are seen to contribute over ninety percent of the total system failure probability. The remaining forty-four components comprising the system are involved only in fourth or higher order failure combinations.

Because of some uncertainties in the present ARMM treatment of standby functions, an approximate hand calculation of the system failure probability, as described below, was made. The simplifying assumptions made are seen to eliminate almost all analytical difficulties, allowing the calculation to be readily performed by hand. Without these assumptions, the calculation would have become prohibitive.

The probability of single component failure, q , is

$$q = 1 - e^{-\lambda t},$$

$$q \approx \lambda t \quad , \quad \lambda t \ll 1$$

where

λ = component failure rate, and

t = operating or aging time.

In this particular problem $t = 1,020$ hr and $\lambda_{\max} = 10 \times 10^{-6} \text{ hr}^{-1}$, hence, $(\lambda t)_{\max} = 1.02 \times 10^{-2}$, implying $q = \lambda t$ within 1 percent and the error is conservative. Further, for n components in series, each with failure probabilities $< 10^{-2}$, the failure probability Q for the series combination is

$$Q = \sum_{i=1}^n q(i)$$

to within 1 percent (again, the error is conservative).

Using these approximations and the reliability block diagram shown in Figure 3.31D, the failure probability for a single air recirculation unit operating for time T (in millions of hours) is

$$\begin{aligned} Q_{\text{unit}} &= (\lambda_{16} + \lambda_{17} + \lambda_{18}) T + (\lambda_{14} + \lambda_{15}) (\lambda_{10} + \lambda_{11} + \lambda_{12} + \lambda_{13}) T^2 \\ &= 1.53 \times 10^{-2}, \end{aligned}$$

using $T = 1,020$ hours and λ values from Table 3.15.

Failure of the air recirculation system requires failure of two or more fan units. Hence, the failure probability of the air recirculation system Q_{ars} , is given by

$$\begin{aligned} Q_{\text{ars}} &= \sum_{i=2}^4 \frac{4!}{i!(4-i)!} (Q_{\text{unit}})^i (1 - Q_{\text{unit}})^{4-i} \\ &\approx 6Q_{\text{unit}}^2 \quad \text{within 1 percent.} \end{aligned}$$

Using the value computed above,

$$Q_{\text{ars}} \approx 14 \times 10^{-4}$$

or conversely, the air recirculation system reliability is

$$R_{ars} \cong 0.9986$$

The failure probability of the containment spray system, to the same level of approximation as above, is

$$Q_{css} = T \sum_{i=70}^{74} \lambda_i + T^2 \left(\sum_{i=54}^{55} \lambda_i \sum_{i=50}^{53} \lambda_i + \sum_{i=56}^{58} \lambda_i \sum_{i=59}^{61} \lambda_i + \sum_{i=62}^{65} \lambda_i \sum_{i=66}^{69} \lambda_i \right) \\ = 3.8 \times 10^{-2},$$

with $T = 1,020$ hours and λ values from Table 3.15.

Conversely, the containment spray system reliability is

$$R_{css} \cong 0.962$$

The containment cooling system failure probability, Q , then becomes

$$Q \cong Q_{ars} Q_{css} \cong 5.3 \times 10^{-5}$$

Conversely, the estimated system reliability is

$$R = 0.999947$$

This assumes (conservatively) that the spray system is alternate to the air recirculation system. If the spray system is treated in standby capacity the estimate of Q will be lower, since components in standby are not aging until the standby function is required to operate.

The general equation for the system failure probability with the spray system in standby to the air recirculation system is

$$Q(\text{standby}) = \int_0^T \dot{Q}_{ars} \int_0^{T-t'} \dot{Q}_{css} dt' dt \quad . \quad (\dot{Q} = \frac{dQ}{dt})$$

At the level of approximation being considered in this case, $Q_{ars} \propto t^2$ and $Q_{css} \propto t$, i.e., the t^2 terms in the expression for Q_{unit} and Q_{css} are negligible. Hence, with the containment spray system in standby

$$Q(\text{standby}) = \frac{1}{3} Q_{\text{ars}} Q_{\text{css}}$$

$$= 1.8 \times 10^{-5}$$

or the estimated system reliability, with the containment spray in standby is

$$R(\text{standby}) = 0.999982.$$

As previously indicated, there are 270 third order and 3,222 fourth order failure combinations resulting in system failure. Table 3.17B shows the estimated percentage contribution of these combinations to the probability of system failure. This estimate was arrived at as follows:

Within the framework of the above approximations, we may write

$$Q_{\text{unit}} = a_{3u}T + a_{4u}T^2$$

$$Q_{\text{css}} = a_{3c}T + a_{4c}T^2$$

where the a's are coefficients relating to the component λ values.

Then,

$$Q(\text{standby}) \propto (Q_{\text{unit}})^2 (Q_{\text{css}})$$

$$Q(\text{standby}) = a_3T^3 + a_4T^4 + a_5T^5 + a_6T^6.$$

The T^3 term gives the contribution from third order failures. The T^4 term gives the fourth order contribution and so on.

Comparison of Tables 3.17A and 3.17B shows good agreement between the ARMM and hand calculated allocation of system failure probability to third and higher order failure combinations. Both methods attribute approximately 90 percent of the system failure probability to third order failure combinations. However, the system failure probability calculated by ARMM is a factor of two higher than the hand calculated value. This disagreement can be expected when considering the way ARMM presently handles standby functions.

Conclusions

The results displayed in Tables 3.16, 3.17A, and 3.17B indicate the following conclusions. In this complex system containing redundant paths and components with failure probabilities $\approx 10^{-2}$, the system unreliability may be attributed almost entirely to those components involved in the lowest order failure combinations. It may be anticipated that components involved in a higher order failure combination will contribute significantly to the system unreliability only if that combination contains a component whose failure rate is at least an order of magnitude greater than that of the components in the lower order combination. This was not the case in the present study.

In this model of the Connecticut Yankee containment cooling system, the greatest contributors to the calculated system unreliability turn out to be the fans and fan motors in the air recirculation units, (Components 17 and 18 in Figure 3.31A) and the valves channeling coolant to the spray header rings in the containment spray system (Components 71 and 72 in Figure 3.31B). Hence, the system reliability estimate will be most sensitive to the particular assumptions made regarding these components. Modification of these assumptions will strongly affect the computed system reliability.

For example, it was assumed in the analysis that the fans and fan motors were being aged over the whole testing interval (720 hours), as well as during the period of incident operation (300 hours). It could be argued that since these components are in continuous operation during the testing interval, their failure would be observed and repair would be effected. Using this reasoning, these components might be considered to be aging only for a period corresponding to the required repair time (say, 1 day) plus incident operating time. The total aging time for these components would then be a factor of three $\left(\frac{300+24}{300+720}\right)$ less than previously assumed and the estimate of system reliability would be increased by a factor of approximately 10.

Regardless of the assumptions used, the primary contributors to system failure are expected to be the fans, fan motors, and spray system valves. If increased reliability is desired in the containment cooling system, it appears that this goal can be most effectively gained through

1. Modifying these components to significantly reduce their failure rates, if further investigation of failure rate assumptions reveal no significant error, and
2. Consideration of additional redundancy in spray loop valves, if this redundancy will not significantly degrade the reliability of emergency core cooling functions.

SAN ONOFRE SAFETY INJECTION SYSTEM

The San Onofre safety injection system is designed to limit core damage due to overheating following a loss-of-coolant accident in the reactor coolant system and to insert negative reactivity, in the form of borated water, during rapid cooldown of the reactor following a turbine-cycle-side steam line rupture. Design criteria used to assure accomplishment of these functions are:

1. The system shall prevent release of fission products from the fuel rods following a rupture of the reactor coolant system for any size break, up to complete severance of the largest line connecting to the reactor coolant loops, i. e., the 10-inch nominal size pressurizer surge line.
2. The system shall limit fission product release for hypothetical break sizes (which are not considered credible), up to the complete severance of a reactor coolant pipe, assuming discharge of coolant from both ends of the pipe.
3. The system shall provide a means of cooling the core for extended periods, following a loss-of-coolant accident.
4. The system shall provide a means of inserting negative reactivity following a loss-of-coolant or a turbine-cycle-side steam line break.
5. The system design shall assure that no inadvertent system operation can be postulated which would constitute a hazard, such as would result from unlimited addition of unborated water to the reactor coolant system.
6. The system shall operate satisfactorily with second-order mechanical equipment failures, i. e., with the loss-of-coolant accident as a first order condition; the failure of any component to respond actively in the prescribed manner can be tolerated without loss of ability to provide the necessary protection. Numerous third order or multiple failures can also be tolerated, but the design is not intended to cover all such cases.
7. Power shall be continuously available to safety injection system equipment.

8. The design of the equipment in the safety injection system and supporting systems shall be in accordance with the seismic ground motion criteria established for the plant.

SYSTEM DESCRIPTION

The safety injection system is made up of two essentially separate systems; one for the initial injection of borated water to the reactor coolant system, and the other for subsequent cooling and recirculation of spilled water back to the reactor coolant system for long-term removal of the core residual heat. These two systems are shown in Figure 3.35.

Injection

The injection system consists of two separate and independent pumping trains for delivery of water, borated at refueling concentration, into the reactor coolant system. This philosophy of equipment separation has been extended so that equipment in each injection train is supplied from independent 4,160-volt and 480-volt buses.

Each injection train uses one of the two feedwater pumps which deliver feedwater to the steam generators during normal operation. These pumps are Byron-Jackson, Type DVMX, two-stage pumps with horizontally split case and double volute. Pump design features are listed in Table 3.18. The pumps are designed to operate at any point over their delivery curve from a minimum flow near shutoff to flows in excess of the nominal 10,500 gpm injection requirement. The pump design was selected for its low net positive suction head requirement and its ability to continue delivery at high flows with some cavitation.

For safety injection service, the feedwater pumps are each supplied with borated refueling water by one of the two safety injection pumps. The safety injection pumps are single-stage, high-capacity, low head units. As shown in Figure 3.35, each pump is designed to supply 10,500 gpm of borated water from the refueling water storage tank to one feedwater pump at a pressure sufficient to prevent feedwater pump cavitation. Each pumping train obtains its borated water from the 240,000-gallon refueling water storage tank (approximately 11 times the reactor vessel volume) and discharges into the injection header, from which three separate injection lines run into the containment sphere and discharge into each of the three reactor coolant loops. The injection lines between the feedwater pump discharge isolation valves and the reactor coolant system isolation valves are always kept filled with borated water. Similarly, the safety injection line to the suction of these pumps is also kept filled with borated water.

Although the accident analysis has shown additional injection flow to be unnecessary, both centrifugal charging pumps in the chemical and volume control system are placed in service to augment injection system flow. The charging pumps, which are in service (one operating and the other standby) during normal operation of the plant, inject into the reactor coolant system upon initiation of safety injection. As shown in Table 3.18, rated flow for each of the two centrifugal charging pumps is 213 gpm. The combined output of both pumps fulfills the requirement for purification flow plus the seal water flow required when all reactor coolant pumps are operating on breakdown bushings and both charging pump bypass lines are open. The discharge pressure of each pump is indicated in the control room and a pressure switch on the pump discharge header automatically starts the standby pump if the header pressure falls below 2,200 psig.

The charging flow is arranged so that it can inject into each of the reactor coolant loops, thereby providing three additional flow paths. A charging pump alone will prevent the release of core fission products for break sizes up to approximately 6 inches and acts as a complete backup for the safety injection system in this range.

Additional injection flow can be provided by the refueling water pumps. These pumps are arranged so that they can inject into the reactor coolant system through the recirculation lines. For this service the pumps have a capacity of 500 gpm. Their primary function, however, is for containment spray. The injection function of these pumps is provided primarily as a backup for recirculation operation after the initial injection phase. Either recirculation pump is capable of delivery of water at a rate in excess of that needed for decay heat removal. Design parameters for these pumps are listed in Table 3.18.

Recirculation

The design basis for recirculation is to provide sufficient water to the reactor core for long-term, post-accident cooling, when operation of the injection subsystem is discontinued. The equipment provided will accomplish this basic purpose with any one component failing to respond as required.

The recirculation system consists of recirculation pumps which take spilled water from the containment sphere sump and pump it through the recirculation heat exchanger to the charging pumps. The charging pumps then return the water to the reactor coolant system via a line from each of the reactor coolant pump seal-water injection lines. The recirculation pumps also supply water for long-term operation of the containment sphere spray system.

The recirculation pumps are canned-motor, submersible units, designed to pump spilled water from the containment sphere sump. Each pump has a flow capacity approximately double that needed to compensate for boil-off of water covering the core due to residual heat generation. The pump design also permits periodic dry-test starts. Design parameters for these pumps are summarized in Table 3.18. The recirculation heat exchanger is a shell and tube unit. It removes decay heat from recirculated water by heat exchange with component cooling water circulating on the shell side. Operating conditions for this heat exchanger vary according to the severity of the loss-of-coolant accident and the equipment available for operation following the accident. The design is conservatively based on the set of parameters shown in Table 3.19.

Electrical Power

Electric power for safety injection system operation is supplied by the plant auxiliary electric power system. As previously indicated, power for each injection pumping train is supplied from independent 4,160-volt and 480-volt buses connected to the station switchyard. If an accident requiring safety injection system operation occurs, power will continue to be supplied to all electrically powered safety injection equipment (pumps, valves, and instrumentation) from the same sources supplying the buses prior to the emergency. No bus transfers are required. For this example application, the plant has been assumed to be provided with two independent sources of power for the auxiliary electrical system.* These originate from:

1. The main turbine-generator unit at the San Onofre Nuclear Generating Station and the Southern California Edison Company's 220-kv system.
2. The San Diego Gas & Electric Company's 138-kv system.

In the event of a loss-of-coolant incident the reactor will scram, the turbine will trip, and the main breakers tying to the 220-kv switchyard will open. However, the 138-kv system will continue to supply power to the buses connected to safety injection equipment. As an emergency safety injection operating procedure, the operator will restore the 220-kv system as an independent backup source of power into the plant

*The existing facility also is provided with emergency diesel generating capability; however, the power system defined in the Final Engineering Report and Hazard Analysis has been used here.

following reactor coolant pump coastdown operation. This source is not required for safety injection power supply, but is made available as standby. Both the 138-kv and 220-kv systems are adequate to supply the electrical power requirements for safety injection. Safety injection system power requirements are summarized in Table 3.20. Figure 3.36 is a single-line diagram showing the electrical power supply to the pumps in the safety injection and recirculation systems. As shown, Bus 3 serves as an alternate power source to either of the normally used 480 v buses (Buses 1 and 2).

A loss-of-coolant accident, coincident with the occurrence of major equipment electrical faults, is not considered credible. The electrical system is arranged, however, so that a large degree of protection is provided should a major electrical fault occur at some time following a safety injection incident.

Injection System Operation

Operation of the injection system is initiated automatically upon coincidence of low pressurizer pressure and low pressurizer water level, when the plant is at power or in the hot shutdown condition. The safety injection signal will initiate a reactor scram if the reactor has not already scrammed from an independent low pressure signal.

To assure reliability of the injection signal and freedom from spurious safety injection signals, the actuation circuit uses three independent pressure channels and three independent pressurizer water level channels. A signal initiating injection system operation is generated when two out of three low water level and two out of three low pressure signals occur. This arrangement allows testing of the actuation circuitry during operation.

When the plant is at normal power operation, the feedwater pumps deliver feedwater to the steam generators. The safety injection signal starts the two safety injection pumps and the standby charging pump, and stops all four condensate pumps and the two heater drain pumps. Motor-operated valves also are actuated to align the pumping flow path for safety injection service and to isolate the feedwater condensate system. All valves act immediately, with the exception of the valves at the point of feedwater pump discharge into the injection header (valves 851A and B). These valves are interlocked to remain closed until the condensate isolation valves at feedwater pump suction (valves 854A and B) have completely closed. This arrangement assures that borated water, from the safety injection pumps, will replace the significant portion of unborated water between the feedwater pump isolation valves before a flow path to the reactor coolant loops is opened. Should valve 854 fail to close, the interlock will prevent delivery of unborated water from the affected train into the injection header.

Isolation valves, which must function in order to align the injection system for operation, are gate valves with Limitorque operators. Each valve is designed to operate under the pressure differentials expected during safety injection and has a motor operator design compatible with operating time requirements and, where applicable, with post-accident ambient conditions within the containment sphere. Reliability of valve operation is assured by a program of testing both in the manufacturer's shop and periodically throughout the plant lifetime.

With the pumps started and the injection flow path aligned, the injection system delivers refueling water at a rate dependent upon break size and reactor coolant system pressure. The feedwater pumps can begin delivery at pressures as high as 1,157 psig. A system delivery of approximately 7,000 gpm is required to meet performance criteria in the case of the hypothetical severance of a reactor coolant pipe. The large feedwater pump capacity assures this delivery even if the hypothetical break occurs at an injection line connection and one injection train fails to function.

When the containment sphere sump level indicator shows an adequate water level for initiation of recirculation, and when the water level in the refueling water storage tank indicates that an adequate amount of refueling water has been delivered into the reactor coolant system, injection flow will be terminated by the operator and the recirculation subsystem placed in operation. For small breaks, the restoration of water level in the pressurizer provides additional indication that the reactor coolant system has been refilled.

The operator terminates injection system operation by blocking the automatic actuation signal, switching the four safety injection relays to the off position, and then individually turning off the feedwater pumps and the safety injection pumps in sequence. With occurrence of a low level in the refueling water storage tank an alarm will sound in the control room before the injection system empties the refueling water storage tank.

Recirculation System Operation

This phase of operation is initiated by the operator after the core has been covered with borated water by the injection system and a sufficient quantity of water has accumulated in the containment sphere sump.

The recirculation subsystem is placed in operation by starting the recirculation pumps and operating appropriate valves to open the recirculation flow paths. The valve isolating the refueling water storage tank is closed. Containment spray also can be initiated using the refueling water pump.

The operator has ample time to initiate recirculation. The refueling water storage tank has a minimum of ten minutes supply of borated water, even in the case of the hypothetical break, when both feedwater pumps deliver at their maximum capability. An additional time of approximately 10 minutes is available for initiating recirculation before the water in the reactor vessel would be evaporated below a level sufficient to assure core cooling. For the credible smaller piping ruptures, injection system operation will continue for longer periods before recirculation system operation is required.

RELIABILITY EVALUATION

Based on the preceding system descriptions and operational information, a preliminary reliability analysis has been performed for the San Onofre safety injection system. The basis which has been chosen for this analysis is the probability of successful operation in conjunction with a postulated break in a 10-inch line in the reactor coolant system. The analysis is made over three time intervals. The first interval is one month or 720 hours; the second interval is 10 minutes; and the third interval is 24 hours. In the first interval, the system is in standby. The feedwater pumps are operating to supply water to the steam generators, and one of the charging pumps is operating as part of the chemical and volume control system. The other charging pump is standby to the first. The break in a 10-inch line occurs at the end of the first interval. During the second interval, the safety injection system pumps the borated water from the refueling water tank to the reactor coolant loops. This requires the startup of the safety injection pumps and the alignment of the flow path by means of operation of the valves. Also, the refueling water pumps and the second charging pump are turned on, although for this size break only the safety injection pumping trains have the capacity to adequately cover the reactor core. However, the two charging pump trains and the two refueling pump trains can contribute to system unreliability during this interval, since at least one of them is required in the third interval. If all four of these latter pumps should fail in the second interval, they would not be available for the third interval. During the third interval, the borated water which has spilled from the break and collected in the containment sump is recirculated into the reactor for the removal of fission product decay heat. For this purpose one of the two recirculation pumps, which were not on during the first two intervals, must operate and, as stated before, one of the charging pump trains or refueling pump trains must work.

During the second and third intervals, the flow through the system is changed by means of actuation of valves and the startup of pumps. To properly consider the contribution of these components to the unreliability during this phase of their operation, they have been assumed to perform this operation at the end of the preceding interval. The pumps have been assigned two failure rates, one for their startup and one for their continuing operation. To do this using the ARMM program, the pumps are described as two components, each with one of the failure rates. The component with the startup failure rate is on during the preceding interval and off the following intervals during which the component with the operating failure rate is on. In effect, the failure rate for the startup component reflects the effect of aging on the likelihood of a pump accomplishing a successful startup. Valves must open or close to align the system properly. They have been assumed to perform this operation at the end of the interval prior to the interval during which this proper alignment is required. For example, the safety injection loop valves must be open during the second interval, so they are assumed to open at the end of the first interval. Once a valve has performed its operation successfully, it is assumed to be perfectly reliable. For example, a valve which is required to open will not fail closed once it has opened. Its only failure is to fail to open in the first place. For this reason, a valve is "on" only during the interval at the end of which it is required to function. Therefore, in this example, the valves on the safety injection loop do not contribute to system unreliability in any but the first time interval. As with the startup of a pump, the opening and closing of a valve is a cyclic operation. It is evaluated by ARMM by using a continuous failure rate which approximates the probability of a single cycle failure at the end of the interval of interest.

The length of the first and third intervals were chosen somewhat arbitrarily. The first interval of one-month duration was assumed to be the interval between tests for all components of the safety injection system. This would not be the procedure followed in the actual plant operation. The feedwater pumps, for example, are operating continuously, so, in a sense, they are continuously monitored and tested. The only time they contribute to the unreliability of the system in the test interval is within a length of time prior to a loss-of-coolant accident equal to the length of time it takes to repair or replace a failed pump, assuming plant operation would continue with one feedwater pump out of service. To reflect this condition in a reliability analysis with ARMM, the failure rates for these pumps would have to be multiplied by the ratio of the repair time to the interval length. The failure rates of other components which have more frequent tests than represented by the interval length would need to be multiplied by the ratio of their test interval to the program interval. This modification was not done in this calculation. The ten minute duration of the second interval was based on the minimum supply of borated water in the refueling water tank assuming the two safety injection pumping trains operate at maximum capability. The length of 24 hours for the third interval was, as stated above, arbitrary. It could easily have taken any other value.

Using the preceding considerations, a failure mode and effect analysis was performed on the safety injection system components to identify the critical nature of component failures. This analysis is illustrated for major system components in Figure 3.37. Such an analysis identifies the cause and effect of component failures, the conditions under which the failures become significant, and the actions which can be taken to eliminate or mitigate such failures. The analysis also was used to assure that subsequent steps in the reliability analysis identify the important failure modes in the equipment being considered.

Based on the preceding work a reliability block diagram was prepared for the safety injection system as shown in Figure 3.38. The diagram was used, in turn, to guide preparation of a reliability model input for analysis by the ARMM program. As shown in Figure 3.38, the number above each block is the component ID used in the ARMM analysis. Several pumps have two ID numbers. These represent the pump during its startup and then during the continuous operation which follows.

In the reliability block diagram in Figure 3.38 each electrical bus is placed in line with the pump or pumps it powers, with one exception. In that case, the 480 volt buses (numbers 1 and 2) appear by themselves and as alternates (in redundancy) to each other in the block diagram immediately following the safety injection loop valves. This allows the reliability analysis to consider the possibility of failure of both buses in this configuration during the first interval. During the second and third intervals, these two buses have this configuration combined with the two recirculation pumps. During the first interval, these two buses are also combined with the refueling water pumps. However, in this combination they have as additional alternates the two charging pump trains.

For this analysis the 220 kv system was assumed to be connected to the 4,160 volt buses, 1A and 1B, and from these buses to the two breakers, 11C01 and 12C01, to the 4,160 volt buses, 1C and 2C. As previously indicated in the system description, the 220 kv system is not reconnected until after the reactor coolant pump coastdown.

The intervals during which each component contributes to system unreliability is given in Table 3.21.

The failure rates used for the components of the safety injection system are given in Table 3.22. As shown in Table 3.22, the tank, sump, and headers were given very low failure rates since they were not expected to fail at rates comparable to those assigned to other active components. If the failure rates for these static components were increased significantly, their serial location in the system reliability model would make them major contributors to system unreliability.

RESULTS OF ANALYSIS

The components which make the largest contribution to system unreliability are listed in Table 3.23 for each time interval and for the total time. Included in the list is the probability that each component might cause system failure and the percentage contribution that a component might be expected to make to system unreliability for the interval or for the entire time.

A comparison of the data for Interval 1 and for the entire time shows that Interval 1 is the period of greatest unreliability. There are several reasons for this. First, the length of the first interval is much greater than the two following intervals. This illustrates the potential value of increasing the frequency of tests. Another reason is the number of components which were considered during the first interval compared with the number in the other two intervals. As shown in Table 3.21, 70 components were considered in the first interval, 42 in the second, and 31 in the third.

The primary contributors to system unreliability in the first interval are the startup components of the two safety injection pumps, the two feed-water pumps, the auxiliary transformer C, and the main transformer. Together they contribute 97.4 percent of total unreliability during that interval.

During the second interval the three major contributors are series components, i.e., components not supported by a redundancy. In the third interval, the major contributor, the recirculation heat exchanger, is also a series component.

This example analysis has shown how the components which can be expected to be major contributors to the unreliability of a given system can be identified. For the San Onofre safety injection system, these components are listed in the summary of Table 3.23. Within the accuracy of the reliability model and failure rate assumptions, these results point out the components which either (1) need better failure rate data, (2) need to be redesigned or replaced, (3) need additional redundancy, or (4) need more frequent testing.

Because the major contributors to the unreliability of the safety injection system are part of redundant units, Number (3) above would not appear to be the solution to better reliability. Because of the long duration of the first interval, Number (4), more frequent testing appears to be the best solution (assuming the failure rate data is reasonably accurate).

TABLE 3.1

PRINCIPAL DESIGN PARAMETERS
FOR DRESDEN-3 PRIMARY CONTAINMENT

Pressure Suppression Chamber Internal Design Pressure	62 psig -1 psig
Drywell Internal Design Pressure	62 psig -2 psig
Initial Suppression Chamber Pressure Rise	21 psi max.
Initial Suppression Chamber Temperature Rise	50° F.
Downcomer Vent Pressure Loss Factor	6.2
Break Area/Vent Pipe Area	.019
Submergence of Vent Pipe Below Pressure Suppression Pool Surface	4 feet
Drywell Free Volume	~ 158,000 ft ³
Pressure Suppression Pool Free Volume	~ 119,500 ft ⁵
Pressure Suppression Pool Water Volume	~ 106,000 ft ³

TABLE 3.2

PRINCIPAL PENETRATIONS OF PRIMARY CONTAINMENT
AND ASSOCIATED ISOLATION VALVES

Type of Service	Number of Lines	Approx. Pipe Size-Inches	Inner Isolation Valves Per Line (Inboard of Primary Containmentment Shell)					Outer Isolation Valves Per Line (Outboard of Primary Containmentment Shell)				
			Number	Power	Closing Signal	Closure Time Sec.	Normal Status	Number	Power	Signal	Closure Time Sec.	Normal Status
† To Isolation Condenser (Steam)	2	14	1	AC	E, B	60	Open	1	DC	E, B	60	Open
† From Isolation Condenser (Water)	2	12	1	AC	E, B	60	Open	1	DC	(A to open)	--	Closed
Standby Liquid Control System	1	2	1	Check	-	--	Closed [†]	1	Check	-	--	Closed
Feedwater	2	18	1	Check	-	--	Open	1	Check	-	--	Open
From Reactor Cleanup	1	6	1	Check	-	--	Open	1	AC	B	40	Open
† To Reactor Cleanup	1	6	1	AC	B, I	40	Open	1	DC	B, I	40	Open
Closed Cooling Water Inlet	1	8	1	Check	-	--	Open	-	--	-	--	--
Closed Cooling Water Outlet	1	8	0	--	-	--	--	1	AC	RM	--	Open
Steam Lines	4	20	1	AC-DC	B, C, D	3-10	Open	1	AC-DC	B, C, D,	3-10	Open
† Steam Line Drain	1	2	1	AC	B, C, D	--	Closed	1	DC	RM	--	Closed
† Sample Line - Recirculation Loop	1	1										
† Shutdown Cooling Inlet	2	14	1	AC	B, J	--	Closed	1	DC	RM	--	Closed
† Shutdown Cooling Outlet	2	16	1	AC	B, J	--	Closed	1	DC	RM	--	Closed
† Equipment Drain Sump	1	3	0	--	-	--	--	2	DC	F	10	Open
† Drywell Floor Drain Sump	1	3	0	--	-	--	--	2	DC	F	10	Open
† Service Water Supply	1	3	1	Check	-	--	Closed	1	Check	-	--	Closed
Control Rod Drive Inlet	185	1	see note	AC	-	--	--	-	--	-	--	--
Control Rod Drive Outlet	185	3/4	see note	--	-	--	--	1	AC	-	--	--
† Control Rod Hyd. Sys. Return	1	4	1	Check	-	--	--	1	Check	-	--	--
† Core Spray Inlet to Reactor	2	10	1	Check	-	--	Closed	2	AC	G	--	Closed
† Head Spray - Reactor Vessel	1	2	1	Check	-	--	Closed	1	AC	B	--	Closed
† Containment Cooling to Suppression Pool*	2	8	1	Check	-	--	Closed	-	--	-	--	--
† Core Spray, Cont. Cooling from Supp. Pool*	3	20	0	--	-	--	--	-	--	-	--	--
† Containment Cooling Inlet to Suppression Pool (Test Line)*	2	16	-	--	-	--	--	1	--	-	--	--
† Containment Cooling to Drywell	2	16	1	Check	-	--	Closed	-	--	-	--	--
† Vacuum Breaker - Reactor Bldg. To Supp. Pool*	1	20	0	--	-	--	--	1	Check	-	--	Closed
† Vacuum Breakers - Suppression Chamber to Drywell	6	24	None	--	-	--	--	None	--	-	--	--
† Drywell Ventilation Inlet-Outlet to Drywell	2	18	-	--	-	--	--	2	Air	F, B	10	Closed
† Construction Drain	2	8	-	--	-	--	--	-	--	-	--	Closed
† Instrumentation and Electrical	61	12	None	--	-	--	--	None	--	-	--	--
† Instrumentation*	8	1	None	--	-	--	--	None	--	-	--	--
† Instrumentation - Traveling Incore Probe	5	6	1	DC	RM	--	Open	1	AC	RM	--	Closed
† Instrument and Breathing Air	2	1	None	--	-	--	--	Check	--	-	--	Open
† Pressure Instrumentation	63	1	None	--	-	--	--	1	Check	-	--	--

* Denotes Suppression Chamber Location

Personnel and Equipment Openings:

Drywell Head - 1
Personnel Access Lock - 1
Suppression Chamber Manholes - 2
Equipment Access Hatch - 2

Signals which close isolation valves:

A - High Reactor Vessel Pressure
B - Low Low Reactor Vessel Water Level
C - High Radiation in Main Steam Lines
D - Main Steam Line Break
E - High Reactor Building Pressure

F - High Drywell Pressure
G - Low Low Water Level in Vessel and Low Reactor Pressure cause these valves to open
H - Remote manual closure on high radiation signal

I - Break, Clean-up System †
J - Break, Shutdown Cooling System †
RM - Remote Manual

NOTE: Control rod hydraulic lines can be isolated by the solenoid valves outside the primary containment. Lines that extend outside the primary containment are of small size and terminate in a system which is designed to prevent out-leakage. Solenoid valves are normally closed but open on rod movement and during reactor scram.

(Conforming amendment of Unit 2 PDAR required where indicated by †)

TABLE 3.3

DRESDEN-3 STANDBY DIESEL GENERATOR
LOADING REQUIREMENTS

LOAD	ESTIMATED POWER REQUIRED (hp)
<u>Automatically Connected Shutdown Loads</u>	
One Core Spray Pump	700
Two Containment Cooling Pumps	700
Two Containment Cooling Service Water Pumps	880
Standby Gas Treatment Equipment	150
All Power Operated Valves Not on D-C	80
Emergency A-C Lighting (time delay transfer from battery)	150
Instrumentation and Control Motor-Generator	<u>25</u>
Total	2,685 hp
<u>Manually Connected Shutdown Loads</u>	
Standby Liquid Control Pump	100
Drywell Cooling Blowers	80
Reactor Building Cooling Water System	400
Service Water System (that portion connected to the reactor building cooling water)	900
Emergency A-C Lighting	150
Instrument Air Compressor	150
Fuel Pool Cooling System	100
Battery Charger	40
Condensate Transfer Pump	50
Control Valves as Required by Above Systems but not included as battery load	15
Instrumentation and Control Motor-Generator	<u>25</u>
Total	2,010 hp

TABLE 3.4

BLOWDOWN ACCIDENT SUMMARY

Case	Containment Sprays On	Core Sprays On	Metal-Water Reaction, %	Peak (1) Containment Pressure, psig	Consequences
a	2	2	< 0.5	39	Acceptable
b	1	2	< 0.5	39	Acceptable
c	0	2	< 0.5	> 62	Unacceptable
d-1	2	0	0	39	Acceptable
d-2	2	0	27.5	39	Acceptable
e-1	0	0	0	> 62	Unacceptable
e-2	0	0	27.5	62	Unacceptable
f	1	0	27.5	42	Acceptable

(1) Containment designed for overpressure of 62 psig.

TABLE 3.5

TIME SEQUENCE
FOR BLOWDOWN ACCIDENT

Event	Time After Main Recirculation Line Break
First Peak in Drywell Pressure (39 psig)	3 sec.
Perforation of 1st Rod	8 sec.
End of Blowdown	24 sec.
Start of Containment Spray System	24 sec.
Equalization of Drywell and Suppression Chamber Pressure (21 psig)	30 sec.
Completion of Containment Isolation (longest valve closure time from end of blowdown 60 sec.)	84 sec.
Start of Metal-Water Reaction	120 sec.
Second Peak in Drywell Pressure (42 psig)	~ 2000 sec.
Perforation of All Fuel Rods	~ 2900 sec.
End of Metal-Water Reactor (~25 percent reaction)	~ 2500 sec.

TABLE 3.6
FAILURE RATE ASSUMPTIONS

Component	Failure Mode	Failure/10 ⁶ Hr.
Hatch Closure Seals	Leak Excessively	.01
Personnel Lock Doors	Open	.1
Personnel Lock Door Seals	Leak Excessively	.1
Personnel Lock Interlock	No Door Lock	.01
Air Operated Valves (Normally Closed)	Fail Open or Leaks	.05 (Designed to fail closed)
Air Operated Valves (Normally Open)	Fail Open or Leaks	.1 (Designed to fail closed)
Motor Operated Valves (Normally Closed)	Fail Open or Leaks	.01 (Designed to fail as-is)
Motor Operated Valves (Normally Open)	Fail Closed	(Designed to fail as-is)
	Fail Open or Leaks	.5 (Designed to fail as-is)
Check Valves (Normally Closed)	Fail to Seat or Leaks	.1 (Designed to close with outflow)
	Fail Open or Leaks	1.0 (Designed to fail as-is)
Suction Strainers	Fail Open or Clogged	.01
Pumps (Normally Off)	Fail to Start	10.0
	Fail to Continue	5.0
Heat Exchanger	Leak Excessively or Badly Fouled	.1
Spray Headers	Plugged	.1
Block Valves (Normally Closed)	Fail Open	1.0
Automatic Trip Devices	Fail to Trip	1.0
Manual Trip Devices	Fail to Trip	0.1

TABLE 3.7
SUMMARY OF RESULTS FOR
DRESDEN-3 PRIMARY CONTAINMENT
RELIABILITY EVALUATION

Case Variables	Case 1	Case 2	Case 3	Case 4
<u>OPERATIONAL CONSIDERATIONS</u>				
Containment Isolation Achieved	Yes	Yes	No	No
Containment Cooling System On	1 of 2 Loops	1 of 2 Loops	No	No
Core Spray System On	No	1 of 2 Loops	1 of 2 Loops	2 of 2 Loops
Emergency AC Power On	Yes	Yes	Yes	Yes
<u>PROBABILITY OF SYSTEM SUCCESS</u>				
Interval 1	0.99981	0.99970	0.99977	0.95746
Interval 2	0.99999	0.99999	0.99999	0.99998
Overall	0.99981	0.99970	0.99977	0.95744
<u>PROBABILITY OF SYSTEM FAILURE</u>				
Interval 1	0.18599×10^{-3}	0.29780×10^{-3}	0.22831×10^{-3}	0.42544×10^{-1}
Interval 2	0.32450×10^{-7}	0.33073×10^{-7}	0.32549×10^{-7}	0.17925×10^{-4}
Overall	0.18602×10^{-3}	0.29783×10^{-3}	0.22835×10^{-3}	0.42561×10^{-1}
<u>NO. OF COMPONENTS CONSIDERED</u>	162	204	66	66

TABLE 3.8

MAJOR CONTRIBUTORS TO PRIMARY CONTAINMENT FAILURE

System Rank	CASE 1			CASE 2		
	ARMM I. D. No.	Component	Percent System Failure	ARMM I. D. No.	Component	Percent System Failure
1	152	Transformer 6	25.8092	152	Transformer 6	20.6034
2	240	Transformer 7	16.0593	240	Transformer 7	15.1461
3	150	Bus 6 - T6 Breaker	11.3768	150	Bus 5 - T6 Breaker	9.2601
4	154	T6 - Bus 2A Breaker	11.3768	154	T6 - Bus 2A Breaker	9.2601
5	238	Bus 6 - T7 Breaker	6.9255	238	Bus 6 - T7 Breaker	6.7644
6	242	T7 - Bus 2B Breaker	6.9255	242	T7 - Bus 2B Breaker	6.7644
7	216	MOV-31 Breaker	6.9255	328	MOV-20 Breaker	5.9851
8	220	MOV-32 Breaker	6.9255	294	MOV-10 Breaker	5.9093
9	140	Service Water Valve Breaker	0.8867	216	MOV-31 Breaker	4.0008
10	144	Spray Test Valve Breaker	0.8867	220	MOV-32 Breaker	4.0008
11	224	MOV-22 Breaker	0.5067	326	Relief Valve	1.4630
12	228	STV-21 Breaker	0.5067	336	Manual Valve Switch	1.4630
13	232	SWV-2 Breaker	0.5067	292	Core Spray Relief Valve	1.4119
14	76	MOV-104	0.3782	302	Manual Switch	1.4119
15	170	Containment Cooling Pump Motor	0.3344	140	Service Water Valve Breaker	0.5122
16	172	Containment Cooling Pump	0.3344	144	Spray Test Valve Breaker	0.5122
17	182	Service Water Pump Motor	0.3344	332	MOV-21 Breaker	0.4596
18	184	Service Water Pump	0.3344	298	MOV-11 Breaker	0.4512
19	164	Containment Cooling Pump Motor	0.3344	224	MOV-22 Breaker	0.2927
20	166	Containment Cooling Pump	0.3344	228	STV-21 Breaker	0.2927
		Total	98.0022		Total	95.9839

TABLE 3.9

COMPONENT GROUPING BY PERCENTAGE CONTRIBUTION TO SYSTEM FAILURE

System Failure Percentage Group	Number Of Components In Group	Percent Of All Components In Group	Probability Of System Failure For Group	Percentage Contribution To System Failure By Group
<u>Case 1</u>				
20 - 30	1	0.6	0.480×10^{-4}	25.81
10 - 20	3	1.9	0.7219×10^{-4}	38.81
1 - 10	4	2.5	0.5152×10^{-4}	-27.70
0.1 - 1	20	12.3	0.1314×10^{-4}	7.68
0.01 - 0.1	15	9.3	0.1000×10^{-5}	7.68
0.001 - 0.01	13	8.0	} $<0.1 \times 10^{-5}$	7.68
< 0.001	106	65.4		
<u>Case 2</u>				
20 - 30	1	0.05	0.6136×10^{-4}	20.60
10 - 20	1	0.05	0.4511×10^{-4}	15.15
1 - 10	12	5.9	0.1720×10^{-3}	57.72
0.1 - 1	23	11.3	0.1650×10^{-4}	6.53
0.01 - 0.1	23	11.3	0.0266×10^{-5}	6.53
0.001 - 0.01	10	4.9	} $<0.1 \times 10^{-5}$	6.53
< 0.001	134	65.6		

TABLE 3.10LOSS OF COOLANT INCIDENT AND
SAFETY INJECTION SYSTEM SUMMARY

Loss of Coolant Condition	Reactor Coolant Pressure, psig	Type of Safety Injection System Operation	Pumping Train Operating Assignment		
			Safety Injection Pumps	Charge Pumps	Residual Heat Removal Pumps
Makeup	~2250	None	None	VCS ⁽¹⁾	None
Incident					
Small Break	500 to 1500	High Pressure	SIS ⁽²⁾	SIS	SIS
Large Break	< 500	Low Pressure	SIS	SIS	CDS ⁽³⁾

(1) VCS = Volume Control System

(2) SIS = Safety Injection System

(3) CDS = Core Deluge Subsystem

TABLE 3.11
RUPTURED PIPE SIZES AND
SAFETY INJECTION SYSTEM OPERATION

Ruptured Pipe Size (inches)	Single or Double-Ended Rupture	Safety Injection Initiation Time After Rupture (seconds)	Low Pressure Recirculation Initiation Time After Rupture (seconds)	Ruptured Pipes Affecting Safety Injection Performance
1-1/2	Single	150	NA ⁽¹⁾	1 Drain Header
3	Single	50	1200	1 Letdown Line
3	Single	50	1400	1 Charge Line ⁽³⁾
4	Single	40	850	1 Core Deluge Line
4	Single	30	1000	1 Safety Injection Line
6	Single	10	350	1 Steam Bypass Line
10	Single	< 10	120	1 Charge Line ⁽²⁾
27-1/2	Double	< 10	10	1 Reactor Coolant Inlet and Outlet Line 1 Safety Injection Line 1 Charge Line ⁽²⁾⁽³⁾
Break 2 sq. ft.	Single	< 10	10	Unspecified

(1) Not Available

(2) Coolant Loop 2

(3) Coolant Loop 4

TABLE 3.12

FAILURE RATE SUMMARY

Component	Failure Mode	Failure per Million Hours
Storage Tank	Rupture or no flow	0.1
Pump	Fail to start	10.0
	Fail to continue running	5.0
Motor Operated Valve	Fail to open or close	10.0 (designed to fail as-is)
Solenoid Valve	Fail to open	5.0 (designed to fail open)
Check Valve	Fail to seat	1.0 (designed to close with backflow)
Heat Exchanger	Rupture	0.3 (designed to ASME code)
Outside Power Source	Fail to supply power	0.1
Transformer	Fail to supply power	5.0
Bus Tie	Fail to close	2.0
Automatic Switch	Fail to trip	5.0
Manual Switch	Fail to trip	5.0
Pressure Switch	Fail to trip	15.0
Level Switch	Fail to trip	15.0

TABLE 3.13
SUMMARY OF SYSTEM UNRELIABILITY

Interval No.	Interval Duration, hours	System Unreliability				
		Case 1 As-is System	Case 2		Case 3	
			Improved System	Percent Reduction	Shorter Test Interval	Percent Reduction
1	720.0 168.0*	$.388 \times 10^{-1}$	$.831 \times 10^{-3}$	97.9	$.908 \times 10^{-2}$	76.6
2	0.1	$.451 \times 10^{-5}$	$.510 \times 10^{-6}$	88.7	$.451 \times 10^{-5}$	0
3	0.3	$.603 \times 10^{-5}$	$.300 \times 10^{-7}$	99.5	$.603 \times 10^{-5}$	0
4	24.0	$.252 \times 10^{-5}$	$.252 \times 10^{-5}$	0	$.252 \times 10^{-5}$	0
Total	744.4 192.4*	$.388 \times 10^{-1}$	$.834 \times 10^{-3}$	97.8	909×10^{-2}	76.6

*Applies to Case 3 only.

TABLE 3.14
MAJOR CONTRIBUTORS TO SYSTEM UNRELIABILITY

Component	Percent System Failure		
	Case 1	Case 2	Case 3
Refueling Water Supply Valve	18.2	5.6 ⁽¹⁾	18.4
Safety Injection Recirculation Valve	18.2	5.6 ⁽¹⁾	18.4
Containment Sump Valve	18.2	5.6 ⁽¹⁾	18.4
Residual Heat Throttle Valve	18.2	5.6 ⁽¹⁾	18.4
Residual Heat Pump Suction Valve	9.1	1.4 ⁽¹⁾	9.2
Residual Heat Bypass Valve	9.1	1.4 ⁽¹⁾	9.2
Charge Pump Suction Valve	2.7	.35 ⁽¹⁾	2.7
Volume Control Valve	2.7	.35 ⁽¹⁾	2.7
Charge Line Control Valve	1.8	.19 ⁽¹⁾	1.8
Safety Injection Valves ⁽²⁾	.78	33.4	.19
Refueling Water Storage Tank	.19	8.1	.21

(1) 2 valves with 1 out of 2 redundancy

(2) 4 valves with 3 out of 1 redundancy

TABLE 3.15

CONNECTICUT YANKEE
CONTAINMENT COOLING SYSTEM
COMPONENT FAILURE RATES

Figure Number	ARMM Component I. D.	Component Failure Rate, Failures per 10 ⁶ hour
3.31A	10, 11, 12, 13	1.0
3.31A	14	2.0
3.31A	15, 18	10.0
3.31A	16	0.1
3.31A	17	5.0
3.31B	50	0.0001
3.31B	51, 52, 54, 71, 72	10.0
3.31B	53, 55, 64, 68, 70, 73, 74	5.0
3.31B	56, 58, 59, 61, 62, 65, 66, 69	1.0
3.31B	57, 60	30.0
3.31B	63, 67	0.1
3.31C	10, 30	0.1
3.31C	20, 40, 60, 70, 100, 110	5.0
3.31C	50, 80, 90, 120	2.0
3.31C	130, 140, 150	90.0
3.31C	160, 170, 180, 190	30.0

TABLE 3.16

COMPONENT FAILURE COMBINATIONS LEADING TO POWER SYSTEM FAILURE*

Component Combinations (Component I. D. Numbers Refer to Figure 3.31C)	Percentage Contribution to Power System Failure Probability
60+90+130 (Third Order)	99.7
20+40+90+130 (Worst Fourth Order)	0.15
All Others	0.15

*Power System Failure Probability = 0.27×10^{-9} .

TABLE 3.17A

COMPONENT CONTRIBUTIONS TO SYSTEM UNRELIABILITY

System: 3-Out-of-4 Air Recirculation Units Plus
Containment Spray System in Standby
(ARMM Calculation)

Figure Number	Component I. D. No.	Contribution to System Failure Probability (Percent)*
3.31A	16 (4 identical components)	.008
3.31A	17 (4 identical components)	13.4
3.31A	18 (4 identical components)	53.3
3.31B	70	2.5
3.31B	71	8.0
3.31B	72	8.0
3.31B	73	2.5
3.31B	74	2.5
Total		90.5

*Probability of system failure = 4.11×10^{-5} .
System reliability = 0.9999589.

TABLE 3.17B
COMPONENT COMBINATIONS CONTRIBUTING
TO SYSTEM FAILURE
(HAND ESTIMATE)

Number of Components Failed	Contribution to System Failure Probability (Percent)*
3	90.5
4	9.5
5 or greater	Negligible

*Probability of system failure = 1.8×10^{-5} .
System reliability = 0.999982.

TABLE 3.18

COMPONENTS - MECHANICAL FEATURES

<u>FEEDWATER PUMPS</u>	
Number of Units	2
Design Flow Rate (feedwater service)	7,000 gpm
Design Head	1,825 feet
Shutoff Head	2,360 feet
Maximum Flow Conditions (safety injection service)	
Flow Required	10,500 gpm
Head	975 feet
NPSH (net positive suction head)	180 feet
Temperature of Pumped Fluid	
Feedwater	351 F
Safety Injection Water	40 F - 90 F
Basic Material	Chrome Alloy Steel
<u>SAFETY INJECTION PUMPS</u>	
Number of Units	2
Design Flow Rate	10,500 gpm
Design Head	245 feet
Design Pressure	150 psig
Design Temperature	250 F
Pumped Fluid	Boric Acid Solution
Temperature of Pumped Fluid	40 F - 90 F
Basic Material	Stainless Steel
<u>RECIRCULATION PUMPS</u>	
Number of Units	2
Design Flow Rate	800 gpm
Design Head	160 feet
Design Pressure	150 psig
Design Temperature	300 F
Pumped Fluid	Boric Acid Solution
Temperature of Pumped Fluid	40 F - 271 F
Basic Material	Carbon Steel

TABLE 3.18 (continued)

<u>CHARGING PUMPS</u>	
Number of Units	2
Design Flow Rate	213 gpm
Design Head	5,325 feet
Design Pressure	2,735 psig
Design Temperature	250 F
Pumped Fluid	Boric Acid Solution
Temperature of Pumped Fluid (normal plant operation)	130 F
Basic Material	Stainless Steel

Note: The centrifugal charging pumps are part of the chemical and volume control system. The following parameters are based upon requirements of that system.

TABLE 3.19

RECIRCULATION HEAT EXCHANGER

Fluid	Shell Side	Tube Side
	Component Cooling Water	17. % - 2.2% by Weight Boric Acid Solution
Flow Rate	1, 000 gpm	1, 600 gpm
Temperature In	110 F	271 F
Temperature Out	158 F	241 F
Operating Pressure	50 psig	100 psig
Pressure Loss, Maximum	15 psi	10 psi
Design Pressure	150 psig	150 psig
Design Temperature	200 F	300 F
Heat Exchanged	Approximately 23.8×10^6 Btu/hour	

TABLE 3.20
COMPONENTS - ELECTRICAL PARAMETERS

Pump Motor	Horsepower	Voltage
Feedwater Pump	3500	4160
Safety Injection Pump	700	4160
Recirculation Pump	60	480
Charging Pump	600	4160
Refueling Water Pump	150	480

TABLE 3.21

INTERVAL COMPONENT CONTRIBUTES TO SYSTEM UNRELIABILITY

ARMM ID	COMPONENT	INTERVAL		
		1	2	3
10	Refueling Water Tank	X	X	
20	Safety Injection Header	X	X	
30	MOV 850 A	X		
40	MOV 850 B	X		
50	MOV 850 C	X		
60	RMS for MOV 883		X	
70	MOV 883		X	
80	Recirculation Header	X	X	X
90	Containment Sump	X	X	X
100	Recirculation Heat Exchanger			X
110	FCV 1115 D	X		
120	MOV 356	X		
130	FCV 1115 E	X		
140	MOV 357	X		
150	FCV 1115 F	X		
160	MOV 358	X		
250	Main Transformer	X	X	X
260	Auxiliary Transformer C	X	X	X
270	Circuit Breaker 12CO2	X	X	X
280	Circuit Breaker 11CO2	X	X	X
290	Tie Breaker 11C11	X	X	X
300	Tie Breaker 12C11	X	X	X
310	Auxiliary Transformer B	X	X	X
320	Auxiliary Transformer A	X	X	X
330	CB 11B04	X	X	X
340	TB 12C01	X	X	X
350	CB 11A04	X	X	X
360	TB 11C01	X	X	X
370	Safety Injection Pump G50A (Start)	X		
380	Safety Injection Pump G50A (Operate)		X	
390	MOV 853 A	X		

TABLE 3.21 (continued)

INTERVAL COMPONENT CONTRIBUTES TO SYSTEM UNRELIABILITY

ARMM ID	COMPONENT	INTERVAL		
		1	2	3
400	Feedwater Pump G-3A	X	X	
410	MOV 854 A	X		
420	MOV 852 A	X		
430	MOV 851 A	X		
440	Interlock A	X		
450	CV 36	X		
460	CV 875 A	X		
470	Safety Injection Pump G 50B (Start)	X		
480	Safety Injection Pump G 50B (Operate)		X	
490	MOV 853 B	X		
500	Feed Water Pump G-3B	X	X	
510	MOV 854 B	X		
520	MOV 852 B	X		
530	MOV 851 B	X		
540	Interlock B	X		
550	CV-37	X		
560	CV-875 B	X		
570	Station Service Transformer #3	X	X	X
580	Station Service Transformer #2	X	X	X
590	Station Service Transformer #1	X	X	X
600	CB-11C10	X	X	X
610	CB-12C10	X	X	X
620	CB-1102	X	X	X
630	CB-1202	X	X	X
640	CB-1303	X	X	X
650	TB-1103	X	X	X
660	TB-1203	X	X	X
670	Manual Start Recirculation Pumps		X	
680	Recirculation Pump G-45A (Start)		X	
690	Recirculation Pump G-45B (Start)		X	

TABLE 3.21 (continued)

INTERVAL COMPONENT CONTRIBUTES TO SYSTEM UNRELIABILITY

ARMM ID	COMPONENT	INTERVAL		
		1	2	3
700	Recirculation Pump G-45A (Operate)			X
710	Recirculation Pump G-45B (Operate)			X
720	MOV 866 A		X	
730	MOV 866 B		X	
740	Refueling Water Pump G 27 (Start)	X		
750	Refueling Water Pump G 27 (Operate)		X	X
760	Refueling Water Pump G 27 S (Start)	X		
770	Refueling Water Pump G 27 S (Operate)		X	X
780	CV 81	X		
790	CV 112	X		
800	MOV 880	X		
810	MOV 1100 B	X		
820	MOV 1100 D	X		
830	Charge Pump G 8A (Operate)	X	X	X
840	Charge Pump G 8B (Start)	X		
849	Charge Pump G 8B (Operate)		X	X
850	Level Sensor #1	X		
851	Level Sensor #2	X		
852	Level Sensor #3	X		
853	Pressure Sensor #1	X		
854	Pressure Sensor #2	X		
855	Pressure Sensor #3	X		
856	Automatic Actuate of SIS	X		
857	Manual Actuate of SIS	X		
Total Number of Components Considered		70	42	31

TABLE 3.22

FAILURE RATE DATA USED
FOR SAN ONOFRE SAFETY INJECTION SYSTEM

COMPONENT	FAILURE RATE PER MILLION HOURS
Pumps	
Start	10
Operate	5
Valves	
Open	0.01
Close	0.01
Auto Trip Devices	1.0
Manual Trip Devices	0.1
Level Sensors	15
Pressure Sensors	15
Tank, Sump	0.0001
Headers	0.0002
Interlock	0.01
Transformers	5
Circuit Breakers	5
Tie Breakers	5
Heat Exchanger	0.1

TABLE 3.23

MAJOR CONTRIBUTORS TO UNRELIABILITY OF SAN ONOFRE
SAFETY INJECTION SYSTEM DURING THREE TIME INTERVALS

<u>INTERVAL 1 (720 HOURS)</u>		
Probability of System Success Prior to this Interval: 1.0		
Probability of System Failure During this Interval: 1.279×10^{-4}		
MAJOR CONTRIBUTOR	SYSTEM PROBABILITY	PERCENT
S. I. Pump G50A (Start)	4.176×10^{-5}	32.0
S. I. Pump G50B (Start)	4.176×10^{-5}	32.0
Feedwater Pump G-3A	1.468×10^{-5}	11.5
Feedwater Pump G-3B	1.468×10^{-5}	11.5
Auxiliary Transformer C	6.986×10^{-6}	5.5
Main Transformer	6.239×10^{-6}	4.9

<u>INTERVAL 2 (10 MINUTES)</u>		
Probability of System Success Prior to this Interval: 0.99987210		
Probability of System Failure During this Interval: 3.518×10^{-8}		
MAJOR CONTRIBUTOR	SYSTEM PROBABILITY	PERCENT
RMS for MOV 883	1.670×10^{-8}	47.5
Manual Start Recirc. Pumps	1.670×10^{-8}	47.5
Refuel Tank Valve MOV 883	1.670×10^{-9}	4.7

TABLE 3.23 (continued)

MAJOR CONTRIBUTORS TO UNRELIABILITY OF SAN ONOFRE
SAFETY INJECTION SYSTEM DURING THREE TIME INTERVALS

<u>INTERVAL 3 (24 HOURS)</u>		
Probability of System Success Prior to this Interval: 0.99987206		
Probability of System Failure During this Interval: 2.436×10^{-6}		
MAJOR CONTRIBUTOR	SYSTEM PROBABILITY	PERCENT
Recirculation Ht. Exch.	2.400×10^{-6}	98.5
Auxiliary Transformer C	7.226×10^{-9}	0.3

<u>SUMMARY</u>		
Probability of System Success: 0.99986962		
MAJOR CONTRIBUTOR	SYSTEM PROBABILITY	PERCENT
S. I. Pump G50A (Start)	4.176×10^{-5}	32.0
S. I. Pump G50B (Start)	4.176×10^{-5}	32.0
Feedwater Pump G-3A	1.468×10^{-5}	11.3
Feedwater Pump G-3B	1.468×10^{-5}	11.3
Auxiliary Transformer C	6.993×10^{-6}	5.4
Main Transformer	6.247×10^{-6}	4.8
Recirculation Ht. Exch.	2.400×10^{-6}	1.8

FIGURE 3.1

SCHEMATIC CROSS-SECTION OF DRESDEN-3 CONTAINMENT

FIGURE 3.2

FUNCTIONAL DIAGRAM - PRIMARY CONTAINMENT

FIGURE 3.3

FUNCTIONAL DIAGRAM - DRYWELL ASSEMBLY

FIGURE 3. 4

FUNCTIONAL DIAGRAM - PRESSURE SUPPRESSION CHAMBER

LEGEND

- = MOTOR OPERATED VALVE
- = " " NORMALLY CLOSED
- = " " NORMALLY OPEN
- = INSTRUMENT INTERLOCKED VALVES

FIGURE 3.6

CONTAINMENT SPRAY COOLING SYSTEM

LEGEND

T = TRANSFORMERS
ACB = AIR CIRCUIT BREAKERS

FIGURE 3.7

SCHEMATIC OF EMERGENCY A-C POWER
SUPPLY FOR CORE SPRAY AND CONTAINMENT COOLING

Note: See Table 3.4 for summary of conditions associated with each curve.

FIGURE 3.8

CONTAINMENT PRESSURE FOR VARIOUS AVAILABLE
ENGINEERED SAFEGUARDS

System Containment
 Subsystem Primary Containment
 Assembly Containment Cooling System
 Function Remove heat from primary containment vessels to preserve containment integrity and reduce driving force for leakage of fission products in the event of a severe accident. Sized to remove all fission product decay heat.

Component ID No.	Component Name	Component Function(s)	Failure Mode(s)	Cause(s) of Failure	Likelihood (No / 10 ⁶ Hrs)	Effect on Subsystem	Effect on System	B Safety Significance	A x B Overall Importance	Remarks (Dependence on redundancy, environmental factors, corrective actions)
SS-1, 2, and 3	Suction Strainer	Prevents debris from entering pump suction	Clogs	Accumulation of debris		Cause pump failure if other two strainers clogged.	Containment pressure might rise above design pressure.	3		Design should attempt to preclude clogging, pool should be checked for construction debris, vent system design should preclude transmission of debris to suppression chamber
			Ruptures.	Corrosion.		Cause pump failure if debris available to flow to pumps.	None unless 2 of 3 pumps fail and alternate pumping string fails to operate.	3		Use corrosion resistant material in strainer design
CCP-11, 12, 13, 21, 22, and 23	Containment Cooling Pump	Supplies water to containment cooling heat exchanger.	Fail to start	Contactors fail to close, pump jammed.		No water to sprays if 2 of 3 pumps fail in both strings.	None unless 2 of 3 pumps fail and alternate pumping string fails to operate	3		Periodically test pumps to exercise contactors and check bearing lubrication
			Fail to continue operation longer than 300 hours	Motor failure, bearings seize.		No water to sprays if 2 of 3 pumps fail in both strings.	None unless 2 of 3 pumps fail and alternate pumping string fails to operate	3		
SWP-11, 12, 21 and 22	Reactor Service Water Pump	Supplies raw water to remove heat from containment cooling heat exchanger	Fail to start	Contactors fail to close, brushes fail.		No cooling of containment.	None if 1 of 2 pumps works.	3		Periodically test pumps to exercise contactors and check bearing lubrication.
			Fail to continue operation longer than 300 hours.	Motor failure, bearings seize		No cooling of containment.	None if 1 of 2 pumps works	3		Periodically test pumps to exercise contactors and check bearing lubrication
MOV-31	Standby String Inlet Valve for Unit 2	Opens to allow use of standby string.	Fail to open.	Valve motor failure, valve binding with corrosion product accumulation.		No spray from standby string.	None if normal string is operable.	3		Exercise valve to clear contacts and valve corrosion product accumulation
MOV-21	Standby String Inlet Valve for Unit 2	Isolates Unit 2 suppression pool.	Fail to open.	Valve designed to fail as-is.		None provides additional water source	None	1		None, inspect to assure valve is closed.

(0) None (2) Minor (4) Major
 (1) Neg (3) Intermediate

FIGURE 3.9

EXAMPLE OF FAILURE MODE AND EFFECTS ANALYSIS

System Containment
 Subsystem Primary Containment
 Assembly Containment Cooling System
 Function Remove heat from primary containment vessels to preserve containment integrity and reduce driving force for leakage of fission products in the event of a severe accident. Sized to remove all fission product decay heat.

Page 2 of 4

Component ID No	Component Name	Component Function(s)	Failure Mode(s)	Cause(s) of Failure	Likelihood (No / 10 ⁶ Hrs)	Effect on Subsystem	Effect on System	B Safety Significance	A x B Overall Importance	Remarks (Dependence on redundancy, environmental factors, corrective actions)
CCX-1 CCX-2	Containment Cooling Heat Exchanger	Cools suppression pool water during accident	Shell rupture Tube leaks	Material failure, corrosion Corrosion		Poor cooling of containment cooling water Loss of containment cooling water to service water system	Poor cooling of containment Decreased cooling radioactivity release to service water	3 2		Test tubes periodically at maximum expected pressure to assure no leaks
SWV-1 SWV-2	Service Water Return Valve	Allows service water to return to river from heat exchanger, provides isolation capability	Fail closed Fail to close	Valve normally open, designed to fail as-is Motor failure.		Loss of cooling None for cooling, uncontrolled release of activity with tube rupture	Loss of cooling if both strings inoperable None for cooling, uncontrolled release of activity with tube rupture	3 1		Inspect to assure that valve is open Exercise valve to assure operability
TTV-11, 12, 21, 22	Test Tap Isolation Valve	Provides means for testing containment cooling flow, isolates cooling system from secondary containment	Fail open	Normally closed hand operated valve		None unless 2nd valve in series is open	None unless 2nd valve in series is open	2		Inspect to assure valve closed
MOV-11 and 23	Drywell Spray Supply Valve	Opens spray water path to drywell, provides isolation with external rupture of spray supply line	Fail closed Fail open	Valve normally open, designed to fail as-is Motor failure		Loss of drywell spray cooling for respective string None on cooling, possible loss of drywell isolation	Drywell pressure higher than design if 3 other spray water paths blocked Leaky containment if spray supply line ruptured	3 2		Inspect to assure proper position. Exercise and inspect for final position

(0) None (2) Minor (4) Major
 (1) Neg. (3) Intermediate

FIGURE 3.9 (continued)

System Containment
 Subsystem Primary Containment
 Assembly Containment Cooling System
 Function See Page 1

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Component ID No	Component Name	Component Function(s)	Failure Mode(s)	Cause(s) of Failure	Likelihood (No / 10 ⁶ Hrs)	Effect on Subsystem	Effect on System	B Safety Significance	A x B Overall Importance	Remarks (Dependence on redundancy environmental factors, corrective actions)
MOV-32	Standby Core Spray Unit 3 Inlet Valve	Allows standby spray system water to go to Unit 3	Fail to open	Motor failure		No containment cooling by standby system possible	Overpressure if normal spray system does not work	4		Exercise periodically, provide manual backup to assure capability to open
			Fail to close	Normally closed, fails as-is		None	None	1		
MOV-22	Standby Core Spray Unit 2 Inlet Valve	Prevents standby spray system from going to Unit 2	Fail to close	Normally closed, fails as-is		Insufficient containment cooling by standby spray system	Overpressure if normal spray system does not work	3		Inspect to insure closure
			Fail to open	Motor failure		None	None	0		Should be exercised periodically to assure that standby system is also available for Unit 2
MOV-12 and 24	Suppression Chamber Spray Inlet Valve	Isolates suppression chamber, provides alternate spray path	Fail to close	Normally closed, fails as-is		Reduces spray efficiency in dry well.	None	1		Inspect to assure closure
			Fail to open	Motor failure		Prevents spray cooling if drywell isolated	Containment overpressure if other spray system failed	2		Exercise periodically, provide manual backup for valve operation
DWS-1,2 SCS-1,2	Spray Header	Distribute spray water	Plugged	Debris in lines		No cooling if other 3 headers plugged	Some overpressure	2		Test by air flow
			Leaks	Corrosion or poor assembly		Reduced efficiency	None	0		Inspect and test with water on initial installation
TTV-13, 14, 23 and 24	Spray Header Test Valve	Permit spray header test, prevent spraywater leakage	Fail open	Left open		Poor spray cooling	Some overpressure	2		Inspect periodically to assure valve closed, provide lock on valve
			Fail closed	Normally closed		None	None	0		

(0) None (2) Minor (4) Major
 (1) Neg. (3) Intermediate

FIGURE 3. 9 (continued)

System Containment
 Subsystem Primary Containment
 Assembly Containment Cooling System
 Function See Page 1

Component ID No	Component Name	Component Function(s)	Failure Mode(s)	Cause(s) of Failure	Likelihood (No / 10 ⁶ Hrs)	Effect on Subsystem	Effect on System	B Safety Significance	A x B Overall Importance	Remarks (Dependence on redundancy environmental factors, corrective actions)
STV-11, -21	Spray Test Valve	Permit spray flow test, prevent spray water diversion	Fail open	Motor operated valve fails as-is, normally closed-spurious signal		No spray cooling	Overpressure	3		Inspect to assure closed position, provide key locked switch to assure normally closed position
			Fail closed	Motor failure, normally closed		None	None	0		
DPM	Drywell Pressure Monitor Trip	Actuates spray system	Fail to trip	Relay failure		No automatic spray cooling	None if manual trip works	3		Test periodically, provide failure alarms on sensors
			Trip spuriously	Relay failure		None	None	0		May cause water damage and shutdown
RWL	Reactor Low Level Trip	Actuates spray system	Fail to trip	Relay failure		No automatic spray cooling	None if manual trip works	3		Test periodically, provide failure alarms on sensors
			Trip spuriously	Relay failure		None	None	0		May cause water damage and shutdown
MSS-11 -21	Manual Trip	Actuates spray system	Fail to trip	Operator error, relay failure		No normal spray cooling	Overpressure	4		Test periodically
			Trip spuriously	Operator error		None	None	0		Cause water damage and shutdown
SAT	Standby Automatic Trip	Actuates standby spray	Fail to trip	Relay failure		No standby spray cooling	None if manual trip works			Test with spray system test by actual shutdown of normal system
			Trip spuriously	Relay failure		None	None	0		Cause water damage

(0) None (2) Minor (4) Major
 (1) Neg. (3) Intermediate

FIGURE 3.9 (continued)

FIGURE 3.10

RELIABILITY BLOCK DIAGRAM
CONTAINMENT ISOLATION AND COOLING
INTERVAL 1

FIGURE 3.10 (continued)

CONTAINMENT
SPRAY LOOP
ALIGNMENT

FIGURE 3.10 (continued)

FIGURE 3.10 (continued)

POWER SUPPLY SOURCES

FIGURE 3.10 (continued)

CORE SPRAY LOOP ALIGNMENT

FIGURE 3. 11

RELIABILITY BLOCK DIAGRAM
CORE SPRAY - INTERVAL 1
(REDUNDANT OPERATION)

FIGURE 3.11 (continued)

FIGURE 3.12

RELIABILITY BLOCK DIAGRAM
 CONTAINMENT COOLING
 INTERVAL 2

FIGURE 3.13

RELIABILITY BLOCK DIAGRAM
CORE SPRAY - INTERVAL 2
(REDUNDANT OPERATION)

FIGURE 3.14

RELIABILITY BLOCK DIAGRAM
CORE SPRAY - INTERVAL 1
(BOTH LOOPS REQUIRED)

FIGURE 3.15

RELIABILITY BLOCK DIAGRAM
CORE SPRAY - INTERVAL 2
(BOTH LOOPS REQUIRED)

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AUTOMATIC RELIABILITY MATH MODEL			PAGE	1
DRESDEN 3 PRIMARY CONTAINMENT CASE 2			00000000, 1900	0000-00
PRIMARY CONTAINMENT CASE 2 CONSIDERS PRIM. CONT. CASE 1 AND CORE SPRAY CASE 1 TOGETHER TWO TIME INTERVALS CONSIDERED INTERVAL 1 ISOLATION AND INITIATION PHASE AT END OF 30 DAYS INTERVAL 2 CONTINUED COOLING FOR 300 HR VALVES,BREAKERS AND SWITCHES NOT CONSIDERED TO FAIL IN INTERVAL 2 IF OPERATED PROPERLY IN INTERVAL 1				
NUMBER OF COMPONENTS 204	NUMBER OF TIME INTERVALS 2	LENGTH OF MISSION 1020.000		
NUMBER OF FUNCTIONS 56	NUMBER OF INTEGRATION INTERVALS 10	PRINT-OUT INDICATOR 1		
MAXIMUM NUMBER OF COMPONENTS FAILED AT A TIME 2	REINITIALIZE INDICATOR 0			

FIGURE 3.16
AUTOMATIC RELIABILITY MATHEMATIC MODEL
DRESDEN-3 PRIMARY CONTAINMENT-CASE 2

DRESDEN 3 PRIMARY CONTAINMENT CASE 2

00000000, 1900 0000-00

SUMMARY

PROBABILITY OF SYSTEM FAILURE = 0.29782989E-03

PROBABILITY OF SYSTEM SUCCESS = 0.99970216

FUNCTION ID	FUNCTION NAME	PROBABILITY OF FUNCTION FAILURE	PERCENT OF SYSTEM FAILURE	RANK
10	DRYWELL HEAD SEAL	0.46850535E-12	0.000	33
15	EQUIP HATCH SEAL 1	0.46850535E-12	0.000	34
20	EQUIP HATCH SEAL 2	0.46850535E-12	0.000	35
30	PERSONNEL LOCK 2	0.51535777E-10	0.000	29
35	ACCESS PORT SEAL 1	0.46850535E-12	0.000	36
40	ACCESS PORT SEAL 2	0.46850535E-12	0.000	37
45	DRYWELL STACK VENT	0.11712220E-08	0.000	19
50	SUP CHBK VAC RLF	0.46847194E-08	0.002	12
55	SUP CHBR STACK VNT	0.11712220E-08	0.000	20
60	DRYWELL VENT INLET	0.11712220E-08	0.000	21
65	PRIM STEAM LINE 1	0.11708426E-06	0.039	5
70	PRIM STEAM LINE 2	0.11708426E-06	0.039	6
75	PRIM STEAM LINE 3	0.11708426E-06	0.039	7
80	PRIM STEAM LINE 4	0.11708426E-06	0.039	8
85	STEAM COND. DRAIN	0.65070213E-06	0.218	3
90	EQUIP DRAIN SUMP	0.46847194E-08	0.002	13
95	FLOOR DRAIN SUMP	0.46847194E-08	0.002	14
100	RECIRC TO CLEANUP	0.11708426E-06	0.039	9
105	CLEANUP RETURN	0.23412639E-06	0.079	4
110	RECIRC CW SUPPLY 1	0.14055069E-09	0.000	23
115	RECIRC CW SUPPLY 2	0.14055069E-09	0.000	24
120	RECIRC CW RETURN 1	0.14055069E-09	0.000	25
125	RECIRC CW RETURN 2	0.14055069E-09	0.000	26
130	ISOL COND INLET	0.11708426E-06	0.039	10
135	ISOL COND OUTLET	0.23420984E-08	0.001	18

FIGURE 3.16 (continued)

DRESDEN 3 PRIMARY CONTAINMENT CASE 2

00000000, 1900 0000-00

SUMMARY

FUNCTION ID	FUNCTION NAME	PROBABILITY OF FUNCTION FAILURE	PERCENT OF SYSTEM FAILURE	RANK
140	SUCTION STRAINER	0.33732044E-15	0.000	40
170	CONT COOL BUS SPWR	0.43163149E-10	0.000	30
-175	CONT COOL VALVES	0.17040808E-03	57.217	1
-180	CONT COOL ACTUATE	0.49397111E-13	0.000	39
-185	CONT COOL PUMP	0.30741719E-08	0.001	16
-190	SERVICE WTR PUMP	0.30741719E-08	0.001	17
-195	CONT COOL SPRAY	0.24990593E-10	0.000	31
-230	CORE SPRAY VALVES	0.12577020E-03	42.229	2
-235	VALVE ACTUATE	0.69597484E-10	0.000	27
-240	PUMP ACTUATE	0.69597484E-10	0.000	28
-245	CORE SPRAY PUMP	0.43383906E-08	0.001	15
-270	CONT COOL PUMP ON	0.71309667E-09	0.000	22
-275	SERVICE WTR PUMPO	0.71168031E-12	0.000	32
-285	CORE SPRAY ON	0.13333664E-12	0.000	38
290	COOL PERIOD PWR	0.32349380E-07	0.011	11

COMPONENT COMBINATIONS		MAJOR CONTRIBUTORS TO SYSTEM UNRELIABILITY	PERCENT
		PROBABILITY	
152	240	0.20904720E-04	6.3435
152	238	0.11624881E-04	3.5276
152	216	0.11624881E-04	3.5276
150	240	0.11624881E-04	3.5276
154	240	0.11624881E-04	3.5276
152	328	0.11624881E-04	3.5276
152	242	0.11624881E-04	3.5276
152	220	0.11624881E-04	3.5276
294	240	0.11624881E-04	3.5276
150	220	0.64644687E-05	1.9616

FIGURE 3.16 (continued)

DRESDEN 3 PRIMARY CONTAINMENT CASE 2

00000000, 1900 0000-00

SUMMARY

COMPONENT CONTRIBUTIONS TO UNRELIABILITY

COMPONENT ID	NAME	FAILURE RATE*10**6	SERIAL PROBABILITY	SERIAL PERCENT	SERIAL RANK	SYSTEM PROBABILITY	SYSTEM PERCENT	SYSTEM RANK
10.00	DRYWELL HEAD SEAL1	0.00	0.65394789E-06	0.0004	122	0.23425270E-12	0.0000	150
12.00	DRYWELL HEAD SEAL2	0.00	0.65394789E-06	0.0004	123	0.23425270E-12	0.0000	151
14.00	EQUIP HATCH SEAL11	0.00	0.65394789E-06	0.0004	124	0.23425270E-12	0.0000	152
16.00	EQUIP HATCH SEAL12	0.00	0.65394789E-06	0.0004	125	0.23425270E-12	0.0000	153
18.00	EQUIP HATCH SEAL21	0.00	0.65394789E-06	0.0004	126	0.23425270E-12	0.0000	154
20.00	EQUIP HATCH SEAL22	0.00	0.65394789E-06	0.0004	127	0.23425270E-12	0.0000	155
36.00	ACCESS PORT SEAL11	0.00	0.65394789E-06	0.0004	128	0.23425270E-12	0.0000	156
38.00	ACCESS PORT SEAL21	0.00	0.65394789E-06	0.0004	129	0.23425270E-12	0.0000	157
40.00	ACCESS PORT SEAL21	0.00	0.65394789E-06	0.0004	130	0.23425270E-12	0.0000	158
42.00	ACCESS PORT SEAL22	0.00	0.65394789E-06	0.0004	131	0.23425270E-12	0.0000	159
44.00	ADV-100	0.05	0.32697394E-04	0.0134	85	0.58561105E-09	0.0002	85
46.00	ADV-200	0.05	0.32697394E-04	0.0134	86	0.58561105E-09	0.0002	86
48.00	CV-200	0.10	0.65394788E-04	0.0368	76	0.23423600E-08	0.0008	74
50.00	ADV-201	0.10	0.65394738E-04	0.0368	77	0.23423600E-08	0.0008	75
52.00	ADV-202	0.05	0.32697394E-04	0.0184	87	0.58561105E-09	0.0002	87
54.00	ADV-203	0.05	0.32697394E-04	0.0184	88	0.58561105E-09	0.0002	88
56.00	ADV-204	0.05	0.32697394E-04	0.0184	89	0.58561105E-09	0.0002	89
58.00	ADV-205	0.05	0.32697394E-04	0.0184	90	0.58561105E-09	0.0002	90
60.00	MOV-100	0.50	0.32697394E-03	0.1840	55	0.58542139E-07	0.0197	49
62.00	MOV-202	0.50	0.32697394E-03	0.1840	56	0.58542139E-07	0.0197	50
64.00	MOV-101	0.50	0.32697394E-03	0.1840	57	0.58542139E-07	0.0197	51
66.00	MOV-203	0.50	0.32697394E-03	0.1840	58	0.58542139E-07	0.0197	52
68.00	MOV-102	0.50	0.32697394E-03	0.1840	59	0.58542139E-07	0.0197	53
70.00	MOV-204	0.50	0.32697394E-03	0.1840	60	0.58542139E-07	0.0197	54
72.00	MOV-103	0.50	0.32697394E-03	0.1840	61	0.58542139E-07	0.0197	55
74.00	MOV-205	0.50	0.32697394E-03	0.1840	62	0.58542139E-07	0.0197	56
76.00	MOV-104	0.00	0.65394739E-06	0.0004	132	0.65070220E-06	0.2185	22
78.00	ADV-206	0.10	0.65394788E-04	0.0368	78	0.23423600E-08	0.0008	76
80.00	ADV-207	0.10	0.65394788E-04	0.0368	79	0.23423600E-08	0.0008	77

FIGURE 3.16 (continued)

DRESDEN 3 PRIMARY CONTAINMENT CASE 2

00000000, 1900 0000-00

SUMMARY

COMPONENT CONTRIBUTIONS TO UNRELIABILITY

COMPONENT ID	NAME	FAILURE RATE*10**6	SERIAL PROBABILITY	SERIAL PERCENT	SERIAL RANK	SYSTEM PROBABILITY	SYSTEM PERCENT	SYSTEM RANK
82.00	MOV-208	0.10	0.65394738E-04	0.0368	80	0.23423600E-08	0.0008	78
84.00	MOV-209	0.10	0.65394738E-04	0.0368	81	0.23423600E-08	0.0008	79
86.00	MOV-109	0.50	0.32697394E-03	0.1840	63	0.58542139E-07	0.0197	57
88.00	MOV-211	0.50	0.32697394E-03	0.1840	64	0.58542139E-07	0.0197	58
90.00	CV-100	1.00	0.65394789E-03	0.3680	50	0.15608427E-05	0.0524	45
92.00	MOV-212	0.50	0.32697394E-03	0.1840	65	0.73042137E-07	0.0262	46
94.00	MOV-110	0.01	0.65394738E-05	0.0037	91	0.70275353E-10	0.0000	111
96.00	MOV-213	0.01	0.65394738E-05	0.0037	92	0.23425118E-10	0.0000	128
98.00	MOV-214	0.01	0.65394738E-05	0.0037	93	0.23425118E-10	0.0000	124
100.00	MOV-215	0.01	0.65394738E-05	0.0037	94	0.23425118E-10	0.0000	130
102.00	MOV-111	0.01	0.65394738E-05	0.0037	95	0.70275353E-10	0.0000	112
104.00	MOV-216	0.01	0.65394738E-05	0.0037	96	0.23425118E-10	0.0000	131
106.00	MOV-217	0.01	0.65394738E-05	0.0037	97	0.23425118E-10	0.0000	132
108.00	MOV-218	0.01	0.65394738E-05	0.0037	98	0.23425118E-10	0.0000	133
110.00	MOV-112	0.01	0.65394738E-05	0.0037	99	0.70275353E-10	0.0000	113
112.00	MOV-219	0.01	0.65394738E-05	0.0037	100	0.23425118E-10	0.0000	134
114.00	MOV-220	0.01	0.65394738E-05	0.0037	101	0.23425118E-10	0.0000	135
116.00	MOV-221	0.01	0.65394738E-05	0.0037	102	0.23425118E-10	0.0000	136
118.00	MOV-113	0.01	0.65394738E-05	0.0037	103	0.70275353E-10	0.0000	114
120.00	MOV-222	0.01	0.65394738E-05	0.0037	104	0.23425118E-10	0.0000	137
122.00	MOV-223	0.01	0.65394738E-05	0.0037	105	0.23425118E-10	0.0000	138
124.00	MOV-224	0.01	0.65394738E-05	0.0037	106	0.23425118E-10	0.0000	139
126.00	MOV-114	0.50	0.32697394E-03	0.1840	66	0.58542139E-07	0.0197	54
128.00	MOV-226	0.50	0.32697394E-03	0.1840	67	0.58542139E-07	0.0197	50
130.00	MOV-116	0.50	0.32697394E-03	0.1840	68	0.22961751E-04	0.0008	80
132.00	MOV-227	0.01	0.65394738E-05	0.0037	107	0.45923502E-10	0.0000	115
150.00	DRYWELL PRESS TRIP	0.10	0.65394738E-04	0.0368	82	0.16802122E-12	0.0000	160
158.00	WATER LEVEL TRIP	0.10	0.65394738E-04	0.0368	83	0.16802122E-12	0.0000	161
160.00	MAN START SWITCH	0.01	0.65394738E-05	0.0037	108	0.33604243E-13	0.0000	171

FIGURE 3.16 (continued)

DRESDEN 3 PRIMARY CONTAINMENT CASE 2

00000000, 1900 0000-00

SUMMARY

COMPONENT CONTRIBUTIONS TO UNRELIABILITY

COMPONENT ID	NAME	FAILURE RATE*10**6	SERIAL PROBABILITY	SERIAL PERCENT	SERIAL RANK	SYSTEM PROBABILITY	SYSTEM PERCENT	SYSTEM RANK
346.00	AUTO VLV SWITCH	5.00	0.	0.	0	0.29086388E-10	0.0000	125
348.00	CSPM BKR	5.00	0.	0.	0	0.22953065E-09	0.0001	102
350.00	CORE SPRAY PP MOTR	10.00	0.	0.	0	0.72095972E-09	0.0002	81
352.00	CORE SPRAY PP	10.00	0.	0.	0	0.72095972E-09	0.0002	82
354.00	CSPM BKR	5.00	0.	0.	0	0.22953065E-09	0.0001	103
356.00	CORE SPRAY PP MOTR	10.00	0.	0.	0	0.72095972E-09	0.0002	83
358.00	CORE SPRAY PP	10.00	0.	0.	0	0.72095972E-09	0.0002	84
392.00	CS PMP MOTR ON	5.00	0.13623914E-02	0.7667	41	0.16667081E-13	0.0000	172
394.00	CORE SPRAY PMP ON	5.00	0.13623914E-02	0.7667	42	0.16667081E-13	0.0000	173
396.00	CS PMP MOTR ON	5.00	0.13623914E-02	0.7667	43	0.16667081E-13	0.0000	174
398.00	CORE SPRAY PMP ON	5.00	0.13623914E-02	0.7667	44	0.16667081E-13	0.0000	175
400.00	CS MPM PMPK ON	5.00	0.	0.	0	0.16667081E-13	0.0000	176
402.00	CORE SPRAY PMP ON	5.00	0.	0.	0	0.16667081E-13	0.0000	177
404.00	CS PMP MOTR ON	5.00	0.	0.	0	0.16667081E-13	0.0000	178
406.00	CORE SPRAY PMP ON	5.00	0.	0.	0	0.16667081E-13	0.0000	179
408.00	34.5 KV LINE ON	10.00	0.27247829E-02	1.5335	30	0.77007144E-08	0.0026	71
410.00	TRANSFORMER 8 ON	5.00	0.13623914E-02	0.7667	45	0.23454976E-08	0.0008	73
412.00	DIESEL GEN ON	9.00	0.24523046E-02	1.3801	31	0.11152539E-07	0.0037	67
414.00	345 KV GRID ON	0.00	0.27247829E-06	0.0002	136	0.21195964E-15	0.0000	185
416.00	TRANSFORMER 3 ON	9.00	0.24523046E-02	1.3801	32	0.11150631E-07	0.0037	68
22.00	PER LOCK DOOR 11	0.01	0.65394788E-05	0.0037	113	0.27684356E-10	0.0000	126
24.00	LOCK DOOR SEAL 11	0.01	0.65394788E-05	0.0037	114	0.12850369E-15	0.0000	186
26.00	LOCK DOOR SEAL 12	0.01	0.65394788E-05	0.0037	115	0.12850369E-15	0.0000	187
28.00	PER LOCK DOOR 21	0.01	0.65394788E-05	0.0037	116	0.23425230E-10	0.0000	127
30.00	DOOR INTERLOCK	0.00	0.65394789E-06	0.0004	135	0.42591422E-12	0.0000	148
32.00	LOCK DOOR SEAL 21	0.01	0.65394788E-05	0.0037	117	0.11244076E-15	0.0000	188
34.00	LOCK DOOR SEAL 22	0.01	0.65394788E-05	0.0037	118	0.11244076E-15	0.0000	189
134.00	SUCTION STRAINER 1	0.01	0.65394788E-05	0.0037	119	0.11244015E-15	0.0000	190
136.00	SUCTION STRAINER 2	0.01	0.65394788E-05	0.0037	120	0.11244015E-15	0.0000	191
138.00	SUCTION STRAINER 3	0.01	0.65394788E-05	0.0037	121	0.11244015E-15	0.0000	192
TOTAL SERIAL UNRELIABILITY			0.17768814E 00					

FIGURE 3.16 (continued)

DRESDEN 3 PRIMARY CONTAINMENT CASE 2

J0000000, 1900 0000-00

SUMMARY

COMPONENT CONTRIBUTIONS TO UNRELIABILITY

COMPONENT ID	NAME	FAILURE RATE*10**6	SERIAL PROBABILITY	SERIAL PERCENT	SERIAL RANK	SYSTEM PROBABILITY	SYSTEM PERCENT	SYSTEM RANK
144.00	SPRAY TEST VLV BKR	1.00	0.65394789E-03	0.3680	53	0.15256264E-05	0.5122	16
146.00	SPRAY TEST VLV	0.01	0.65394788E-05	0.0037	112	0.28867524E-09	0.0001	100
148.00	CONT COOL EXCHANGR	0.10	0.92642616E-04	0.0521	75	0.23810471E-07	0.0080	61
150.00	BUS5-T6 BKR	5.00	0.32697394E-02	1.8402	23	0.27579226E-04	9.2601	3
152.00	TRANSFORMER 6	9.00	0.58855310E-02	3.3123	13	0.61363136E-04	20.6034	1
154.00	T6-BUS2A BKR	5.00	0.32697394E-02	1.8402	24	0.27579226E-04	9.2601	4
216.00	MUV-31 BKR	5.00	0.	0.	0	0.11915530E-04	4.0008	9
218.00	STDBY LOOP SUC VLV	0.50	0.	0.	0	0.25475607E-06	0.0855	37
220.00	MUV-32 BKR	5.00	0.	0.	0	0.11915530E-04	4.0008	10
222.00	STDBY LOOP DIS VLV	0.50	0.	0.	0	0.25475607E-06	0.0855	38
224.00	MUV-22 BKR	1.00	0.	0.	0	0.87171913E-06	0.2927	19
226.00	STDBY LOOP ISOLVLV	0.01	0.	0.	0	0.16236259E-09	0.0001	104
228.00	STV-21 BKR	1.00	0.	0.	0	0.87171913E-06	0.2927	20
230.00	SPRAY TEST VLV	0.01	0.	0.	0	0.16236259E-09	0.0001	105
232.00	SWV-2 BKR	1.00	0.	0.	0	0.87171913E-06	0.2927	21
234.00	SER WTR RTN VLV	0.01	0.	0.	0	0.16236259E-09	0.0001	106
236.00	CONT COOL EXCHANGR	0.10	0.	0.	0	0.13100754E-07	0.0044	65
238.00	BUS6-T7 BKR	5.00	0.	0.	0	0.20146422E-04	6.7644	5
240.00	TRANSFORMER 7	9.00	0.	0.	0	0.45109661E-04	15.1461	2
242.00	T7-BUS2B BKR	5.00	0.	0.	0	0.20146422E-04	6.7644	6
244.00	STDBY AUTO STRT SW	0.10	0.	0.	0	0.11692726E-14	0.0000	181
246.00	MAN START SW	0.10	0.	0.	0	0.11692726E-14	0.0000	182
248.00	CCPM BKR	5.00	0.	0.	0	0.15638201E-09	0.0001	107
250.00	CONT COOL PMP MOTR	10.00	0.	0.	0	0.49532018E-09	0.0002	91
252.00	CONT COOL PMP	10.00	0.	0.	0	0.49532018E-09	0.0002	92
254.00	CCPM BKR	5.00	0.	0.	0	0.15638201E-09	0.0001	108
256.00	CONT COOL PMP MOTR	10.00	0.	0.	0	0.49532018E-09	0.0002	93
258.00	CONT COOL PMP	10.00	0.	0.	0	0.49532018E-09	0.0002	94
260.00	SER WTR PP MTR BKR	5.00	0.	0.	0	0.15638201E-09	0.0001	109

FIGURE 3.16 (continued)

DRESDEN 3 PRIMARY CONTAINMENT CASE 2

00000000, 1900 0000-00

SUMMARY

COMPONENT CONTRIBUTIONS TO UNRELIABILITY

COMPONENT ID	NAME	FAILURE RATE*10**6	SERIAL PROBABILITY	SERIAL PERCENT	SERIAL RANK	SYSTEM PROBABILITY	SYSTEM PERCENT	SYSTEM RANK
262.00	SER WTR PP MTR	10.00	0.	0.	0	0.49532018E-09	0.0002	95
264.00	SER WTR PP	10.00	0.	0.	0	0.49532018E-09	0.0002	96
266.00	SER WTR PP MTR BKR	5.00	0.	0.	0	0.15638201E-09	0.0001	110
268.00	SER WTR PP MTR	10.00	0.	0.	0	0.49532018E-09	0.0002	97
270.00	SER WTR PP	10.00	0.	0.	0	0.49532018E-09	0.0002	98
272.00	MOV-23 BKR	1.00	0.	0.	0	0.21288046E-11	0.0000	147
274.00	DRYWELL SPRAY VLV	0.01	0.	0.	0	0.23508288E-15	0.0000	184
276.00	DRYWELL SPRAY HDR	0.00	0.	0.	0	0.23586806E-17	0.0000	194
278.00	MOV-24 BKR	5.00	0.	0.	0	0.10725236E-10	0.0000	144
280.00	SUP CHBR SPRAY VLV	0.01	0.	0.	0	0.87469176E-16	0.0000	193
282.00	SUP CHBR SPRAY HDR	0.00	0.	0.	0	0.87733366E-18	0.0000	195
284.00	T8-BUS6 BKR	5.00	0.	0.	0	0.	0.	0
286.00	DGEN-BUS6 BKR	5.00	0.	0.	0	0.	0.	0
288.00	T3-BUS4 BKR	5.00	0.	0.	0	0.	0.	0
290.00	BUS4-BUS6 BKR	5.00	0.	0.	0	0.	0.	0
360.00	CONT COOL PP MTRON	5.00	0.13623914E-02	0.7667	33	0.33070159E-10	0.0000	116
362.00	CONT COOL PP ON	5.00	0.13623914E-02	0.7667	34	0.33070159E-10	0.0000	117
364.00	CONT COOL PP MTRON	5.00	0.13623914E-02	0.7667	35	0.33070159E-10	0.0000	118
366.00	CONT COOL PP ON	5.00	0.13623914E-02	0.7667	36	0.33070159E-10	0.0000	119
368.00	SER WTR PP MTR ON	5.00	0.13623914E-02	0.7667	37	0.33070159E-10	0.0000	120
370.00	SER WTR PP ON	5.00	0.13623914E-02	0.7667	38	0.33070159E-10	0.0000	121
372.00	SER WTR PP MTR ON	5.00	0.13623914E-02	0.7667	39	0.33070159E-10	0.0000	122
374.00	SER WTR PP ON	5.00	0.13623914E-02	0.7667	40	0.33070159E-10	0.0000	123
376.00	CONT COOL PP MTRON	5.00	0.	0.	0	0.14348443E-12	0.0000	162
378.00	CONT COOL PP ON	5.00	0.	0.	0	0.14348443E-12	0.0000	163
380.00	CONT COOL PP MTRON	5.00	0.	0.	0	0.14348443E-12	0.0000	164
382.00	CONT COOL PP ON	5.00	0.	0.	0	0.14348443E-12	0.0000	165
384.00	SER WTR PP MTR ON	5.00	0.	0.	0	0.14348443E-12	0.0000	166
386.00	SER WTR PP ON	5.00	0.	0.	0	0.14348443E-12	0.0000	167

FIGURE 3.16 (continued)

DRESDEN 3 PRIMARY CONTAINMENT CASE 2

00000000, 1900 0000-00

SUMMARY

COMPONENT CONTRIBUTIONS TO UNRELIABILITY

COMPONENT ID	NAME	FAILURE RATE*10**6	SERIAL PROBABILITY	SERIAL PERCENT	SERIAL RANK	SYSTEM PROBABILITY	SYSTEM PERCENT	SYSTEM RANK
388.00	SER WTR PP MTR ON	5.00	0.	0.	0	0.14348443E-12	0.0000	168
390.00	SER WTR PP ON	5.00	0.	0.	0	0.14348443E-12	0.0000	169
306.00	MAN VLV SWITCH	2.00	0.13078958E-02	0.7361	46	0.83322538E-08	0.0028	69
308.00	AUTO VLV SWITCH	5.00	0.32697394E-02	1.8402	25	0.20830634E-07	0.0070	62
310.00	MAN PMP SWITCH	2.00	0.13078958E-02	0.7361	47	0.83322538E-08	0.0028	70
312.00	AUTO PMP SWITCH	5.00	0.32697394E-02	1.8402	26	0.20830634E-07	0.0070	63
314.00	CSPM BKR	5.00	0.32697394E-02	1.8402	27	0.16447568E-06	0.0552	43
316.00	CORE SPRAY PP MOTR	10.00	0.65394788E-02	3.6803	9	0.51646828E-06	0.1734	33
318.00	CORE SPRAY PP	10.00	0.65394788E-02	3.6803	10	0.51646828E-06	0.1734	34
320.00	CSPM BKR	5.00	0.32697394E-02	1.8402	28	0.16440157E-06	0.0552	44
322.00	CORE SPRAY PP MOTR	10.00	0.65394788E-02	3.6803	11	0.51654239E-06	0.1734	31
324.00	CORE SPRAY PP	10.00	0.65394788E-02	3.6803	12	0.51654239E-06	0.1734	32
292.00	RELIEF VLV	2.00	0.13078958E-02	0.7361	48	0.42944786E-05	1.4419	13
294.00	MOV-10 BKR	5.00	0.32697394E-02	1.8402	29	0.17599574E-04	5.9093	8
296.00	SPRAY INLET VLV	0.50	0.32697394E-03	0.1840	69	0.39468931E-06	0.1325	36
298.00	MOV-11 BKR	1.00	0.65394789E-03	0.3680	54	0.13437097E-05	0.4512	18
300.00	SPRAY INLET VLV	0.10	0.65394788E-04	0.0368	84	0.19508176E-07	0.0066	64
302.00	MAN SWITCH	2.00	0.13078958E-02	0.7361	49	0.42944786E-05	1.4419	14
304.00	CORE SPRAY HDR	0.20	0.13078958E-03	0.0736	74	0.72798377E-07	0.0244	48
326.00	RELIEF VLV	2.00	0.	0.	0	0.43573654E-05	1.4630	11
328.00	MOV-20 BKR	5.00	0.	0.	0	0.17825329E-04	5.9851	7
330.00	SPRAY ISOL VLV	0.50	0.	0.	0	0.40486960E-06	0.1359	35
332.00	MOV-21 BKR	1.00	0.	0.	0	0.13687662E-05	0.4596	17
334.00	SPRAY INLET VLV	0.01	0.	0.	0	0.23039947E-09	0.0001	101
336.00	MAN VLV SWITCH	2.00	0.	0.	0	0.43573654E-05	1.4630	12
338.00	CORE SPRAY HDR	0.20	0.	0.	0	0.75731236E-07	0.0254	47
340.00	MAN VLV SWITCH	2.00	0.	0.	0	0.11634555E-10	0.0000	142
342.00	AUTO VLV SWITCH	5.00	0.	0.	0	0.29086388E-10	0.0000	124
344.00	MAN PMP SWITCH	2.00	0.	0.	0	0.11634555E-10	0.0000	143

FIGURE 3.16 (continued)

DRESDEN 3 PRIMARY CONTAINMENT CASE 2

00000000, 1900 0000-00

SUMMARY

COMPONENT CONTRIBUTIONS TO UNRELIABILITY

COMPONENT ID	NAME	FAILURE RATE*10**6	SERIAL PROBABILITY	SERIAL PERCENT	SERIAL RANK	SYSTEM PROBABILITY	SYSTEM PERCENT	SYSTEM RANK
162.00	CCPM BKR	5.00	0.32697394E-02	1.8402	14	0.18311600E-06	0.0615	39
164.00	CONT COOL PMP MTR	10.00	0.65394738E-02	3.6803	1	0.57527821E-06	0.1932	27
166.00	CONT COOL PMP	10.00	0.65394738E-02	3.6803	2	0.57527821E-06	0.1932	28
168.00	CCPM BKR	5.00	0.32697394E-02	1.8402	15	0.18303352E-06	0.0615	41
170.00	CONT COOL PMP MTR	10.00	0.65394738E-02	3.6803	3	0.57536070E-06	0.1932	23
172.00	CONT COOL PMP	10.00	0.65394738E-02	3.6803	4	0.57536070E-06	0.1932	24
174.00	SER WTR PP MTR BKR	5.00	0.32697394E-02	1.8402	16	0.18311600E-06	0.0615	40
176.00	SER WTR PP MTR	10.00	0.65394738E-02	3.6803	5	0.57527821E-06	0.1932	29
178.00	SER WTR PP	10.00	0.65394738E-02	3.6803	6	0.57527821E-06	0.1932	30
180.00	SER WTR PP MTR BKR	5.00	0.32697394E-02	1.8402	17	0.18303352E-06	0.0615	42
182.00	SER WTR PP MTR	10.00	0.65394738E-02	3.6803	7	0.57536070E-06	0.1932	25
184.00	SER WTR PP	10.00	0.65394738E-02	3.6803	8	0.57536070E-06	0.1932	26
186.00	MCV-11 BKR	1.00	0.65394789E-03	0.3680	51	0.25535184E-08	0.0009	72
188.00	DRYWELL SPRAY VLV	0.01	0.65394738E-05	0.0037	109	0.28372733E-12	0.0000	149
190.00	DRYWELL SPRAY HDR	0.00	0.65394789E-06	0.0004	133	0.28412187E-14	0.0000	180
192.00	MCV-12 BKR	5.00	0.32697394E-02	1.8402	18	0.12862219E-07	0.0043	66
194.00	SUP CHBR SPRAY VLV	0.01	0.65394738E-05	0.0037	110	0.11167798E-12	0.0000	170
196.00	SUP CHBR SPRAY HDR	0.00	0.65394789E-06	0.0004	134	0.11208860E-14	0.0000	183
198.00	34.5 KV LINE	0.40	0.26157915E-03	0.1472	70	0.71942184E-11	0.0000	145
200.00	TRANSFORMER 8	0.40	0.26157915E-03	0.1472	71	0.71942184E-11	0.0000	146
202.00	T8-BUS5 BKR	5.00	0.32697394E-02	1.8402	19	0.	0.	0
204.00	DIESEL GENERATOR	0.40	0.26157915E-03	0.1472	72	0.14388437E-10	0.0000	140
206.00	DGEN-BUS5 BKR	5.00	0.32697394E-02	1.8402	20	0.	0.	0
208.00	34.5 KV GRID	0.00	0.26157915E-07	0.0000	137	0.21581446E-18	0.0000	196
210.00	TRANSFORMER 3	0.40	0.26157915E-03	0.1472	73	0.14386279E-10	0.0000	141
212.00	T3-BUS3 BKR	5.00	0.32697394E-02	1.8402	21	0.	0.	0
214.00	BUS3-BUS5 BKR	5.00	0.32697394E-02	1.8402	22	0.	0.	0
140.00	SERV WTR VLV BKR	1.00	0.65394789E-03	0.3680	52	0.15256264E-05	0.5122	15
142.00	SERV WTR RTN VLV	0.01	0.65394738E-05	0.0037	111	0.28867524E-09	0.0001	99

FIGURE 3.16 (continued)

FIGURE 3.18

SCHEMATIC FLOW DIAGRAM
RESIDUAL HEAT REMOVAL SECONDARY WATER SYSTEM
CONNECTICUT YANKEE

S.I. SAFETY INJECTION
 S.S. STATION SERVICE
 TRANS TRANSFORMER

FIGURE 3.19

115 KV/4160 VOLT SCHEMATIC DIAGRAM
FOR SAFETY INJECTION SYSTEM

FIGURE 3.20

480 VOLT SCHEMATIC DIAGRAM
FOR SAFETY INJECTION SYSTEM

FIGURE 3. 21

SCHEMATIC DIAGRAM

FIGURE 3.22

LOSS-OF-COOLANT INCIDENT
3-INCH CHARGING LINE BREAK

System Safety Injection
 Subsystem Primary Water
 Assembly
 Function Deliver borated water to reactor vessel for cooling reactor core following a loss-of-coolant accident

Component ID No	Component Name	Component Function(s)	Failure Mode(s)	Cause(s) of Failure	Likelihood (No / 10 ⁶ Hrs)	Effect on Subsystem	Effect on System	B Safety Significance	A x B Overall Importance	Remarks (Dependence on redundancy, environmental factors, corrective actions)
TK-4-1A	Refueling Water Storage Tank	Water storage for refueling and safety injection	Fail to hold adequate water supply	Tank rupture, debris, low level, freeze	0 1	No water supply	Complete system failure	1	0 1	Inspect interior of tank for corrosion and debris Periodically test level indicator and heating unit
P-14-1A and 1B	Residual Heat Removal Pump (2)	Supply water to residual heat exchanger	Fail to start	Contactors failed to close, pump jammed	10	No water recirculation from containment sump	None unless both pumps fail	1	10	1-out-of-2 redundancy Periodically test pumps to exercise contactors and check bearing lubrication
			Fail to continue running	Motor failure, bearing seizure	5	No water recirculation from containment sump	None unless both pumps fail	1	5	Periodically test pumps to exercise contactors and check bearing lubrication
P-15-1A and 1B	Safety Injection Pump (2)	Supply water to safety injection loop	Fail to start	Contactors failed to close, pump jammed	10	No water in safety injection loop	None unless both pumps fail	1	10	1-out-of-2 redundancy Periodically test pumps to exercise contactors and check bearing lubrication
			Fail to continue running	Motor failure, bearing seizure	5	No water in safety injection loop	None unless both pumps fail	1	5	Periodically test pumps to exercise contactors and check bearing lubrication
P-18-1A and 1B	Charge Pump (2)	Supply water to charge line loop	Fail to start	Contactors failed to close pump jammed	10	No water in charge line loop	None unless both pumps fail	1/6	1 5	1-out-of-2 redundancy Periodically test pumps to exercise contactors and check bearing lubrication
			Fail to continue running	Motor failure bearing seizure	5	No water in charge line loop	None unless both pumps fail	1/6	0 75	Periodically test pumps to exercise contactors and check bearing lubrication
ST-MOV-24	Refueling Water Supply Valve	Allow flow to safety injection, charge, and residual heat removal pumps	Fail to open	Motor failure, valve binding Designed to fail as-is	10	No water supply	Complete system failure	1	10	Exercise valve to assure operability, provide redundant valve in parallel
SI-MOV-B61A B, C and D	Safety Injection Isolation Valve (4)	Allow flow into reactor coolant loop	Fail closed	Normally closed	10	Loss of safety injection	None unless 2 or more fail	1	10	3-out-of-4 redundancy Exercise valve to assure operability

FIGURE 3. 23

FAILURE MODE AND EFFECT ANALYSES

System Safety Injection
Subsystem Primary Water
Assembly
Function Deliver borated water to reactor vessel for cooling reactor core following a loss-of-coolant accident.

Page 2 of 6

Component ID No	Component Name	Component Function(s)	Failure Mode(s)	Cause(s) of Failure	Likelihood (No / 10 ⁶ Hrs)	Effect on Subsystem	Effect on System	B Safety Significance	A x B Overall Importance	Remarks (Dependence on redundancy, environmental factors, corrective actions)
BA-MOV-257	Volume Control Valve	Stop flow from volume control tank.	Fail open	Normally open, designed to fail-as-is	10	Draw water from small volume control tank.	None unless impossible to close manually	1/6	1.5	Exercise valve to assure operability
BA-MOV-373	Charge Pump Suction Valve	Allow flow to charge pump.	Fail closed	Normally closed.	10	Loss of charge line injection.	None unless impossible to close manually.	1/6	1.5	Exercise valve to assure operability.
	Charge Line Control Valve	Allow flow to charge line.	Fail closed.	Normally open, designed to fail open.	5	Loss of charge line injection	None unless impossible to close manually.	1/6	1.0	Exercise valve to assure operability.
CL-VV-290 and 292	Charge Line Isolation Valve (2)	Allow flow into reactor coolant loop.	Fail closed	Normally closed, designed to fail-as-is.	10	Loss of charge line injection	None unless both valves fail.	1/6	1.5	1-out-of-2 redundancy. Exercise valve to assure operability.
RH-MOV-21	Residual Heat Removal Pump Suction Valve	Control flow to residual heat removal pump from water storage tank	Fail open.	Normally open.	10	Draw water from storage tank instead of containment sump.	Deplete water supply if not completely closed	1/2	5	Exercise valve to assure operability, provide redundant valve in parallel
RH-MOV-22	Containment Sump Valve	Control flow to residual heat removal pump.	Fail closed.	Normally closed	10	No recirculation of water.	Deplete water supply.	1	10	Exercise valve to assure operability, provide redundant valve in parallel.
RH-MOV-374	Safety Injection Recirculation Valve	Control flow of recirculation water	Fail closed.	Normally closed.	10	No recirculation of water.	Deplete water supply.	1	10	Exercise valve to assure operability, provide redundant valve in parallel.
	Residual Heat Throttle	Control flow of residual heat removal loop.	Fail to open.	No signal, valve failure	10	No flow for core deluge.	None unless low pressure safety injection required	1	10	Exercise valve to assure operability, provide redundant valve in parallel
	Residual Heat Bypass Valve	Control flow to bypass residual heat exchangers	Fail to open.	No signal, valve failure.	10	No flow for core deluge	None unless low pressure safety injection required	1/2	5	Exercise valve to assure operability

FIGURE 3.23 (continued)

System Safety Injection
 Subsystem Primary Water
 Assembly
 Function Deliver borated water to reactor vessel for cooling reactor core following a loss-of-coolant accident

Page 3 of 6

Component ID No.	Component Name	Component Function(s)	Failure Mode(s)	Cause(s) of Failure	Likelihood (No / 10 ⁶ Hrs)	Effect on Subsystem	Effect on System	B Safety Significance	A x B Overall Importance	Remarks (Dependence on redundancy, environmental factors, corrective actions)
CD-VV-871A and B	Core Deluge Isolation Valve (2)	Supply water to reactor vessel head.	Fail closed	Normally closed	10	Loss of core deluge	None unless low pressure safety injection required	1	10	1-out-of-2 redundancy Exercise valve to assure operability
	Safety Injection Pump Check Valve (2)	Stop backflow if pump fails	Fail open	Fail to seat properly	1	Loss of head pressure for operating pump (with other pump failed)	None unless one pump fails.	1	1	Inspect valve to assure operability.
	Charge Pump Check Valve (2)	Stop backflow if pump fails	Fail open	Fail to seat properly	1	Loss of head pressure for operating pump (with other pump failed).	None unless one pump fails.	1/6	0 15	Inspect valve to assure operability.
	Residual Heat Pump Check Valve (2)	Stop backflow if pump fails.	Fail open	Fail to seat properly	1	Loss of head pressure for operating pump (with other pump failed).	None unless one pump fails.	1	1	Inspect valve to assure operability.
W-540-F-416A and B	Residual Heat Exchanger (2)	Cool recirculation water.	Shell rupture	Material failure	0.3	No cooling of recirculation water	Loss of cooling capability.	1	0 3	1-out-of-2 redundancy. Inspect shell plate for deterioration
			Tube leak.	Corrosion.		Loss of recirculation water to service water.	Radioactivity released to service water.			Test tubes periodically to assure no leaks

FIGURE 3.23 (continued)

System Safety Injection
 Subsystem Secondary Water
 Assembly
 Function Deliver service water to residual heat exchanger for cooling (primary) recirculating water

Page 4 of 6

Component ID No.	Component Name	Component Function(s)	Failure Mode(s)	Cause(s) of Failure	Likelihood (No / 10 ⁶ Hrs)	Effect on Subsystem	Effect on System	B Safety Significance	A x B Overall Importance	Remarks (Dependence on redundancy, environmental factors, corrective actions)
P-37-1A, B, C, and D	Service Water Pump (4)	Supply service water to shell side of residual heat exchanger.	Fail to continue running.	Motor failure, bearings seizure.	5	Loss of cooling water.	None unless all pumps fail.	1	5	1-out-of-4 redundancy Periodically service pump and check bearing lubrication
SW-MOV-3 and 4	Service Water Valve (2)	Control flow to component cooling heat exchanger .	Fail open	Normally open.	10	Divert cooling water.	None unless both valves fail.	1/2	5	Exercise valve to assure operability
SW-MOV-5 and 6	Service Water Valve (2)	Control flow to residual heat exchanger.	Fail closed	Normally closed.	10	Loss of cooling capability.	None unless both valves fail.	1	10	1-out-of-2 redundancy Exercise valve to assure operability.

FIGURE 3. 23 (continued)

System Safety Injection
 Subsystem Power and Control
 Assembly
 Function Provide power and control to mechanical system.

Page 5 of 6

Component ID No.	Component Name	Component Function(s)	Failure Mode(s)	Cause(s) of Failure	Likelihood (No / 10 ⁶ Hrs)	Effect on Subsystem	Effect on System	B Safety Significance	A x B Overall Importance	Remarks (Dependence on redundancy, environmental factors, corrective actions)
772 and 12500	Power Line	Provide outside power source.	Fail to continue providing power.	Loss of outside power source.	0.1	Complete loss of power and control.	None unless both lines fail.	1	0.1	1-out-of-2 redundancy.
2 and 3	Station Service Transformer(2)	115 KV/4160 volt.	Fail to supply 4160 volt.	Loss of outside power, transformer failure.	5	Complete loss of power and control.	None unless both transformers fail.	1	5	1-out-of-2 redundancy.
4, 5, 6, and 7	Station Service Transformer(4)	4160/480 volt.	Fail to supply 480 volt.	Loss of 4160 volt, transformer failure.	5	Loss of 480 volt power and all control.	None unless Nos. 5 and 6 fail.	1	5	Inspect periodically.
2T3	Bus Tie	Bus tie between 4160 volt buses.	Fail to close.	Loss of automatic switching.	2	Partial loss of 4160 volt (with Transformers 2 or 3 failed).	None unless Transformer 2 or 3 fails.	1	2	Check automatic switching periodically.
4T5, 5T6, and 6T7	Bus Tie (3)	Bus tie between 480 volt buses.	Fail to close.	Switchgear Failure.	2	Partial loss of 480 volt (with Transformers 4 5, 6, or 7 failed).	None unless Buses 5 and 6 are out of power.	1	2	Check switchgear periodically.
EG-1A, B, and C	Emergency Generator (3)	Provide power if outside power fails.	Fail to start.	Diesel engine or starter motor failure, lack of fuel.	1	Loss of 480 volt power.	None unless more than one generator fails.	1	5	Test periodically to assure operability.
			Fail to continue running.	Diesel engine or generator failure, lack of fuel.						
	Automatic Permissive Switch	Unblock automatic operation when reactor coolant pressure is above 1700 psig.	Fail open.	Relay failure.	5	No initiation signal.	No safety injection.	1		Test periodically, provide failure indicator.
	Manual Switch	Allow manual actuation.	Fail to close.	Contactors failed to close.	5	No initiation signal.	None unless automatic operation fails.	1		Test periodically.
			Premature operation.	Operator error.		None.	None.			Reactor shutdown.

FIGURE 3.23 (continued)

System Safety Injection
 Subsystem Power and Control
 Assembly
 Function Provide power and control to mechanical system.

Page 6 of 6

Component ID No	Component Name	Component Function(s)	Failure Mode(s)	Cause(s) of Failure	Likelihood (No / 10 ⁶ Hrs)	Effect on Subsystem	Effect on System	B Safety Significance	A x B Overall Importance	Remarks (Dependence on redundancy, environmental factors, corrective actions)
PS-1, 2, and 3	Pressure Switch (3)	Actuate safety injection signal.	Fail to trip Spurious trip.	Relay failure Relay failure.	15	No initiation signal. None.	None unless manual switch fails. None unless two or more level switches trip spuriously.	1	15	2-out-of-3 redundancy. Test periodically.
LS-1, 2, and 3	Level Switch (3)	Actuate safety injection signal	Fail to trip. Spurious trip	Relay failure. Relay failure	15	No initiation signal. None	None unless manual switch fails. None unless two or more pressure switches trip spuriously.	1	15	2-out-of-3 redundancy Test periodically

FIGURE 3.23 (continued)

- NOTE: (1) TYPICAL FUNCTION I.D. NO. FOR ARMM: REFER TO FIGURE 11.
 (2) FUNCTION NOT REQUIRED FOR CORE DELUGE ONLY (i.e. WITHOUT SAFETY INJECTION)
 (3) FUNCTION NOT REQUIRED FOR HIGH PRESSURE SAFETY INJECTION (i.e. WITHOUT CORE DELUGE)
 (4) FUNCTION NOT REQUIRED FOR LOW PRESSURE SAFETY INJECTION (i.e. WITH CORE DELUGE)
 (5) FUNCTION TO START
 (6) FUNCTION TO CONTINUE RUNNING
 (7) FUNCTION WITHOUT RECIRCULATION

FIGURE 3.24

RELIABILITY BLOCK DIAGRAM
SAFETY INJECTION SYSTEM
CONNECTICUT YANKEE

FIGURE 3.24 (continued)

FIGURE 3.24 (continued)

Figure 3.25

FIGURE 3.25

RELIABILITY BLOCK DIAGRAM
EMERGENCY POWER FOR CORE DELUGE SYSTEM

No. of Components		MAX 500		No. of Time Intervals		TOTAL TIME		FL. PT. No		MAX. No. COMP. PAID AT A TIME		No. of Functions		MAX 300		No. of Integ. Intervals		MAX 1000		PARTIAL DATA TO		No. of Major Contributors to Sys. Load		FORM A		ARMM					
5		10		15		20		25		30		35		40		45		50		55		60		65		70		75		80	
7.2	4	7.44	4	2	5.3	1.0	1		0																						5
7.2	4	7.44	4	2	5.3	1.0	1		1																						10
7.2	4	19.2	4	2	5.3	1.0	1		1																						15
CASE 1... SAFETY INJECTION - CONN. YANKEE																															
CASE 2... SAFETY INJECTION - CONN. YANKEE																															
CASE 3... SAFETY INJECTION - CONN. YANKEE																															
4 - CONNECTICUT YANKEE - LOSS OF COOLANT INCIDENT																															
4 CASE 1... SAFETY INJECTION INITIATED AT THE END OF ONE MONTH TEST																															
4 INTERVAL HIGH PRESSURE RECIRCULATION STARTED AT 6 MINUTES																															
4 AND SWITCHED TO LOW PRESSURE RECIRCULATION AT 24 MINUTES																															
4 AFTER INITIATION, AND CONTINUED FOR 24 HOURS																															
4 CASE 2... SAME AS CASE 1, EXCEPT ALL CRITICAL IN-SERIES VALVES																															
4 ASSUMING 1 OUT OF 2 REDUNDANCIES																															
4 CASE 3... SAME AS CASE 1, EXCEPT TEST INTERVAL SHORTENED TO ONE WEEK																															

FIGURE 3.26

ARMM INPUT LOADSHEETS - CASE 1

ID No. (1st col.) For Study	FUNCTION NAME	No. of Modes Available	No. of Modes Required	No. of Alt Functions	First Alt Function ID	2nd	3rd	4th	5th	6th	7th	8th	9th	FORM B ARMM
5	10	25	30	35	40	45	50	55	60	65	70	75	80	
1	1.05 WATER STORAGE	1	1	0										1.05
1	1.10 WATER SUPPLY	1	1	0										1.10
1	1.15 CHARGE LINE	1	1	0										1.15
1	1.20 SAFETY INJ. RECIRC.	1	1	0										1.20
1	1.25 RES. ID. HEAT. RECIRC.	1	1	0										1.25
1	1.30 CONTAIN. JUMP RECIRC.	1	1	0										1.30
1	1.35 CØRE DELUGE LINE	1	1	0										1.35
1	1.40 R. H. EXCH. BYPASS	1	1	0										1.40
1	1.45 CHARGE LINE DIST.	2	1	0										1.45
1	1.50 CØRE DELUGE DIST.	2	1	0										1.50
1	1.55 SERVICE WATER DIST.	2	1	0										1.55
1	1.60 R. H. PUMP. IAB. - START	2	1	0										1.60
1	1.61 R. H. PUMP. IAB. - RUN	2	1	0										1.61
1	1.62 R. H. PUMP. IAB. - RUN	1	1	1	1.63									1.62
1	1.63 R. H. CHECK VALVE 1.2	1	1	1	1.62									1.63
1	1.65 INJ. PUMP. IAB. - START	2	1	0										1.65
1	1.66 INJ. PUMP. IAB. - RUN	2	1	0										1.66
1	1.67 INJ. PUMP. IAB. - RUN	1	1	1	1.68									1.67
1	1.68 INJ. CHECK VALVE 1.2	1	1	1	1.67									1.68
1	1.70 C.H. PUMP. IAB. - START	2	1	0										1.70
1	1.71 C.H. PUMP. IAB. - RUN	2	1	0										1.71
1	1.72 C.H. PUMP. IAB. - RUN	1	1	1	1.73									1.72
1	1.73 CHARGE SK. VALVE 1.2	1	1	1	1.72									1.73
1	1.75 R. H. EXCH. W/ CØFILING	2	1	0										1.75
1	1.77 R. H. EXCH. W/ CØFIL.	2	1	0										1.77
1	1.80 P.ØW. EIR. 2.3	2	1	0										1.80
1	1.85 P.ØW. EIR. 2.3	1	1	1	1.90									1.85
1,2	3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24	25,26,27,28	29,30,31,32	33,34,35,36	37,38,39,40	41,42,43,44	45,46,47,48	49,50,51,52	53,54,55,56	57,58,59,60	61,62,63,64,65,66,67,68	69,70,71,72	73,74,75,76,77,78,79,80	

FIGURE 3.26 (continued)

ID. No. (1) to col. 3 For Standby	FUNCTION NAME	No. of Modes Available	No. of Modes Required	No. of Alt Functions	First Alt Function ID	2nd	3rd	4th	5th	6th	7th	8th	9th	FORM B ARM
5	10	25	30	35	40	45	50	55	60	65	70	75	80	
1-190	POWER, 2, 3	1	1	1	1, 8, 5									1, 9, 0
1-195	SAFETY, INJ. DIST.	4	3	10										1, 9, 5
1-200	MANUAL OPERATION	1	1	3	2, 0, 5	A, 2, 1, 0	A, 2, 1, 5							2, 0, 0
1-205	AUTOP. OPERATION	1	1	1	2, 0, 0									2, 0, 5
1-210	PRESSURE, SENS. ØR	3	2	1	2, 0, 0									2, 1, 0
1-215	LEVEL, SENS. ØR	3	2	1	2, 0, 0									2, 1, 5
1-220	P.Ø.WER, 4, 5	2	1	1, 5	2, 3, 5	A, 2, 4, 0	A, 2, 4, 5	A, 2, 7, 0	2, 3, 5	A, 2, 4, 0	A, 2, 7, 5	2, 3, 5	A, 2, 4, 0	2, 2, 0
1-225	P.Ø.WER, 4, 5	1	1	1	A, 2, 5, 0	A, 2, 9, 0	2, 5, 5	A, 2, 6, 0	A, 2, 6, 5	A, 2, 8, 0				2, 2, 1
1-230	P.Ø.WER, 6	1	1	1	3, 0, 0									2, 2, 5
1-235	P.Ø.WER, 6	1	1	1	3, 1, 5									2, 3, 0
1-235	P.Ø.WER, 5, 6	2	1	8	2, 2, 0	A, 2, 2, 5	A, 2, 3, 0	A, 2, 7, 0	2, 5, 5	A, 2, 6, 0	A, 2, 6, 5	A, 2, 8, 0		2, 3, 5
1-240	P.Ø.WER, 5, 6	1	1	1	3, 0, 5									2, 4, 0
1-245	P.Ø.WER, 4	1	1	1	3, 2, 0									2, 4, 5
1-250	P.Ø.WER, 7	1	1	1	3, 2, 5									2, 5, 0
1-255	P.Ø.WER, 6, 7	2	1	1, 5	2, 2, 0	A, 2, 2, 5	A, 2, 3, 0	A, 2, 7, 0	2, 3, 5	A, 2, 4, 0	A, 2, 4, 5	A, 2, 7, 0	2, 3, 5	2, 5, 5
1-260	P.Ø.WER, 6, 7	1	1	1	3, 1, 0	A, 2, 4, 0	A, 2, 7, 5	2, 3, 5	A, 2, 4, 0	A, 2, 5, 0	A, 2, 8, 0			2, 5, 6
1-265	P.Ø.WER, 5	1	1	1	3, 3, 0									2, 6, 0
1-270	SERV. W. PUMP, ABC	3	1	8	2, 3, 5	A, 2, 4, 0	A, 2, 5, 0	A, 2, 8, 0	2, 5, 5	A, 2, 6, 0	A, 2, 6, 5	A, 2, 8, 0		2, 6, 5
1-275	SERV. W. PUMP, BC	2	1	1, 6	2, 2, 0	A, 2, 2, 5	A, 2, 3, 0	A, 2, 7, 0	2, 3, 5	A, 2, 4, 0	A, 2, 4, 5	A, 2, 7, 0	2, 3, 5	2, 7, 0
1-280	SERV. W. PUMP, BC, D	3	1	8	2, 2, 0	A, 2, 4, 0	A, 2, 5, 0	A, 2, 8, 0	2, 5, 5	A, 2, 6, 0	A, 2, 6, 5	A, 2, 8, 0		2, 7, 5
1-290	SERV. W. PUMP, BC, D	3	1	8	2, 2, 0	A, 2, 2, 5	A, 2, 3, 0	A, 2, 7, 0	2, 3, 5	A, 2, 4, 0	A, 2, 4, 5	A, 2, 7, 0		2, 8, 0
1-300	P.Ø.WER, 4, 5, 6	1	1	1	2, 2, 5									3, 0, 0
1-305	P.Ø.WER, 5, 6, 7	1	1	1	2, 4, 0									3, 0, 5
1-310	P.Ø.WER, 6, 7, 8	1	1	1	2, 6, 0									3, 1, 0
1-315	P.Ø.WER, 5, 6, 7	1	1	1	2, 3, 0									3, 1, 5
1-320	P.Ø.WER, 4, 5, 6	1	1	1	2, 4, 5									3, 2, 0
1, 2	3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80													

FIGURE 3.26 (continued)

ID No. (1) in col. 3 for Summary	FUNCTION NAME										No. of Modes Available	No. of Modes Required	No. of Alt FUNCTIONS	First Alt FUNCTION ID	2nd	3rd	4th	5th	6th	7th	8th	9th	FORM B ARMM	
5	10										25	30	35	40	45		50	55	60	65		70	75	80
1-3.2.5	P.F.WEIR 6.T.7.													25.0										32.5
1-3.3.0	P.F.WEIR 5.T.6.													36.5										33.0
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COMPONENT ID NO.	- In col 3 if comp is above	COMPONENT NAME	PRIOR OPERATING TIME (FL PT. NO.)	CYCLIC FAILURE RATE Failures/10 ⁶ cycles	(FL PT. NO.)	AVG. NO. OF CYCLES/HR.	(FL PT. NO.)	CONT. FAIL. RATE Failures/10 ⁶ hrs	FL PT. NO.	NO. OF FUNCTIONS SUPPORTED	NO. OF DEPENDENT COMPONENTS	WEIBULL SHAPE PARAMETER "b" (FL PT. NO.)	FORM C ARM
2	50.5	STORAGE TANK						0.1	1	0			50.5
2	51.0	WATER SUPPLY VALVE						1.0	0	1	0		51.0
2	51.5	CHARGE SUCT. VALVE						1.5	1	2			51.5
2	52.0	CHARGE CONTR. VALVE						1.0	1	1			52.0
2	52.5	VOLUME CONTR. VALVE						1.5	1	0			52.5
2	53.0	INT. RECIRC. VALVE						1.0	0	1	0		53.0
2	53.5	REHEAT SUCT. VALVE						5.0	1	0			53.5
2	54.0	CONTAIN. SUMP. VALVE						1.0	0	1	0		54.0
2	54.5	R.H. THROT. VALVE						1.0	0	1	0		54.5
2	55.0	R.H. BYPASS VALVE						5.0	1	0			55.0
2	55.5	CHARGE VALVE 29.0						1.5	1	0			55.5
2	56.0	CHARGE VALVE 29.2						1.5	1	0			56.0
2	56.5	DELUGE VALVE A						1.0	0	1	0		56.5
2	57.0	DELUGE VALVE B						1.0	0	1	0		57.0
2	57.5	IERV. W. VALVE 3						5.0	1	0			57.5
2	58.0	IERV. W. VALVE 4						5.0	1	0			58.0
2	58.5	R.H. PUMP A - START						1.0	0	1	0		58.5
2	58.5...0.1	R.H. PUMP A - RUN						5.0	2	0			58.5...0.1
2	59.0	R.H. PUMP B - START						1.0	0	1	0		59.0
2	59.0...0.1	R.H. PUMP B - RUN						5.0	2	0			59.0...0.1
2	59.2	R.H. CHECK VALVE 1,2						1.0	1	0			59.2
2	59.5	INTJ. PUMP A - START						1.0	0	1	0		59.5
2	59.5...0.1	INTJ. PUMP A - RUN						5.0	2	0			59.5...0.1
2	6.00	INTJ. PUMP B - START						1.0	0	1	0		6.00
2	6.00...0.1	INTJ. PUMP B - RUN						5.0	2	0			6.00...0.1
2	6.02	INTJ. CHECK VALVE 1,2						1.0	1	0			6.02
2	6.05	CHR. PUMP A - START						1.5	1	0			6.05

FIGURE 3.26 (continued)

COMPONENT ID NO. - in col 3 if comp is abortive	COMPONENT NAME					PRIOR OPERATING TIME (FL PT. NO.)	CYCLIC FAILURE RATE FAILURES/10 ⁶ CYCLES	(FL PT. NO.)	AVG. NO. OF CYCLES/HR.	(FL PT. NO.)	CONT. FAIL. RATE FAILURES/10 ⁶ HRS	FL PT. NO.	NO. OF FUNCTIONS SUPPORTED	NO. OF DEPENDENT COMPONENTS	WEIBULL SHAPE PARAMETER "b" FL PT. NO.	FORM C ARM	
	5	10	15	20	25											75	80
2	6.0.5.0.1	CH.R. PUMP. A. 1- RUN									0.75	2	0			6.0.5.0.1	
2	6.1.0	CH.R. PUMP. B. 1- START									1.5	1	0			6.1.0	
2	6.1.0.0.1	CH.R. PUMP. B. 1- RUN									0.75	2	0			6.1.0.0.1	
2	6.1.2	CH.R. CHK. VALVE. 1.2									0.15	1	0			6.1.2	
2	6.1.5	R.H. EXCH. A									0.3	2	1			6.1.5	
2	6.2.0	R.H. EXCH. B									0.3	2	1			6.2.0	
2	6.2.5	SERV. W. VALVE. 5									10.0	1	0			6.2.5	
2	6.3.0	SERV. W. VALVE. 6									10.0	1	0			6.3.0	
2	6.3.5	LINE. 7.7.2									0.1	2	1			6.3.5	
2	6.4.0	LINE. 12.5.0.0									0.1	2	1			6.4.0	
2	6.4.5	TRANSFORMER. 2									5.0	2	0			6.4.5	
2	6.5.0	TRANSFORMER. 3									5.0	2	0			6.5.0	
2	6.5.5	BUS. TIE. 2.7.3									2.0	1	0			6.5.5	
2	6.6.0	INJ. VALVE. A									10.0	1	0			6.6.0	
2	6.6.5	INJ. VALVE. B									10.0	1	0			6.6.5	
2	6.7.0	INJ. VALVE. C									10.0	1	0			6.7.0	
2	6.7.5	INJ. VALVE. D									10.0	1	0			6.7.5	
2	6.8.0	MANUAL SW. TCH.									5.0	1	0		3.	6.8.0	
2	6.8.5	AUTO. PERMISSIVE SW									5.0	1	0			6.8.5	
2	6.9.0	PRESSURE SW. 1									15.0	1	0			6.9.0	
2	6.9.5	PRESSURE SW. 2									15.0	1	0			6.9.5	
2	7.0.0	PRESSURE SW. 3									15.0	1	0			7.0.0	
2	7.0.5	LEVEL SW. 1									15.0	1	0			7.0.5	
2	7.1.0	LEVEL SW. 2									15.0	1	0			7.1.0	
2	7.1.5	LEVEL SW. 3									15.0	1	0			7.1.5	
2	7.2.0	TRANSFORMER. 4									5.0	3	0		4.	7.2.0	
2	7.2.5	TRANSFORMER. 5									5.0	5	0			7.2.5	
1, 2	3, 4, 5, 6, 7, 8, 9	10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21	22, 23, 24	25, 26, 27	28, 29, 30	31, 32	33, 34, 35	36, 37, 38, 39	40, 41, 42, 43, 44, 45	46	47, 48, 49, 50	51, 52, 53, 54	55, 56	57, 58, 59, 60	61, 62, 63, 64, 65, 66, 67	68, 69, 70, 71, 72	73, 74, 75, 76, 77, 78, 79, 80

FIGURE 3.26 (continued)

FIGURE 3.26 (continued)

FIGURE 3.26 (continued)

FIGURE 3.26 (continued)

FUNCTION SUPPORTED			FUNCTION SUPPORTED		FUNCTION SUPPORTED		FUNCTION SUPPORTED		FUNCTION SUPPORTED		FUNCTION SUPPORTED		FUNCTION SUPPORTED		FUNCTION SUPPORTED		FUNCTION SUPPORTED		FUNCTION SUPPORTED		FORM E ARMM																					
Func.	ID	QNA WF FACTOR	ID	WF	ID	WF	ID	WF	ID	WF	ID	WF	ID	WF	ID	WF	ID	WF	ID	WF																						
5			10		15		20		25		30		35		40		45		50		55		60		65		70		75													
1.7.1		1	1.7.2																												6.06.0											
1.7.0		1																														6.1										
1.7.1		1	1.7.2																													6.1.1...0										
1.7.3		1																														6.1.3										
1.7.5		1	1.7.7																													6.1.7										
1.7.5		1	1.7.7																													6.2										
1.7.5		1																														6.26										
1.7.5		1																														6.3.1										
1.8.0		1	1.8.5																													6.37										
1.8.0		1	1.8.5																													6.4.2										
1.8.0		1	1.8.5																													6.46										
1.8.0		1	1.8.5																													6.5										
1.9.0		1																														6.56										
1.9.5		1																														6.6.1										
1.9.5		1																														6.66										
1.9.5		1																														6.7.1										
1.9.5		1																														6.76										
2.0.0		1																														6.8.1										
2.0.5		1																														6.86										
2.1.0		1																														6.9.1										
2.1.0		1																														6.96										
2.1.0		1																														7.0.1										
2.1.5		1																														7.06										
2.1.5		1																														7.1.1										
2.1.5		1																														7.16										
2.2.0		1	2.2.5			2.4.5																											7.2.1									
2.2.0		1	2.2.5			2.3.5			2.4.0			2.6.5																					7.26									
1, 2, 3, 4, 5, 6, 7			8, 9, 10		11, 12, 13, 14		15, 16, 17		18, 19, 20, 21		22, 23, 24		25, 26, 27, 28		29, 30, 31		32, 33, 34, 35		36, 37, 38		39, 40, 41, 42		43, 44, 45		46, 47, 48, 49		50, 51		52, 53, 54, 55, 56		57, 58, 59		60, 61, 62, 63		64, 65, 66		67, 68, 69, 70		71, 72, 73, 74, 75		76, 77, 78, 79, 80	

FIGURE 3.26 (continued)

FIGURE 3.26 (continued)

FIGURE 3.26 (continued)

FIGURE 3.26 (continued)

COMPONENT ID NO. - in col 3 if comp. is obsolete	COMPONENT NAME					PRIOR OPERATING TIME (FLPT. NO.)	CYCLIC FAILURE RATE Failures/10 ⁶ Cycles (FLPT. NO.)	AVG. NO. OF CYCLES/HR.	(FLPT. NO.)	CONT. FAIL. RATE Failures/10 ⁶ HRS	FLPT. NO.	NO. OF FUNCTIONS SUPPORTED.	NO. OF DEPENDENT COMPONENTS	WEIBULL SHAPE PARAMETER "b" FLPT. NO.	FORM C ARMM		
	5	10	15	20	25	30	35	40	45	50	55	60		65	70	75	80
2		5.1.0		WATER SUPPLY VALVE						5.0	1	0					5.1.0
2		5.1.2		WATER SUPPLY VALVE						1.0	1	0					5.1.2
2		5.1.2		WATER SUPPLY VALVE						5.0	1	0					5.1.2
2		5.3.0		S. INTJ. RECIRC. VALVE						5.0	1	0					5.3.0
2		5.3.2		S. INTJ. RECIRC. VALVE						1.0	1	0					5.3.2
2		5.3.2		S. INTJ. RECIRC. VALVE						5.0	1	0					5.3.2
2		5.3.5		RE. HEAT SUCT. VALVE						2.5	1	0					5.3.5
2		5.3.7		RE. HEAT SUCT. VALVE						5.0	1	0					5.3.7
2		5.3.7		RE. HEAT SUCT. VALVE						2.5	1	0					5.3.7
2		5.4.0		C. NTAIN. SUMP VALVE						5.0	1	0					5.4.0
2		5.4.2		C. NTAIN. SUMP VALVE						1.0	1	0					5.4.2
2		5.4.2		C. NTAIN. SUMP VALVE						5.0	1	0					5.4.2
2		5.4.5		R. H. THROT. T. LE. VALVE						5.0	1	0					5.4.5
2		5.4.7		R. H. THROT. T. LE. VALVE						1.0	1	0					5.4.7
2		5.4.7		R. H. THROT. T. LE. VALVE						5.0	1	0					5.4.7
2		5.5.0		R. H. BYPASS VALVE						2.5	1	0					5.5.0
2		5.5.2		R. H. BYPASS VALVE						5.0	1	0					5.5.2
2		5.5.2		R. H. BYPASS VALVE						2.5	1	0					5.5.2
2		5.1.5		C. HARGE SUCT. VALVE						0.75	1	2					5.1.5
2		5.1.8		C. HARGE SUCT. VALVE						1.5	1	2					5.1.8.0
2		5.1.8		C. HARGE SUCT. VALVE						10.75	1	2					5.1.8.0
2		5.2.0		C. HARGE C. NTR. VALVE						0.5	1	1					5.2.0
2		5.2.3		C. HARGE C. NTR. VALVE						1.0	1	1					5.2.3.0
2		5.2.3		C. HARGE C. NTR. VALVE						0.5	1	1					5.2.3.0
2		5.2.5		V. FLUME C. NTR. VALVE						10.75	1	0					5.2.5
2		5.2.8		V. FLUME C. NTR. VALVE						1.5	1	0					5.2.8.0
2		5.2.8		V. FLUME C. NTR. VALVE						0.75	1	0					5.2.8.0
1, 2	3, 4, 5	6, 7, 8, 9	10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32	33, 34, 35, 36, 37, 38, 39	40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54	55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72	73, 74, 75, 76, 77, 78, 79, 80										

FIGURE 3.27

ARMM INPUT LOADSHEETS - CASE 2

FIGURE 3.27 (continued)

FIGURE 3.27 (continued)

FIGURE 3.27 (continued)

CASE 1. SAFETY INJECTION - CONN. YANKEE

00000000, 1900 0000-00

SUMMARY

COMPONENT CONTRIBUTIONS TO UNRELIABILITY

COMPONENT ID	NAME	FAILURE RATE*10**6	SERIAL PROBABILITY	SERIAL PERCENT	SERIAL RANK	SYSTEM PROBABILITY	SYSTEM PERCENT	SYSTEM RANK
505.00	STORAGE TANK	0.10	0.66180061E-04	0.0310	59	0.72973454E-04	0.1883	23
510.00	WATER SUPPLY VALVE	5.00	0.32023185E-02	1.5007	29	0.35271056E-02	9.0992	1
512.00	WATER SUPPLY VALVE	5.00	0.32023185E-02	1.5007	30	0.35271056E-02	9.0992	2
515.00	CHARGE SUCT VALVE	0.75	0.48008106E-03	0.2250	47	0.52958684E-03	1.3662	13
518.00	CHARGE SUCT VALVE	0.75	0.48008106E-03	0.2250	48	0.52958684E-03	1.3662	14
520.00	CHARGE CONTR VALVE	0.50	0.32005404E-03	0.1500	51	0.35308967E-03	0.9109	17
523.00	CHARGE CONTR VALVE	0.50	0.32005404E-03	0.1500	52	0.35308967E-03	0.9109	18
525.00	VOLUME CONTR VALVE	0.75	0.48008106E-03	0.2250	49	0.52958684E-03	1.3662	15
528.00	VOLUME CONTR VALVE	0.75	0.48008106E-03	0.2250	50	0.52958684E-03	1.3662	16
530.00	S INJ RECIRC VALVE	5.00	0.32023185E-02	1.5007	31	0.35271056E-02	9.0992	3
532.00	S INJ RECIRC VALVE	5.00	0.32023185E-02	1.5007	32	0.35271056E-02	9.0992	4
535.00	RE HEAT SUCT VALVE	2.50	0.16004925E-02	0.7500	39	0.17644182E-02	4.5518	9
537.00	RE HEAT SUCT VALVE	2.50	0.16004925E-02	0.7500	40	0.17644182E-02	4.5518	10
540.00	CONTAIN SUMP VALVE	5.00	0.32009849E-02	1.5000	33	0.35256637E-02	9.0955	5
542.00	CONTAIN SUMP VALVE	5.00	0.32009849E-02	1.5000	34	0.35256637E-02	9.0955	6
545.00	R H THROTTLE VALVE	5.00	0.32005404E-02	1.4998	36	0.35251832E-02	9.0942	7
547.00	R H THROTTLE VALVE	5.00	0.32005404E-02	1.4998	37	0.35251832E-02	9.0942	8
550.00	R H BYPASS VALVE	2.50	0.16004925E-02	0.7500	41	0.17644182E-02	4.5518	11
552.00	R H BYPASS VALVE	2.50	0.16004925E-02	0.7500	42	0.17644182E-02	4.5518	12
555.00	CHARGE VALVE 290	1.50	0.96016212E-03	0.4499	43	0.57149072E-06	0.0015	44
560.00	CHARGE VALVE 292	1.50	0.96016212E-03	0.4499	44	0.57149072E-06	0.0015	45
565.00	DELUGE VALVE A	10.00	0.64010809E-02	2.9997	9	0.25244723E-04	0.0651	26
570.00	DELUGE VALVE B	10.00	0.64010809E-02	2.9997	10	0.25244723E-04	0.0651	27
575.00	SERV W VALVE 3	5.00	0.	0.	0	0.	0.	0
580.00	SERV W VALVE 4	5.00	0.	0.	0	0.	0.	0
585.00	R H PUMP A - START	10.00	0.64010809E-02	2.9997	11	0.25244723E-04	0.0651	28
585.01	R H PUMP A - RUN	5.00	0.10846277E-03	0.0508	55	0.80746634E-08	0.0000	58
590.00	R H PUMP B - START	10.00	0.64010809E-02	2.9997	12	0.25244723E-04	0.0651	29
590.01	R H PUMP B - RUN	5.00	0.10846277E-03	0.0508	56	0.80746634E-08	0.0000	59

FIGURE 3.28

COMPONENT CONTRIBUTIONS TO UNRELIABILITY

CASE 1. SAFETY INJECTION - CONN. YANKEE

00000000, 1900 0000-00

SUMMARY

COMPONENT CONTRIBUTIONS TO UNRELIABILITY

COMPONENT ID	NAME	FAILURE RATE*10**6	SERIAL PROBABILITY	SERIAL PERCENT	SERIAL RANK	SYSTEM PROBABILITY	SYSTEM PERCENT	SYSTEM RANK
592.00	R H CHECK VALVE 12	1.00	0.	0.	0	0.46142885E-09	0.0000	62
595.00	INJ PUMP A - START	10.00	0.64010809E-02	2.9997	13	0.25244723E-04	0.0651	30
595.01	INJ PUMP A - RUN	5.00	0.10846277E-03	0.0508	57	0.80746634E-08	0.0000	60
600.00	INJ PUMP B - START	10.00	0.64010809E-02	2.9997	14	0.25244723E-04	0.0651	31
600.01	INJ PUMP B - RUN	5.00	0.10846277E-03	0.0508	58	0.80746634E-08	0.0000	61
602.00	INJ CHECK VALVE 12	1.00	0.	0.	0	0.46142885E-09	0.0000	63
605.00	CHR PUMP A - START	1.50	0.96016212E-03	0.4499	45	0.57149072E-06	0.0015	46
605.01	CHR PUMP A - RUN	0.75	0.16269415E-04	0.0076	62	0.18169866E-09	0.0000	64
610.00	CHR PUMP B - START	1.50	0.96016212E-03	0.4499	46	0.57149072E-06	0.0015	47
610.01	CHR PUMP B - RUN	0.75	0.16269415E-04	0.0076	63	0.18169866E-09	0.0000	65
612.00	CHR CHK VALVE 12	0.15	0.	0.	0	0.10383290E-10	0.0000	70
615.00	R H EXCH A	0.30	0.19854019E-03	0.0930	53	0.67175526E-07	0.0002	54
620.00	R H EXCH B	0.30	0.19854019E-03	0.0930	54	0.67175526E-07	0.0002	55
625.00	SERV W VALVE 5	10.00	0.64019698E-02	3.0001	7	0.26720431E-04	0.0689	24
630.00	SERV W VALVE 6	10.00	0.64019698E-02	3.0001	8	0.26720431E-04	0.0689	25
635.00	LINE 772	0.10	0.66180061E-04	0.0310	60	0.99503046E-08	0.0000	56
640.00	LINE 12500	0.10	0.66180061E-04	0.0310	61	0.99503046E-08	0.0000	57
645.00	TRANSFORMER 2	5.00	0.33090032E-02	1.5507	19	0.84050844E-05	0.0217	34
650.00	TRANSFORMER 3	5.00	0.33090032E-02	1.5507	20	0.84050844E-05	0.0217	35
655.00	BUS TIE 2T3	2.00	0.	0.	0	0.15490359E-05	0.0040	40
660.00	INJ VALVE A	10.00	0.64010809E-02	2.9997	15	0.75734169E-04	0.1954	19
665.00	INJ VALVE B	10.00	0.64010809E-02	2.9997	16	0.75734169E-04	0.1954	20
670.00	INJ VALVE C	10.00	0.64010809E-02	2.9997	17	0.75734169E-04	0.1954	21
675.00	INJ VALVE D	10.00	0.64010809E-02	2.9997	18	0.75734169E-04	0.1954	22
680.00	MANUAL SW	5.00	0.32009849E-02	1.5000	35	0.71631931E-05	0.0185	38
685.00	AUTO PERMISSIVE SW	5.00	0.32005404E-02	1.4998	38	0.63339216E-05	0.0163	39
690.00	PRESSURE SW 1	15.00	0.96016213E-02	4.4995	1	0.34865525E-06	0.0009	48
695.00	PRESSURE SW 2	15.00	0.96016213E-02	4.4995	2	0.34865525E-06	0.0009	49
700.00	PRESSURE SW 3	15.00	0.96016213E-02	4.4995	3	0.34865525E-06	0.0009	50

FIGURE 3.28 (continued)

CASE 1. SAFETY INJECTION - CONN. YANKEE

00000000, 1900 0000-00

SUMMARY

COMPONENT CONTRIBUTIONS TO UNRELIABILITY

COMPONENT ID	NAME	FAILURE RATE*10**6	SERIAL PROBABILITY	SERIAL PERCENT	SERIAL RANK	SYSTEM PROBABILITY	SYSTEM PERCENT	SYSTEM RANK
705.00	LEVEL SW 1	15.00	0.96016213E-02	4.4995	4	0.34865525E-06	0.0009	51
710.00	LEVEL SW 2	15.00	0.96016213E-02	4.4995	5	0.34865525E-06	0.0009	52
715.00	LEVEL SW 3	15.00	0.96016213E-02	4.4995	6	0.34865525E-06	0.0009	53
720.00	TRANSFORMER 4	5.00	0.33090032E-02	1.5507	21	0.81559856E-05	0.0210	36
725.00	TRANSFORMER 5	5.00	0.33090032E-02	1.5507	22	0.16311971E-04	0.0421	32
730.00	TRANSFORMER 6	5.00	0.33090032E-02	1.5507	23	0.16311971E-04	0.0421	33
735.00	TRANSFORMER 7	5.00	0.33090032E-02	1.5507	24	0.81559856E-05	0.0210	37
740.00	BUS TIE 4T5	2.00	0.	0.	0	0.14521144E-05	0.0037	41
745.00	BUS TIE 5T6	2.00	0.	0.	0	0.14521144E-05	0.0037	42
750.00	BUS TIE 6T7	2.00	0.	0.	0	0.14521144E-05	0.0037	43
755.00	SERV WATER PUMP A	5.00	0.33090032E-02	1.5507	25	0.40896410E-10	0.0000	66
760.00	SERV WATER PUMP B	5.00	0.33090032E-02	1.5507	26	0.40896410E-10	0.0000	67
765.00	SERV WATER PUMP C	5.00	0.33090032E-02	1.5507	27	0.40896410E-10	0.0000	68
770.00	SERV WATER PUMP D	5.00	0.33090032E-02	1.5507	28	0.40896410E-10	0.0000	69
TOTAL SERIAL UNRELIABILITY			0.21339339E 00					

FIGURE 3.28 (continued)

CASE 2. SAFETY INJECTION - CONN. YANKEE

00000000, 1900 0000-00

SUMMARY

COMPONENT CONTRIBUTIONS TO UNRELIABILITY

COMPONENT ID	NAME	FAILURE RATE*10**6	SERIAL PRCBABILITY	SERIAL PERCENT	SERIAL RANK	SYSTEM PRCBABILITY	SYSTEM PERCENT	SYSTEM RANK
505.00	STORAGE TANK	0.10	0.64960165E-04	0.0267	59	0.67436652E-04	8.0850	5
510.00	WATER SUPPLY VALVE	10.00	0.62865806E-02	2.5828	7	0.23232622E-04	2.7854	8
512.00	WATER SUPPLY VALVE	10.00	0.62865806E-02	2.5828	8	0.23232622E-04	2.7854	9
515.00	CHARGE SUCT VALVE	1.50	0.94246351E-03	0.3872	43	0.14727094E-05	0.1766	34
518.00	CHARGE SUCT VALVE	1.50	0.94246351E-03	0.3872	44	0.14727094E-05	0.1766	35
520.00	CHARGE CONTR VALVE	1.00	0.62830900E-03	0.2581	51	0.79493982E-06	0.0953	42
523.00	CHARGE CONTR VALVE	1.00	0.62830900E-03	0.2581	52	0.79493982E-06	0.0953	43
525.00	VOLUME CONTR VALVE	1.50	0.94246351E-03	0.3872	45	0.14727094E-05	0.1766	36
528.00	VOLUME CONTR VALVE	1.50	0.94246351E-03	0.3872	46	0.14727094E-05	0.1766	37
530.00	S INJ RECIRC VALVE	10.00	0.62865806E-02	2.5828	9	0.23232622E-04	2.7854	10
532.00	S INJ RECIRC VALVE	10.00	0.62865806E-02	2.5828	10	0.23232622E-04	2.7854	11
535.00	RE HEAT SUCT VALVE	5.00	0.31419813E-02	1.2909	37	0.58290827E-05	0.6988	29
537.00	RE HEAT SUCT VALVE	5.00	0.31419813E-02	1.2909	38	0.58290827E-05	0.6988	30
540.00	CONTAIN SUMP VALVE	10.00	0.62839626E-02	2.5818	11	0.23232618E-04	2.7854	12
542.00	CONTAIN SUMP VALVE	10.00	0.62839626E-02	2.5818	12	0.23232618E-04	2.7854	13
545.00	R H THROTTLE VALVE	10.00	0.62830900E-02	2.5814	15	0.23232617E-04	2.7854	14
547.00	R H THROTTLE VALVE	10.00	0.62830900E-02	2.5814	16	0.23232617E-04	2.7854	15
550.00	R H BYPASS VALVE	5.00	0.31419813E-02	1.2909	39	0.58290827E-05	0.6988	31
552.00	R H BYPASS VALVE	5.00	0.31419813E-02	1.2909	40	0.58290827E-05	0.6988	32
555.00	CHARGE VALVE 290	1.50	0.94246350E-03	0.3872	47	0.52594058E-06	0.0631	44
560.00	CHARGE VALVE 292	1.50	0.94246350E-03	0.3872	48	0.52594058E-06	0.0631	45
565.00	DELUGE VALVE A	10.00	0.62830900E-02	2.5814	17	0.23232616E-04	2.7854	16
570.00	DELUGE VALVE B	10.00	0.62830900E-02	2.5814	18	0.23232616E-04	2.7854	17
575.00	SERV W VALVE 3	5.00	0.	0.	0	0.	0.	0
580.00	SERV W VALVE 4	5.00	0.	0.	0	0.	0.	0
585.00	R H PUMP A - START	10.00	0.62830900E-02	2.5814	19	0.23232616E-04	2.7854	18
585.01	R H PUMP A - RUN	5.00	0.10646348E-03	0.0437	55	0.83932753E-08	0.0010	58
590.00	R H PUMP B - START	10.00	0.62830900E-02	2.5814	20	0.23232616E-04	2.7854	19
590.01	R H PUMP B - RUN	5.00	0.10646348E-03	0.0437	56	0.83932753E-08	0.0010	59

FIGURE 3.28 (continued)

CASE 2. SAFETY INJECTION - CONN. YANKEE

00000000, 1900 0000-00

SUMMARY

COMPONENT CONTRIBUTIONS TO UNRELIABILITY

COMPONENT ID	NAME	FAILURE RATE*10**6	SERIAL PRCBABILITY	SERIAL PERCENT	SERIAL RANK	SYSTEM PRCBABILITY	SYSTEM PERCENT	SYSTEM RANK
592.00	R H CHECK VALVE 12	1.00	0.	0.	0	0.47963603E-09	C.C001	62
595.00	INJ PUMP A - START	10.00	0.62830900E-02	2.5814	21	0.23232616E-04	2.7854	20
595.01	INJ PUMP A - RUN	5.00	0.10646348E-03	0.0437	57	0.83932753E-08	C.0010	60
600.00	INJ PUMP B - START	10.00	0.62830900E-02	2.5814	22	0.23232616E-04	2.7854	21
600.01	INJ PUMP B - RUN	5.00	0.10646348E-03	0.0437	58	0.83932753E-08	C.0010	61
602.00	INJ CHECK VALVE 12	1.00	0.	0.	0	0.47963603E-09	C.0001	63
605.00	CHR PUMP A - START	1.50	0.94246350E-03	0.3872	49	0.52594058E-06	C.0631	46
605.01	CHR PUMP A - RUN	0.75	0.15969521E-04	0.0066	62	0.18886917E-09	C.0000	64
610.00	CHR PUMP B - START	1.50	0.94246350E-03	0.3872	50	0.52594058E-06	C.0631	47
610.01	CHR PUMP B - RUN	0.75	0.15969521E-04	0.0066	63	0.18886917E-09	C.C000	65
612.00	CHR CHK VALVE 12	0.15	0.	0.	0	0.10792996E-10	C.C000	70
615.00	R H EXCH A	0.30	0.19488050E-03	0.0801	53	0.61824332E-07	C.0074	54
620.00	R H EXCH B	0.30	0.19488050E-03	0.0801	54	0.61824332E-07	C.C074	55
625.00	SERV W VALVE 5	10.00	0.62839626E-02	2.5818	13	0.24590704E-04	2.9482	6
630.00	SERV W VALVE 6	10.00	0.62839626E-02	2.5818	14	0.24590704E-04	2.9482	7
635.00	LINE 772	0.10	0.64960165E-04	0.0267	60	0.91585158E-08	C.0011	56
640.00	LINE 12500	0.10	0.64960165E-04	0.0267	61	0.91585158E-08	C.C011	57
645.00	TRANSFORMER 2	5.00	0.32480084E-02	1.3344	27	0.77362577E-05	C.9275	24
650.00	TRANSFORMER 3	5.00	0.32480084E-02	1.3344	28	0.77362577E-05	C.9275	25
655.00	BUS TIE 2T3	2.00	0.	0.	0	0.14257726E-05	C.1709	38
660.00	INJ VALVE A	10.00	0.62830900E-02	2.5814	23	0.69697848E-04	8.3561	1
665.00	INJ VALVE B	10.00	0.62830900E-02	2.5814	24	0.69697848E-04	8.3561	2
670.00	INJ VALVE C	10.00	0.62830900E-02	2.5814	25	0.69697848E-04	8.3561	3
675.00	INJ VALVE D	10.00	0.62830900E-02	2.5814	26	0.69697848E-04	8.3561	4
680.00	MANUAL SW	5.00	0.31419813E-02	1.2909	41	0.66495248E-05	C.7972	28
685.00	AUTC PERMISSIVE SW	5.00	0.31415450E-02	1.2907	42	0.58290823E-05	C.6988	33
690.00	PRESSURE SW 1	15.00	0.94246349E-02	3.8721	1	0.32086600E-06	C.0385	48
695.00	PRESSURE SW 2	15.00	0.94246349E-02	3.8721	2	0.32086600E-06	C.0385	49
700.00	PRESSURE SW 3	15.00	0.94246349E-02	3.8721	3	0.32086600E-06	C.0385	50

FIGURE 3.28 (continued)

AUTOMATIC RELIABILITY MATH MODEL

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CASE 2. SAFETY INJECTION - CONN. YANKEE

00000000, 1900 0000-00

SUMMARY

COMPONENT CONTRIBUTIONS TO UNRELIABILITY

COMPONENT ID	NAME	FAILURE RATE*10**6	SERIAL PRCBABILITY	SERIAL PERCENT	SERIAL RANK	SYSTEM PRCBABILITY	SYSTEM PERCENT	SYSTEM RANK
705.00	LEVEL SW 1	15.00	0.94246349E-02	3.8721	4	0.32086600E-06	0.0385	51
710.00	LEVEL SW 2	15.00	0.94246349E-02	3.8721	5	0.32086600E-06	0.0385	52
715.00	LEVEL SW 3	15.00	0.94246349E-02	3.8721	6	0.32086600E-06	0.0385	53
720.00	TRANSFORMER 4	5.00	0.32480084E-02	1.3344	29	0.75069807E-05	0.9000	26
725.00	TRANSFORMER 5	5.00	0.32480084E-02	1.3344	30	0.15013961E-04	1.8000	22
730.00	TRANSFORMER 6	5.00	0.32480084E-02	1.3344	31	0.15013961E-04	1.8000	23
735.00	TRANSFORMER 7	5.00	0.32480084E-02	1.3344	32	0.75069807E-05	0.9000	27
740.00	BUS TIE 4T5	2.00	0.	0.	0	0.12365635E-05	0.1602	39
745.00	BUS TIE 5T6	2.00	0.	0.	0	0.12365635E-05	0.1602	40
750.00	BUS TIE 6T7	2.00	0.	0.	0	0.12365635E-05	0.1602	41
755.00	SERV WATER PUMP A	5.00	0.32480084E-02	1.3344	33	0.37636805E-10	0.0000	66
760.00	SERV WATER PUMP B	5.00	0.32480084E-02	1.3344	34	0.37636805E-10	0.0000	67
765.00	SERV WATER PUMP C	5.00	0.32480084E-02	1.3344	35	0.37636805E-10	0.0000	68
770.00	SERV WATER PUMP D	5.00	0.32480084E-02	1.3344	36	0.37636805E-10	0.0000	69
TOTAL SERIAL UNRELIABILITY			0.24339731E 00					

FIGURE 3.28 (continued)

CASE 3. SAFETY INJECTION - CONN. YANKEE

00000000, 1900 0000-00

SUMMARY

COMPONENT CONTRIBUTIONS TO UNRELIABILITY

COMPONENT ID	NAME	FAILURE RATE*10**6	SERIAL PRCDABILITY	SERIAL PERCENT	SERIAL RANK	SYSTEM PRCDABILITY	SYSTEM PERCENT	SYSTEM RANK
505.00	STORAGE TANK	0.10	0.18698501E-04	0.0335	59	0.19146147E-04	0.2106	19
510.00	WATER SUPPLY VALVE	5.00	0.81830240E-03	1.4677	29	0.83805773E-03	9.2166	1
512.00	WATER SUPPLY VALVE	5.00	0.81830240E-03	1.4677	30	0.83805773E-03	9.2166	2
515.00	CHARGE SUCT VALVE	0.75	0.12245380E-03	0.2196	47	0.12545616E-03	1.3797	13
518.00	CHARGE SUCT VALVE	0.75	0.12245380E-03	0.2196	48	0.12545616E-03	1.3797	14
520.00	CHARGE CONTR VALVE	0.50	0.81635870E-04	0.1464	55	0.83635197E-04	0.9198	17
523.00	CHARGE CONTR VALVE	0.50	0.81635870E-04	0.1464	56	0.83635197E-04	0.9198	18
525.00	VOLUME CONTR VALVE	0.75	0.12245380E-03	0.2196	49	0.12545616E-03	1.3797	15
528.00	VOLUME CONTR VALVE	0.75	0.12245380E-03	0.2196	50	0.12545616E-03	1.3797	16
530.00	S INJ RECIRC VALVE	5.00	0.81830240E-03	1.4677	31	0.83805773E-03	9.2166	3
532.00	S INJ RECIRC VALVE	5.00	0.81830240E-03	1.4677	32	0.83805773E-03	9.2166	4
535.00	RE HEAT SUCT VALVE	2.50	0.40842231E-03	0.7325	39	0.41837346E-03	4.6011	9
537.00	RE HEAT SUCT VALVE	2.50	0.40842231E-03	0.7325	40	0.41837346E-03	4.6011	10
540.00	CONTAIN SUMP VALVE	5.00	0.81684462E-03	1.4650	33	0.83657137E-03	9.2002	5
542.00	CONTAIN SUMP VALVE	5.00	0.81684462E-03	1.4650	34	0.83657137E-03	9.2002	6
545.00	R H THROTTLE VALVE	5.00	0.81635870E-03	1.4642	36	0.83607591E-03	9.1948	7
547.00	R H THROTTLE VALVE	5.00	0.81635870E-03	1.4642	37	0.83607591E-03	9.1948	8
550.00	R H BYPASS VALVE	2.50	0.40842231E-03	0.7325	41	0.41837346E-03	4.6011	11
552.00	R H BYPASS VALVE	2.50	0.40842231E-03	0.7325	42	0.41837346E-03	4.6011	12
555.00	CHARGE VALVE 290	1.50	0.24490761E-03	0.4393	43	0.31608976E-07	0.0003	44
560.00	CHARGE VALVE 292	1.50	0.24490761E-03	0.4393	44	0.31608976E-07	0.0003	45
565.00	DELUGE VALVE A	10.00	0.16327174E-02	2.9283	9	0.14028391E-05	0.0154	26
570.00	DELUGE VALVE B	10.00	0.16327174E-02	2.9283	10	0.14028391E-05	0.0154	27
575.00	SERV W VALVE 3	5.00	0.	0.	0	0.	0.	0
580.00	SERV W VALVE 4	5.00	0.	0.	0	0.	0.	0
585.00	R H PUMP A - START	10.00	0.16327174E-02	2.9283	11	0.14028391E-05	0.0154	28
585.01	R H PUMP A - RUN	5.00	0.11856638E-03	0.2127	51	0.83238990E-08	0.0001	48
590.00	R H PUMP B - START	10.00	0.16327174E-02	2.9283	12	0.14028391E-05	0.0154	29
590.01	R H PUMP B - RUN	5.00	0.11856638E-03	0.2127	52	0.83238990E-08	0.0001	49

FIGURE 3.28 (continued)

CASE 3. SAFETY INJECTION - CONN. YANKEE

00000000, 1900 0000-00

SUMMARY

COMPONENT CONTRIBUTIONS TO UNRELIABILITY

COMPONENT ID	NAME	FAILURE RATE*10**6	SERIAL PRCBABILITY	SERIAL PERCENT	SERIAL RANK	SYSTEM PRCBABILITY	SYSTEM PERCENT	SYSTEM RANK
592.00	R H CHECK VALVE 12	1.00	0.	0.	0	0.47567145E-09	C.0000	62
595.00	INJ PUMP A - START	10.00	0.16327174E-02	2.9283	13	0.14028391E-05	C.0154	30
595.01	INJ PUMP A - RUN	5.00	0.11856638E-03	0.2127	53	0.8323899CE-08	C.C001	50
600.00	INJ PUMP B - START	10.00	0.16327174E-02	2.9283	14	0.14028391E-05	C.0154	31
600.01	INJ PUMP B - RUN	5.00	0.11856638E-03	0.2127	54	0.8323899CE-08	C.0001	51
602.00	INJ CHECK VALVE 12	1.00	0.	0.	0	0.47567145E-09	C.0000	63
605.00	CHR PUMP A - START	1.50	0.24490761E-03	0.4393	45	0.31608976E-07	C.C003	46
605.01	CHR PUMP A - RUN	0.75	0.17784957E-04	0.0319	62	0.18730704E-09	C.0000	64
610.00	CHR PUMP B - START	1.50	0.24490761E-03	0.4393	46	0.31608976E-07	C.0003	47
610.01	CHR PUMP B - RUN	0.75	0.17784957E-04	0.0319	63	0.18730704E-09	C.C000	65
612.00	CHR CHK VALVE 12	0.15	0.	0.	0	0.10703785E-10	C.0000	66
615.00	R H EXCH A	0.30	0.56095504E-04	0.1006	57	0.37438642E-08	C.C000	58
620.00	R H EXCH B	0.30	0.56095504E-04	0.1006	58	0.37438642E-08	C.0000	59
625.00	SERV W VALVE 5	10.00	0.16336892E-02	2.9301	7	0.1484625CE-05	C.0163	24
630.00	SERV W VALVE 6	10.00	0.16336892E-02	2.9301	8	0.1484625CE-05	C.0163	25
635.00	LINE 772	0.10	0.18698501E-04	0.0335	60	0.5609100CE-09	C.0000	60
640.00	LINE 12500	0.10	0.18698501E-04	0.0335	61	0.5609100CE-09	C.0000	61
645.00	TRANSFORMER 2	5.00	0.93492507E-03	1.6768	19	0.47455974E-06	C.C052	35
650.00	TRANSFORMER 3	5.00	0.93492507E-03	1.6768	20	0.47455974E-06	C.C052	36
655.00	BUS TIE 2T3	2.00	0.	0.	0	0.87357445E-07	C.C010	40
660.00	INJ VALVE A	10.00	0.16327174E-02	2.9283	15	0.42085172E-05	C.0463	20
665.00	INJ VALVE B	10.00	0.16327174E-02	2.9283	16	0.42085172E-05	C.0463	21
670.00	INJ VALVE C	10.00	0.16327174E-02	2.9283	17	0.42085172E-05	C.0463	22
675.00	INJ VALVE D	10.00	0.16327174E-02	2.9283	18	0.42085172E-05	C.0463	23
680.00	MANUAL SW	5.00	0.81684462E-03	1.4650	35	0.85100454E-06	C.0094	34
685.00	AUTO PERMISSIVE SW	5.00	0.81635870E-03	1.4642	38	0.35100442E-06	C.C039	39
690.00	PRESSURE SW 1	15.00	0.24490761E-02	4.3925	1	0.45394765E-08	C.C000	52
695.00	PRESSURE SW 2	15.00	0.24490761E-02	4.3925	2	0.45394765E-08	C.C000	53
700.00	PRESSURE SW 3	15.00	0.24490761E-02	4.3925	3	0.45394765E-08	C.0000	54

FIGURE 3.28 (continued)

CASE 3. SAFETY INJECTION - CONN. YANKEE

00000000, 1900 0000-CC

SUMMARY

COMPONENT CONTRIBUTIONS TO UNRELIABILITY

COMPONENT ID	NAME	FAILURE RATE*10**6	SERIAL PROBABILITY	SERIAL PERCENT	SERIAL RANK	SYSTEM PROBABILITY	SYSTEM PERCENT	SYSTEM RANK
705.00	LEVEL SW 1	15.00	0.24490761E-02	4.3925	4	0.45394765E-08	0.0000	55
710.00	LEVEL SW 2	15.00	0.24490761E-02	4.3925	5	0.45394765E-08	0.0000	56
715.00	LEVEL SW 3	15.00	0.24490761E-02	4.3925	6	0.45394765E-08	0.0000	57
720.00	TRANSFORMER 4	5.00	0.93492507E-03	1.6768	21	0.46050939E-06	0.0051	37
725.00	TRANSFORMER 5	5.00	0.93492507E-03	1.6768	22	0.92101877E-06	0.0101	32
730.00	TRANSFORMER 6	5.00	0.93492507E-03	1.6768	23	0.92101877E-06	0.0101	33
735.00	TRANSFORMER 7	5.00	0.93492507E-03	1.6768	24	0.46050939E-06	0.0051	38
740.00	BUS TIE 4T5	2.00	0.	0.	0	0.81896192E-07	0.0009	41
745.00	BUS TIE 5T6	2.00	0.	0.	0	0.81896192E-07	0.0009	42
750.00	BUS TIE 6T7	2.00	0.	0.	0	0.81896192E-07	0.0009	43
755.00	SERV WATER PUMP A	5.00	0.93492507E-03	1.6768	25	0.12378174E-12	0.0000	67
760.00	SERV WATER PUMP B	5.00	0.93492507E-03	1.6768	26	0.12378174E-12	0.0000	68
765.00	SERV WATER PUMP C	5.00	0.93492507E-03	1.6768	27	0.12378174E-12	0.0000	69
770.00	SERV WATER PUMP D	5.00	0.93492507E-03	1.6768	28	0.12378174E-12	0.0000	70
TOTAL SERIAL UNRELIABILITY			0.55755603E-01					

FIGURE 3.28 (continued)

CASE 1. SAFETY INJECTION - CONN. YANKEE

00000000, 1900 0000-00

SUMMARY

PROBABILITY OF SYSTEM FAILURE = 0.38762840E-01

PROBABILITY OF SYSTEM SUCCESS = 0.96123715

FUNCTION ID	FUNCTION NAME	PROBABILITY OF FUNCTION FAILURE	PERCENT OF SYSTEM FAILURE	RANK
105	WATER STORAGE	0.72973438E-04	0.188	9
110	WATER SUPPLY	0.70542102E-02	18.198	1
115	CHARGE LINE	0.28245263E-02	7.287	7
120	SAFETY INJ RECIRC	0.70542102E-02	18.198	2
125	RESID HEAT RECIRC	0.35288359E-02	9.104	5
130	CONTAIN SUMP RECIR	0.70513265E-02	18.191	3
135	CORE DELUGE LINE	0.70503653E-02	18.188	4
140	R H EXCH BYPASS	0.35288359E-02	9.104	6
145	CHARGE LINE DIST	0.11429813E-05	0.003	25
150	CORE DELUGE DIST	0.50489440E-04	0.130	11
160	R H PUMP AB -START	0.50489440E-04	0.130	12
161	R H PUMP AB -RUN	0.13842147E-07	0.000	28
-163	R H CHECK VALVE 12	0.27685660E-08	0.000	30
165	INJ PUMP AB -START	0.50489440E-04	0.130	13
166	INJ PUMP AB -RUN	0.13842147E-07	0.000	29
-168	INJ CHECK VALVE 12	0.27685660E-08	0.000	31
170	CH PUMP AB -START	0.11429813E-05	0.003	26
171	CH PUMP AB -RUN	0.31148008E-09	0.000	32
-173	CHARGE CK VALVE 12	0.62299584E-10	0.000	34
175	R H EXCH W/COOLING	0.53575156E-04	0.138	10
177	R H EXCH W/O COOL	0.49836486E-10	0.000	35
180	POWER 23	0.13194936E-04	0.034	14
-190	POWER 2T3	0.51841672E-05	0.013	19
195	SAFETY INJ DIST	0.30293663E-03	0.782	8
200	MANUAL OPERATION	0.48061415E-06	0.001	27

FIGURE 3.29

FUNCTION CONTRIBUTIONS TO UNRELIABILITY

CASE 2. SAFETY INJECTION - CONN. YANKEE

00000000, 1900 0000-00

SUMMARY

PROBABILITY CF SYSTEM FAILURE = 0.83409745E-03

PROBABILITY OF SYSTEM SUCCESS = 0.99916590

FUNCTION ID	FUNCTION NAME	PROBABILITY OF FUNCTION FAILURE	PERCENT CF SYSTEM FAILURE	RANK
105	WATER STORAGE	0.67436637E-04	8.085	2
110	WATER SUPPLY	0.46465238E-04	5.571	4
115	CHARGE LINE	0.74807162E-05	0.897	18
120	SAFETY INJ RECIRC	0.46465238E-04	5.571	5
125	RESID HEAT RECIRC	0.11658164E-04	1.398	15
130	CONTAIN SUMP RECIR	0.46465230E-04	5.571	6
135	CORE DELUGE LINE	0.46465229E-04	5.571	7
140	R H EXCH BYPASS	0.11658164E-04	1.398	16
145	CHARGE LINE DIST	0.10518810E-05	0.126	25
150	CORE DELUGE DIST	0.46465226E-04	5.571	8
160	R H PUMP AB -START	0.46465226E-04	5.571	9
161	R H PUMP AB -RUN	0.14388334E-07	0.002	28
-163	R H CHECK VALVE 12	0.28778088E-08	0.000	30
165	INJ PUMP AB -START	0.46465226E-04	5.571	10
166	INJ PUMP AB -RUN	0.14388334E-07	0.002	29
-168	INJ CHECK VALVE 12	0.28778088E-08	0.000	31
170	CH PUMP AB -START	0.10518810E-05	0.126	26
171	CH PUMP AB -RUN	0.32377052E-09	0.000	32
-173	CHARGE CK VALVE 12	0.64757814E-10	0.000	34
175	R H EXCH W/COOLING	0.49304999E-04	5.911	3
177	R H EXCH W/O COOL	0.51802944E-10	0.000	35
180	POWER 23	0.12144962E-04	1.456	11
-190	POWER 2T3	0.47716412E-05	0.572	19
195	SAFETY INJ DIST	0.27879136E-03	33.424	1
200	MANUAL OPERATION	0.49957641E-06	0.060	27

FIGURE 3.29 (continued)

CASE 3. SAFETY INJECTION - CONN. YANKEE

00000000, 1900 0000-CC

SUMMARY

PROBABILITY CF SYSTEM FAILURE = 0.90929305E-02

PROBABILITY OF SYSTEM SUCCESS = 0.99090707

FUNCTION ID	FUNCTION NAME	PROBABILITY OF FUNCTION FAILURE	PERCENT CF SYSTEM FAILURE	RANK
105	WATER STORAGE	0.19146139E-04	0.211	8
110	WATER SUPPLY	0.16761153E-02	18.433	1
115	CHARGE LINE	0.66910295E-03	7.358	7
120	SAFETY INJ RECIRC	0.16761153E-02	18.433	2
125	RESID HEAT RECIRC	0.83674685E-03	9.202	5
130	CONTAIN SUMP RECIR	0.16731426E-02	18.400	3
135	CORE DELUGE LINE	0.16721516E-02	18.390	4
140	R H EXCH BYPASS	0.83674685E-03	9.202	6
145	CHARGE LINE DIST	0.63217946E-07	0.001	24
150	CORE DELUGE DIST	0.28056779E-05	0.031	11
160	R H PUMP AB -START	0.28056779E-05	0.031	12
161	R H PUMP AB -RUN	0.14269404E-07	0.000	28
-163	R H CHECK VALVE 12	0.28540217E-08	0.000	30
165	INJ PUMP AB -START	0.28056779E-05	0.031	13
166	INJ PUMP AB -RUN	0.14269404E-07	0.000	29
-168	INJ CHECK VALVE 12	0.28540217E-08	0.000	31
170	CH PUMP AB -START	0.63217946E-07	0.001	25
171	CH PUMP AB -RUN	0.32109434E-09	0.000	32
-173	CHARGE CK VALVE 12	0.64222547E-10	0.000	33
175	R H EXCH W/COOLING	0.29766860E-05	0.033	10
177	R H EXCH W/O COOL	0.51374757E-10	0.000	34
180	POWER 23	0.74522764E-06	0.008	14
-190	POWER 2T3	0.29237095E-06	0.003	20
195	SAFETY INJ DIST	0.16834067E-04	0.185	9
200	MANUAL OPERATION	0.49545842E-06	0.005	19

FIGURE 3.29 (continued)

FIGURE 3.30

AIR RECIRCULATION FAN - COOLING COIL UNIT
CONNECTICUT YANKEE

FIGURE 3.31A

RELIABILITY BLOCK DIAGRAM
CONNECTICUT YANKEE - AIR RECIRCULATION UNIT

FIGURE 3.31B
RELIABILITY BLOCK DIAGRAM
CONNECTICUT YANKEE
CONTAINMENT SPRAY SYSTEM

FIGURE 3.31C
RELIABILITY BLOCK DIAGRAM
CONNECTICUT YANKEE
POWER SUPPLY AND SERVICE WATER SYSTEM PUMPS

FIGURE 3.31D

CONTAINMENT COOLING SYSTEM
RELIABILITY BLOCK DIAGRAM - CONNECTICUT YANKEE

FIGURE 3. 32

RESIDUAL HEAT REMOVAL SYSTEM IN CONTAINMENT SPRAY MODE
CONNECTICUT YANKEE

FIGURE 3.33

CONNECTICUT YANKEE CONTAINMENT PRESSURE TRANSIENT

System Containment
Subsystem Containment Cooling
Assembly Air Recirculation Unit
Function Provide containment atmosphere heat sink for containment pressure relief following loss-of-coolant accident.

Page 1 of 1

Component ID No	Component Name	Component Function(s)	Failure Mode(s)	Cause(s) of Failure	Likelihood (No / 10 ⁶ Hrs)	Effect on Subsystem	Effect on System	B Safety Significance	A x B Over-all Importance	Remarks (Dependence on redundancy, environmental factors, corrective actions)
10	Incident Flow Inlet Damper	Directs air flow to filter banks	Damper fails closed.	Spring failure.		Incident flow path unavailable for containment cooling.	No filtration of containment atmosphere.			Full flow available to cooling coils via normal inlet dampers.
11	Moisture Separator	Removes moisture from air recirculated via incident flow path	Clogged	Excess moisture and particulate matter in flow		Partial or total loss of containment cooling (see remark).	Containment overpressure (see remark).			Manual reversal of damper positions reestablishes full containment cooling effectiveness.
12	Particulate Filter	Removes particulate matter from air recirculated via incident flow path.	Clogged.	Excess moisture and particulate matter in flow.		Partial or total loss of containment cooling (see remark)	Containment overpressure (see remark).			Manual reversal of damper positions reestablishes full containment cooling effectiveness
13	Charcoal Filters	Removes iodines from incident flow	Clogged.	Excess moisture and particulate matter in flow.		Partial or total loss of containment cooling (see remark).	Containment overpressure (see remark).			Manual reversal of damper positions reestablishes full containment cooling effectiveness
15	Normal Flow Inlet Damper	Directs air flow to cooling coils	Fail to open	Damper motor failure.		Partial loss of containment cooling if incident damper not open.	Containment overpressure if more than one unit fails as specified			
14	Damper Position Reversal Switch	Switch flow from incident to normal path	Fail to actuate.	Switch failure, operator error.		Partial loss of containment cooling if incident damper not open	Containment overpressure if more than one unit fails as specified.			
16	Cooling Coils	Cool recirculation flow	Fail to cool	Service water system failure, coil rupture.		Loss of pressure control capability.	Containment overpressure if more than one unit fails			
17	Fan	Provides driving force for flow.	Stopped	Motor failure, coupling failure.		Loss of pressure control capability.	Containment overpressure if more than one unit fails.			
18	Fan Motor	Drives fan.	Stopped.	Loss of power.		Loss of pressure control capability	Containment overpressure if more than one unit fails.			

FIGURE 3.34 A

FAILURE MODE AND EFFECT ANALYSIS
CONNECTICUT YANKEE - CONTAINMENT SPRAY SYSTEM

System Containment
 Subsystem Containment Cooling
 Assembly Containment Spray System
 Function Provide containment atmosphere heat sink for containment pressure relief following loss-of-coolant accident.

Page 1 of 2

Component ID No	Component Name	Component Function(s)	Failure Mode(s)	Cause(s) of Failure	Likelihood (No / 10 ⁶ Hrs)	Effect on Subsystem	Effect on System	B Safety Significance	A x B Over-all Importance	Remarks (Dependence on redundancy, environmental factors, corrective actions)
50	Refueling Water Storage Tank	Coolant water storage.	Burst.	Seismic disturbance		Loss of tank coolant supply.	Loss of containment pressure control if air recirculation system has failed.			Requires loss of air recirculation system and containment sump water supply to become significant.
51,52	Refueling Water Storage Tank and Tank Line Block Valves (motor operated)	Refueling water storage tank isolation.	Leak badly. Fail to open.	Corrosion. Motor failure, operator error. Valve binding due to corrosion.		Loss of tank coolant supply.	Loss of containment pressure control if air recirculation system has failed.			Requires loss of air recirculation system and containment sump water supply to become significant.
53	Refueling Water Storage Tank Line Check Valve	Prevent back flow to storage tank.	Fail closed.	Valve binding due to corrosion.		Loss of tank coolant supply.	Loss of containment pressure control if air recirculation system has failed.			Requires loss of air recirculation system and containment sump water supply to become significant.
54	Containment Sump Line Block Valve (motor operated)	Containment sump isolation.	Fail closed.	Motor failure, operator error. Valve binding due to corrosion.		Loss of containment sump coolant supply.	Loss of containment pressure control if air recirculation system has failed.			Requires loss of air recirculation system to become significant.
55	Containment Sump Line Check Valve	Prevent back flow to containment sump.	Fail closed.	Valve binding due to corrosion.		Loss of containment sump coolant supply.	Loss of containment pressure control if air recirculation system has failed.			Requires loss of air recirculation system to become significant.
56,58,59,61,62,65,66,69	Residual Heat Removal Pumps and Residual Heat Exchangers Inlet and Outlet Valves (locked open)	Pumps and heat exchangers isolation	Fail closed.	Operator error.		Loss of spray coolant flow.	Loss of containment pressure control if air recirculation system has failed.			Requires valve failure on each redundant path to become significant.

FIGURE 3.34B

FAILURE MODE AND EFFECT ANALYSIS
CONNECTICUT YANKEE - AIR RECIRCULATION UNIT

System Containment
 Subsystem Containment Cooling
 Assembly Containment Spray System
 Function Provide containment atmosphere heat sink for containment pressure relief following loss-of-coolant accident.

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Component ID No	Component Name	Component Function(s)	Failure Mode(s)	Cause(s) of Failure	Likelihood (No / 10 ⁶ Hrs)	Effect on Subsystem	Effect on System	B Safety Significance	A x B Overall Importance	Remarks (Dependence on redundancy, environmental factors, corrective actions)
57, 60	Residual Heat Removal Pumps	Pump spray system flow during accident.	Fail to continue running.	Motor failure, bearings seized		Loss of spray coolant flow.	Loss of containment pressure control if air recirculation system has failed.			Requires loss of air recirculation system to become significant. Both pumps must fail to become significant.
64, 68	Residual Heat Removal Pump Check Valves	Prevent backflow to pumps.	Fail closed.	Valve binding due to corrosion.		Loss of spray coolant flow.	Loss of containment pressure control if air recirculation system has failed.			Both valves must fail to become significant.
54	Containment Sump Block Valve	Containment sump isolation.	Fail closed.	Motor failure, operator error.		Loss of containment sump coolant supply.	Spray water supply.			
55	Containment Sump Check Valve	Prevent backflow to containment sump.	Fail closed.			Loss of containment sump coolant supply.	Spray water supply.			
70	Containment Spray Inlet Line Check Valve	Prevent backflow in inlet line.	Fail closed.							
71	Containment Spray Inlet Line Block Valve	Containment spray header ring isolation.	Fail closed.	Motor failure, operator error.						
72	Reactor Vessel Head Block Valve	Reactor vessel head isolation.	Fail open.	Motor failure, operator error.						

FIGURE 3.34B (continued)

FIGURE 3.35

SCHEMATIC OF SAN ONOFRE SAFETY INJECTION SYSTEM

FIGURE 3.36

ELECTRICAL POWER TO SAFETY INJECTION SYSTEM - SAN ONOFRE

System Reactor Cooling
Subsystem Safety Injection
Assembly Injection and Recirculation Equipment
Function To provide emergency core cooling with loss or leakage of reactor coolant and to provide secondary means of nuclear shutdown.

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Component ID No.	Component Name	Component Function(s)	Failure Mode(s)	Cause(s) of Failure	Likelihood (No / 10 ⁶ Hrs)	Effect on Subsystem	Effect on System	B Safety Significance	A x B Overall Importance	Remarks (Dependence on redundancy, environmental factors, corrective actions)
MOV-850A, 850B, 850C	Refueling Water Tank	Contains 240,000 gallons borated water.	Large leak	Disaster causes tank to crack.		No water for safety injection.	No emergency core cooling available.	4		Test by flow. Exercise periodically.
	Safety Injection Header	Combine flow from safety injection trains and distribute to three coolant loops.	Rupture.	Corrosion, accident.		No safety injection	No emergency core cooling available	4		
	Safety Injection Loop Valves	Direct safety injection to three coolant loops.	Fail to open.	Stuck from corrosion, failed motor.		Failure if two valves fail.	Possible core melting with loss of coolant.	3		
	Main Transformer	220 Kv/18 Kv	Cease to operate.	Fire in transformer, open windings.		No direct power to 4160 volt Buses 1A and 1B.	No effect as long as there is power to 4160 volt Buses 1C and 2C	2		
	Auxiliary Transformers A and B	18 Kv/4160 volt Buses 1A and 1B	Cease to operate.	Fire in transformer, open windings.		No direct power to 4160 volt Buses 1A and 1B	No effect as long as there is power to 4160 volt Buses 1C and 2C	2		
	Auxiliary Transformer C	138 Kv/4160 volt Buses 1C and 2C.	Cease to operate.	Fire in transformer, open windings.		No direct power to 4160 volt Buses 1C and 2C	No effect if there is power to Buses 1C and 2C through the main transformer and Buses 1A and/or 1B.	3		
CB-11A04, 11B04, 11C02, 12C02	Circuit Breakers	Connect power to 4160 volt Buses 1A, 1B, 1C, and 2C.	Fail to close and stay closed.	Broken parts, overcurrent.		No direct power to corresponding 4160 volt bus.	If ties work, there are alternate sources of power to each bus.	2		
TB-11C11, 12C11, 11C01, 12C01	Tie Breakers	Tie 4160 volt buses together.	Fail to close.	Broken parts, overcurrent		No tie between buses if backup needed.	Reduced redundancy in power.	2		

(0) None (2) Minor (4) Major
(1) Negligible (3) Intermediate

FIGURE 3.37

FAILURE MODE AND EFFECT ANALYSIS
SAN ONOFRE - SAFETY INJECTION SYSTEM

System Reactor Cooling
Subsystem Safety Injection
Assembly Injection and Recirculation Equipment
Function To provide emergency core cooling with loss or leakage of reactor coolant and to provide secondary means of nuclear shutdown.

Page 2 of 5

Component ID No.	Component Name	Component Function(s)	Failure Mode(s)	Cause(s) of Failure	Likelihood (No / 10 ⁶ Hrs)	Effect on Subsystem	Effect on System	B Safety Significance	A x B Overall Importance	Remarks (Dependence on redundancy, environmental factors, corrective actions)
SST 1, 2, 3	Station Service Transformers	4160 volt/480 volt.	Cease to operate	Open windings, fire		No power to corresponding 480 volt bus.	Reduced redundancy	3		
CB-11C10, 12C10, 1102, 1202, 1303	Circuit Breakers	Connect power from 4160 volt buses to 480 volt buses	Fail to close.	Broken parts, overcurrent.		Prevent direct power to 480 volt buses.	Reduced redundancy.	2		
TB-1103, 1203	Tie Breakers	Tie 480 volt Buses 1 and 2 to Bus 3.	Fail to close	Broken parts, overcurrent.		No tie between buses so no backup when needed.	Reduced redundancy	2		
G50A, G50B	Safety Injection Pumps	Inject borated water into core following loss of coolant accident	Fail to start. Fail to continue operating.	Contactors fail to close, brushes fail Motor failure, bearing seized		Loss of one safety injection train for each pump failed.	No emergency core cooling if both trains fail, possible core melt	4		
G-3A, G-3B	Feedwater Pumps	Assist in injecting borated water into core.	Fail to operate	Motor failure, bearing seized.		Loss of one safety injection train for each pump failed	No emergency core cooling if both trains fail, possible core melt.	4		
MOV-851A, 851B, 853A, 853B	Motor-Operated Valves	Open to direct flow along safety injection pumping trains.	Fail to open.	Stuck from corrosion, failed motor.		No flow through one or both pumping trains.	No emergency core cooling if both trains fail, possible core melt.	4		Exercise periodically.
MOV-852A, 852B, 854A, 854B	Motor-Operated Valves.	Close to stop flow from heaters.	Fail to close.	Stuck from corrosion, failed motor		Interlock prevents flow through corresponding safety injection train	No emergency core cooling if both trains fail, possible core melt	3		Exercise periodically.
	Interlocks A and B	Prevent MOV-851 A or B from opening until MOV-854 A or B closes respectively.	Fail to let MOV-851 A or B open after MOV-854 A or B have closed	Short.		Blocked Safety Injection Train A or B.	No emergency core cooling if both trains fail, possible core melt.	4		Test periodically.

FIGURE 3. 37 (continued)

System Reactor Cooling
 Subsystem Safety Injection
 Assembly Injection and Recirculation Equipment
 Function To provide emergency core cooling with loss or leakage of reactor coolant and to provide secondary means of nuclear shutdown.

Component ID No.	Component Name	Component Function(s)	Failure Mode(s)	Cause(s) of Failure	Likelihood (No / 10 ⁶ Hrs)	Effect on Subsystem	Effect on System	B Safety Significance	A x B Overall Importance	Remarks (Dependence on redundancy, environmental factors, corrective actions)
CV-36, 37, 875A, 875B	Control Valves	To cut off flow from feedwater pumps to condenser hotwell and recirculation back to refueling water tank	Fail to close.	Stuck from corrosion.		Drain part of water from flow to core.	None unless accident requires full capacity of safety injection system.	1		Exercise periodically.
	Recirculation Header	Combine flow from charging pumps and refuel pumps and distribute to three coolant loops.	Rupture	Corrosion, accident.		No recirculation	No decay heat removal	4		Test by flow.
	FCV-1115D, 1115E, 1115F	Flow Control Motor-Operated Valves	Fail to open.	Stuck from corrosion.		Block recirculation to one or more loops.	If flow to two loops is blocked, no effective decay heat removal.	3		Exercise periodically
	MOV-356, 357, 358	Containment Sump	Fail to hold spilled water.	Natural disaster.		No water for recirculation.	No decay heat removal	4		
	Recirculation Heat Exchanger	Cool recirculation water from sump.	Rupture and leak.	Corrosion, accident.		Inadequate cooling of water	Inadequate decay heat removal.	3		Check periodically for leaks.
MOV-883	Motor-Operated Valve	To stop flow from refueling water tank to refuel and charge pumps and prevent flow of recirculation water back into tank	Fail to close	Motor failure, stuck from corrosion.		Uncertain, assume loss of recirculation.	Assume system failure	2		Install check valve (which is actually the case) though not considered in this analysis.
	Remote Manual Switch	Actuate MOV-883	Fail to connect.	Poor contacts, broken line.		Uncertain, assume loss of recirculation.	Assume system failure.	2		Test periodically.

FIGURE 3.37 (continued)

System Reactor Cooling
 Subsystem Safety Injection
 Assembly Injection and Recirculation Equipment
 Function To provide emergency core cooling with loss or leakage of reactor coolant and to provide secondary means of nuclear shutdown.

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Component ID No.	Component Name	Component Function(s)	Failure Mode(s)	Cause(s) of Failure	Likelihood (No / 10 ⁶ Hrs)	Effect on Subsystem	Effect on System	B Safety Significance	A x B Overall Importance	Remarks (Dependence on redundancy, environmental factors, corrective actions)
G-8A, 8B	Charging Pumps	Pump recirculation water to coolant loops.	Fail to start, fail to continue operating	Contactors fail to close, brushes fail, motor failure, bearing seized.		Reduced recirculation	If refuel pumps continue to operate, no effect	2		Monitor frequently.
MOV-1100B, 1100D	Motor-Operated Valve	Open to allow flow to charging pumps.	Fail to open.	Stuck from corrosion, motor failed.		Charge pumps out of operation if both valves fail.	Reduced decay heat removal reliability.	2		Exercise periodically
CV-81, 112	Control Valves	Refuel water pumps discharge valves.	Fail to open	Stuck from corrosion.		No flow from corresponding refuel water pump.	Reduced decay heat removal reliability.	2		Exercise periodically
G-27, 27S	Refueling Water Pumps	Share recirculation duty with charging pumps.	Fail to start. Fail to continue operating.	Contactors fail to close, brushes fail. Motor failure, bearings seized.		Reduced redundancy in recirculation	Reduced decay heat removal reliability.	2		Test periodically.
MOV-880	Motor-Operated Valve	Directs flow from refueling water pumps to recirculation header.	Fail to open	Same as other valves.		No flow to recirculation through refuel pump.	Reduced decay heat removal reliability.	3		Exercise periodically
	Manual Start	Start recirculation pumps.	Fail to actuate.	Relay failure operator error.		No pumping from sump.	No recirculation, no decay heat removal.	4		Test periodically.
G-45A, 45B	Recirculation Pump	Pump spilled water from sump through recirculation system.	Fail to start. Fail to operate.	Contactors fail to close, brushes fail. Motor failure, bearing seized.		No recirculation.	No decay heat removal.	4		Test periodically.
MOV-866A, 866B	Motor-Operated Valves	Recirculation pump discharge valves.	Fail to open.	Stuck by corrosion.		Block flow from sump	No recirculation, no decay heat removal.	4		Exercise periodically.
LS 1, 2, 3	Level Sensors	Sense low pressurizer water level.	Fail to sense 2 out of 3.	Disconnected cable.		No actuation of safety injection system.	No emergency core cooling, possible melt.	4		Monitor frequently

FIGURE 3. 37 (continued)

System Reactor Cooling
 Subsystem Safety Injection
 Assembly Injection and Recirculation Equipment
 Function To provide emergency core cooling with loss or leakage of reactor coolant and to provide secondary means of nuclear shutdown

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Component ID No	Component Name	Component Function(s)	Failure Mode(s)	Cause(s) of Failure	Likelihood (No / 10 ⁶ Hrs)	Effect on Subsystem	Effect on System	B Safety Significance	A x B Over-all Importance	Remarks (Dependence on redundancy, environmental factors, corrective actions)
PS 1, 2, 3	Pressure Sensors	Sense low pressurizer pressure	Fail to sense 2 out of 3	Disconnected cable.		No actuation of safety injection system.	No emergency core cooling, possible melt	4		Monitor frequently.
	Automatic Actuate of Safety Injection System	Upon signal from sensors actuate safety injection system	Fail to trip	Relay failure.		No safety injection if manual fails.	No emergency core cooling if manual actuate also fails.	4		Test periodically.
	Manual Actuate.	If automatic fails, perform its function		Operator error relay failure.		No safety injection.	No emergency core cooling, possible melt	4		Test periodically.

FIGURE 3. 37 (continued)

FIGURE 3.38

RELIABILITY BLOCK DIAGRAM
SAFETY INJECTION SYSTEM

FIGURE 3.38 (continued)

FIGURE 3. 38 (continued)

FIGURE 3.38 (continued)

FIGURE 3.38 (continued)

APPENDIX A

PRESENT DATA COLLECTION PRACTICES IN
OPERATING NUCLEAR POWER PLANTS

APPENDIX A

PRESENT DATA COLLECTION PRACTICES IN OPERATING NUCLEAR POWER PLANTS

Data management at five operating nuclear power plants in the United States has been reviewed to determine the applicability of current in-plant forms and procedures to the generation of reliability data. The plants included were:

1. Dresden Nuclear Power Station Unit No. 1.
2. Yankee Atomic Power Station.
3. Indian Point Station.
4. Humboldt Bay Unit No. 3.
5. Shippingport Atomic Power Station.

As indicated in the following discussion, much of the in-plant information necessary for reliability data is now being collected and recorded. Furthermore, formats closely paralleling the failure event form suggested in this study are now in use. The remaining requirements for adapting present data management practices to reliability data generation are minor modifications and use of one or, at most, two existing forms for the basic reliability data input and specification of procedures which assure consistent, total adherence to completion of these forms.

DRESDEN NUCLEAR POWER STATION

Operating and Outage Summary Reports

Monthly Operating Reports - Each month data from the preceding logs and reports, as well as various process data sheets, are used to prepare a summary of operations. Preparation of this monthly report includes inputs from the chemistry, thermal, and nuclear engineers on the technical staff as well as maintenance summaries by the mechanical, electrical, and instrument maintenance groups. Emphasis is given to reporting and evaluation of plant and reactor performance during both normal operation and tests and includes a day-by-day listing of significant events. Plant radiation protection, including radwaste inventories, and plant chemistry data are presented in separate sections of the report.

Outage Reports - These are special reports detailing work performed and results of tests made during extended outages such as refuelings. They are written by the plant engineering staff.

Annual Reports - Subsequent to the first year of operation after rated power tests, the Dresden staff has prepared annual reports for the AEC. These reports, as did the quarterly reports in the first year of operation, describe operating experience pertinent to nuclear safety and changes in facility design, performance characteristics, and operating procedures during the reporting period.

Failure Reports and Maintenance Requests

Maintenance Requests - Dresden uses a system of "maintenance requests" to define work to be done on plant components and to provide administrative control of such work. These maintenance requests reflect work performed on all plant equipment except during outages at which time they are supplanted by outage schedules.

Equipment Maintenance Files - Two separate files exist on equipment maintenance, one on instrument maintenance and the other on mechanical and electrical maintenance. These files represent an organized record of work performed on specific pieces of equipment. They are primarily derived from maintenance request completions.

Maintenance requirements arising during tests and checking operation, or during normal operation, are recorded and transmitted by maintenance work requests. As shown in Figure A.1, these requests may be originated by anyone on the station staff. Most frequently they are written by the reactor operators or the shift engineers. Few work requests originate in the maintenance staff. Following the flow shown in Figure A.1, work requests are written in quadruplicate and submitted to the shift engineer who forwards those requests requiring action to the station operating engineers for authorization. The station operating engineers authorize the requests and indicate action to be taken including assignment to electrical, mechanical, or instrument maintenance groups. Since the station maintenance engineer may not be present at Dresden on a continuous basis due to similar commitments at other power stations, the master mechanic directs action on all mechanical and electrical work requests at Dresden. Instrument maintenance is performed by the instrument mechanics under the electrical station operating engineer's direction. Action on a work request may be deferred, when possible, to the next major outage when it is scheduled with other maintenance activities.

Upon completion of the required maintenance, the four copies of the work requests are signed and dated by the responsible mechanic. Unusual maintenance requirements may be noted on the work request; however, normally only the date of completion is noted. Completed work requests are distributed to the shift engineer, the master mechanic, and the appropriate station operating engineer. The operating engineers and master mechanic maintain files of the completed requests by number and year.

YANKEE ATOMIC POWER STATION

Operating and Outage Summary Reports

Operation Report - This report presents a summary of general operations including the status of construction and nonoperating activities such as receipt and shipment of fuel. Only major maintenance activities are reported; and, in general, this information represents some enlargement on similar information in the weekly reports. Summary data includes plant chemistry; turbine plant performance; reactor plant performance; radiation exposure and radioactivity release; and in-plant training activities, primarily for sponsor company technical personnel. Other information included in the operation report on an as-available basis are special reports on reactor performance tests and summaries of scheduled and unscheduled plant shutdowns.

Abnormal Occurrence Reports - These reports provide descriptions, analyses, and corrective actions taken for abnormal or unusual events which are of significance in plant operations. Many of the events included have been reported to the AEC under reactor operating license requirements, but this record is not restricted to reportable incidents. Examples of abnormal occurrences are control rod malfunctions, primary coolant leaks or spills, and turbine throttle valve malfunctions.

Failure Reports and Maintenance Requests

Maintenance Requests - Equipment deficiencies or malfunctions noted by plant personnel are reported on maintenance requests. These requests are provided with spaces for equipment identification, description of defect, work to be done, materials used, work done, and the names and dates associated with each of the preceding items.

Corrective maintenance is implemented primarily by use of maintenance requests and to a lesser extent by inspection activities associated with

outage schedules. The flow of maintenance requests is illustrated in Figure A.2, and a blank request form is shown in Figure A.3. Most maintenance requests are written by the shift supervisors; however, all plant personnel may initiate such requests. The requests are used primarily as a tool to initiate and control maintenance work. Their value as a historical record is limited to information transferred from the requests to equipment history cards. The requests are ultimately returned to the originator who generally disposes of them. The requests also are used by the maintenance supervisors as a guide to maintenance work loads, both past and present.

Equipment History File - Repair and parts replacement for all plant mechanical and electrical equipment, except instrumentation, is recorded in a card file maintained by the administrative assistant. The file is indexed according to the paragraph numbering established in the Final Hazard Summary Report. The maintenance information is obtained from completed maintenance requests and, as a result, is dependent on the completeness of information in maintenance requests and the correct handling of the requests. The completeness of information contained on these cards has improved with time when compared to information in other plant records such as the reactor log and weekly report.

Instrument Maintenance File - Records of parts replacement or repair in components of the instrumentation system are maintained in a card file by the control engineering department. Information included on the cards identifies the instrument, the date of each maintenance, and the part replaced or repair performed. Information is recorded on the cards by the control engineer or technical assistants. The maintenance file records are augmented by special summaries of significant maintenance activities prepared by the control engineer as time allows.

INDIAN POINT STATION

Operating and Outage Summary Reports

Monthly Report - This report contains a summary of plant performance data, major events, and significant health physics data for company management. These reports are prepared by the production staff and approved by the general superintendent. They serve as one input for semiannual reports.

Semiannual Report - Plant operations (including shutdowns and unusual operating conditions), test results, maintenance and design changes, radio-chemistry data, and health physics statistics are summarized each six months. The report is prepared by Consolidated Edison for the AEC in accordance with requirements in the Provisional Operating License.

Outage Report - Significant testing and maintenance performed during major outages are summarized subsequent to the outage. Important safety information includes repair and replacement data on safety system and safeguard components which may not be recorded elsewhere.

Unit History - A continuous statistical history of operations is maintained in terms of major unit availability, outage causes, and protective system trips. This record is developed from operating logs by the production operating staff.

Failure Reports and Maintenance Requests

Maintenance Memoranda (MM) - These memos or work requests, a copy of which is shown in Figure A.4, identify equipment found in need of repair by the operating staff. The memos are valuable not only in the identification of equipment malfunctions but also as a record of repairs found necessary.

The use of MM in the initiation and control of routine maintenance may be traced along one of two paths depending upon whether the work requested involved production maintenance personnel or test bureau personnel. In either case, the memoranda are written by the members of the operating staff when deficiencies are noted during inspections, checkoffs, normal operations, or tests. Blank memorandum forms are retained in single books in the central control room and chemical systems control room and are filled out in triplicate (white, yellow, and pink) copies. Although it is possible for other production staff members to write MM, only the general watch foreman or watch foreman may sign and thereby initiate the memo.

For work involving the production maintenance group, the MM flow is as shown on Figure A.5. With the foreman's signature, the white copy of each memo is forwarded to the reactor engineer or superintendent to receive final approval and priority number. The pink copy is placed in the general watch foreman's "Maintenance Memoranda Pending" file. Where the requested repair is best suited to outage time and may be postponed, the reactor engineer may assign the memo work to the next appropriate outage. With assignment of priority the white copy of the memo is forwarded to the production maintenance group.

When the maintenance requested on a memo is completed, the general maintenance foreman moves the pink copy of the memo from the "Maintenance Memoranda Pending" file to the "Maintenance Memoranda Completed by Maintenance" file in the general watch foreman's office noting the work done on the memo. These completed MM are reviewed by the general watch foreman and then returned to the production office where they are compared with the third (yellow) copy of each MM which is retained in exhausted MM books from the control rooms. The completed MM are also used to compile equipment histories.

If an MM item is completed by shift maintenance personnel rather than the production maintenance group, the general watch foreman removes the pink copy from the "Maintenance Memoranda Pending" file, initials the copy, and places it in the "Maintenance Memoranda Completed by the Watch" file. The production maintenance foreman checks this file each morning to eliminate completed work from the collection of MM received. The pink copies in the "Maintenance Memoranda Completed by the Watch" file are also forwarded to the production office for final checkoff and equipment history data. The white copies of these memoranda are retained by the general maintenance foreman.

For work involving test bureau personnel (instrument and control repair), the MM flow is as shown in Figure A. 6. Briefly the flow is the same as for the production maintenance MM through the assignment of work priority. Test bureau MM are identified by marking the "Test Bureau" at the top of each applicable form. After assignment of priority the pink and white copies of the MM are sent to the production staff technician who forwards the white copy to the test bureau for action and files the pink copy under "Test Bureau MM" for subsequent follow-up. With completion of the requested work the test bureau notifies operations and the production staff technician who notes the information on the respective MM pink copies and keeps the reactor engineer and superintendent informed of the work status. The white copy of the test bureau MM is retained by the test bureau which maintains records of all work done on controls and instrumentation.

In actual practice, some minor routine maintenance is performed without writing an MM. This work includes adjustment and servicing by operating mechanics in the shift crews and instrument technicians working in the amplifier room. If this minor maintenance is significant to safety or operations, it will be recorded in the general watch foreman's log or the test bureau log maintained in the amplifier room. As a result of these practices, complete equipment histories are available

and only by searching a number of records. This is particularly true for items such as flux amplifier replacements made by operating mechanics during shifts when the test bureau technicians are off duty. These replacements are noted in the general watch foreman's log but may not appear in test bureau records.

Major maintenance, including shop work, is initiated by issuing production department maintenance orders to the station construction and shops department. As a record of systems performance and reliability, the MM are more important since they are a record of operating difficulties while the maintenance orders represent a finalization of work required as a result of operating difficulties or design changes previously recorded in other station records.

Plant Equipment Histories - A technician in the administrative services group periodically reviews MM and outage reports and records data from these documents in equipment history files (loose-leaf notebooks) to establish complete histories on major components in the process systems. Instrumentation and control histories are kept in the test bureau logs. This recording practice is intended as an aid in scheduling maintenance and identifying trends in maintenance requirements. It also serves as a quick means of identifying weak components in various safeguard systems.

PLANT OUTAGE LAY UNIT NO. 3

Operation and Outage Summary Reports

Monthly Reports (Quarterly Reporting) - These reports are a summarization of operations, testing activities, and significant mechanical, electrical, and instrument maintenance performed during each month. This report is prepared for internal use by PG&E. Other material included in the report is a master log which is a day-by-day list of tests, safety system trips, and equipment modifications and maintenance. Other information contained in the monthly reports includes individual reports of each scram and outage occurring during the report period, a day-by-day summary of plant performance (Form 51) which is taken from the daily summaries, and summaries of work performed during each outage including work chronologies whenever the outage is extensive. As of January 1965, monthly reports were changed to quarterly reports because the regularity of operation did not justify reporting on a monthly period.

Semiannual Reports to the AEC - The provisional operating license for Unit No. 3 requires a semiannual report of operations. This report is prepared by the on-site staff and the general office and is edited by the general office. It contains general operating data on facility use, electrical output and shutdowns and data on radiation measurements, coolant chemistry, radioactive material releases, discharges and shipments, maintenance and facility changes, tests and test results, and meteorology. This data primarily derives from daily and monthly reports written for internal use.

Annual Operating Report - Operations during each calendar year are summarized in an annual report for internal use by PG&E. This report is prepared by the on-site staff from monthly or quarterly report data and includes statistical summaries of plant performance in terms of average rates of occurrence or levels. Estimates of fuel usage are also included.

Scram and Outage Reports - PG&E practices require preparation of individual reports covering the circumstances surrounding each scram and outage. Data included in each scram report are time of scram; type of scram (planned or unplanned, manual or automatic, real or spurious); cause and effect of scram; and corrective action, if any. Data included in outage reports are time of outage, duration of outage, type of outage (scheduled or unscheduled), and reasons for outage.

Failure Reports and Maintenance Requests

Forms 23's (Work Requests) - Maintenance requirements noted by the operating staff during each shift are normally forwarded to the appropriate maintenance group by use of a Form 23 or work request. This form indicates equipment involved; observed malfunctions or operating problems; and, when completed, the work performed by the maintenance staff. Work requests are used to initiate maintenance according to the request flow diagram shown in Figure A.7. These work requests are primarily a monitoring tool to initiate and assure performance of the desired maintenance including the preparation of outage work schedules. They are retained as a record until no further surveillance of the pertinent maintenance is necessary, and then they are discarded after transferring maintenance data to the appropriate logs or maintenance card files. The completed work requests also are used by the maintenance foremen or instrument engineers to prepare summaries of maintenance work for each monthly report.

Maintenance Card Files - Each component in the plant has a maintenance card file provided for recording repairs, replacements, and modifications. Routine or scheduled servicings are not indicated on these cards unless a repair or replacement is required during the servicing. The format for the cards varies according to the type of component, e.g., motors, pumps, valves, and electronic instruments; but in all cases a standard entry is provided for the date and work done (see Figures A.8 and A.9). The instrumentation cards are kept in a file which visually indicates whether maintenance is being performed by the presence or absence of the card. This file also may be used to schedule routine tests and servicings.

SHIPPINGPORT ATOMIC POWER STATION

Operating and Outage Summary Reports

Summary information on experience of significance to safety may be found in incident reports, monthly (now quarterly) operating reports, quarterly technical progress reports, and summary reports covering approximately the period from startup on one seed to startup on the next seed. The monthly operating reports and summary reports for the operating period of each seed are based on observations and data accumulated in records of daily operation, maintenance, and periodic checks and tests.

Reports of incidents provide complete analyses of unusual occurrences primarily in the reactor plant. These incident reports are summarized in monthly operating reports and summary reports of seed operations. The status of investigations into each incident is monitored by issuance of a quarterly incident status report which indicates incidents that have occurred, planned or accomplished corrective actions, and closes out incidents which were resolved since issuance of the preceding status report.

Failure Reports and Maintenance Requests

Plant maintenance activities are recorded and regulated by use of work item cards and equipment history cards. The equipment history cards, shown in Figure A.10a, summarize identification numbers, name plate specifications, and significant repairs or servicings on mechanical and electrical components and all instrumentation. These 5 x 8 cards also are provided with monthly edge marks to enable use of the cards in a color coded, tickler file for scheduling preventive maintenance.

Maintenance data entered on the cards is taken from work item cards by a clerk. Only data selected by the foremen or engineers is transferred to the equipment history cards. The equipment history cards were kept current from their initiation in 1961 until the end of Core 1 operation. Since that time, reduction in the station complement has caused some lag in the transferral of work item data to the equipment history cards.

The work items or work requests are 8-1/2 x 11 cards filled out by foremen in different plant areas to request and record preventive and corrective maintenance on equipment. Servicings such as lubrication or oil changes are not entered as work items but are initiated from records kept in the control room. Information provided on the work item cards includes identification and location of equipment, nature of work or trouble, time and material requirements, and description of work performed. A blank work item card is shown in Figure A.10b. The work item cards are reviewed and signed by appropriate supervisory personnel; and, generally, they are retained if they contain significant maintenance information. As previously indicated, this information is transferred to the equipment history cards at the direction of the foremen or engineers.

ACTION

Maintenance requirement noted and request written

Reviews and authorizes request and forwards request to appropriate Station Operating Engineer

Approve requests, assign priorities, and forward requests to appropriate maintenance group or assign them to outage schedules

Perform required repairs, note work completion on requests and forward work request copies to appropriate individuals

Review completed work and file requests on annual basis

FLOW

FIGURE A. 1

MAINTENANCE REQUEST FLOW

FIGURE A. 2

MAINTENANCE REQUEST FLOW

YANKEE ATOMIC ELECTRIC COMPANY
MAINTENANCE REQUEST

EQUIPMENT _____

NATURE OF DEFECT _____

REPORTED BY _____ DATE _____

ACTION TAKEN

INVESTIGATION BY _____

WORK TO BE DONE _____

WORK ASSIGNED TO _____

WORK COMPLETED BY _____ DATE _____

DESCRIPTION OF WORK DONE _____

MATERIAL USED _____

TO BE ENTERED ON EQUIPMENT CARD _____ YES _____ NO _____

RETURN TO _____

FIGURE A. 3
MAINTENANCE REQUEST FORM

G. E. CO. OF N. Y., INC.

MAINTENANCE MEMORANDUM

Nº 81913

DATE _____

WATCH _____

APPARATUS	WORK

REPORTED BY _____
WATCH FOREMAN

APPROVED FOR INTERDEPARTMENTAL WORK REQUEST _____

13-60 (EA.) 7-62 PRODUCTION

FIGURE A. 4

MAINTENANCE MEMORANDUM

FIGURE A. 5

MAINTENANCE MEMORANDUM FLOW
FOR ELECTRICAL AND MECHANICAL WORK

ACTION

Maintenance requirement noted on instruments, "Not Working Properly" tag placed on equipment and memorandum written.

Reviews and initiates memorandum.

Assigns priority to memorandum.

Forwards white copy to Test Bureau and retains pink copy for follow-up.

Performs work, records completed work in log, reports completed work to Production Staff Technician and Watch and removes "Not Working Properly" tag.

Reports status of Test Bureau work to Reactor Engineer or Superintendent and files completed memos.

Y - Yellow copy
W - White copy
P - Pink copy

FLOW

FIGURE A. 6

TEST BUREAU MAINTENANCE MEMORANDUM FLOW

ACTION

Work request made out in triplicate and individual copies forwarded.

Operations retains 1 copy for followup; maintenance group receives second copy for scheduling; Assistant Superintendent or Power Plant Engineer receives third copy, approves request, assigns priority, and provides any additional work directives needed by maintenance groups.

Assigns work to mechanics, electricians, or technicians.

Performs approved work; enters work description in maintenance log or card file and on both copies of work request; forwards both copies of completed requests.

Compares original request to corresponding completed copies; discards original; retains 1 completed copy; forwards other completed copy.

Assistant Superintendent reviews and then discards completed work requests; operations retains completed requests until no further surveillance considered necessary and then discards request.

FLOW

FIGURE A.7

WORK REQUEST (FORM 23) FLOW

CARD NO.	<div style="display: flex; justify-content: space-around;"> <div style="background-color: black; color: white; padding: 2px 5px;">OUT</div> <div style="background-color: black; color: white; padding: 2px 5px;">OUT</div> <div style="background-color: black; color: white; padding: 2px 5px;">OUT</div> <div style="background-color: black; color: white; padding: 2px 5px;">OUT</div> <div style="background-color: black; color: white; padding: 2px 5px;">OUT</div> <div style="background-color: black; color: white; padding: 2px 5px;">OUT</div> </div>					
EQUIPMENT DESIGNATION			MANUFACTURER			EQUIPMENT
MODEL NO.	SERIAL NO.	LOCATION				
P. & I. D. NO.	BECHTEL INST. NO.	P. G. & E. REF. DWG. NO.				
MFG. REF. DWG. NO.	REF. MATERIAL LOCATION	M*OR P.O. NO.				
EQUIP. RANGE						
CONTROL & ALARM SETTINGS						RED GREEN
SPECIAL PRECAUTIONS						1 27
REMARKS:						2 28
DATE	WHY WORK WAS DONE	DESCRIPTION OF WORK	M.H.	BY	3 29	
					4 30	
					5 31	
					6 32	
					7 33	
					8 34	
					9 35	
					10 36	
					11 37	
					12 38	
					13 39	
					14 40	
					15 41	
					16 42	
					17 43	
					18 44	
					19 45	
					20 46	
					21 47	
					22 48	
					23 49	
					24 50	
					25 51	
					26 52	

Visteon, Inc.
 Chicago, IL 60641
 W 1272-A/ AP 8

PACIFIC GAS & ELECTRIC CO. - HUMBOLDT UNIT NO. 3

8.5 x 11 .75"
 #132
 MLLCO. Z-12395

FIGURE A. 8

EQUIPMENT MAINTENANCE RECORD FORM

SERVICE			LOCATION			FILE		
MAKE	H.P.	CLASS	TYPE	CODE	FRAME	MODEL	SOURCE OF POWER	
VOLTS	AMPS, F.L.	AMPS, START		AMPS, FREE RUN		SERIAL NO.		
PHASE	FREQ.	R.P.M.	TEMP. RISE	EFFICIENCY		MOUNT	POWER FACTOR	
ROTATION INBOARD END		LUBE	MAG. CENTER UNLD.		VIBR. FREE RUN:	HORIZ.	VERT.	END
BRGS: INBOARD NO.		OUTBOARD NO.		MFR. PARTS BUL. NO.		MAINTENANCE PERIOD		DATE
GENERAL REMARKS:								

[illegible]

A-19

MOTOR MAINTENANCE RECORD FORM

[illegible][illegible]

Work Item Card

FIGURE A.10

MAINTENANCE RECORD FORMS

APPENDIX B

DATA MANAGEMENT PRACTICES IN RELATED AREAS

APPENDIX B

DATA MANAGEMENT PRACTICES IN RELATED AREAS

Several reliability data classification and/or collection programs related to the nuclear, utility, aerospace, and merchant marine industries have been reviewed to establish guidelines and formats for the reliability monitoring program data management system. Of these programs, the following have provided the most useful background materials:

1. United Kingdom Atomic Energy Authority (UKAEA) Reactor Fault Reporting System.
2. PM-1 Data Evaluation Program.
3. Maritime Administration (MARAD) Maintenance and Reliability Program.
4. Edison Electric Institute (EEI) Equipment Availability Program.
5. Interservice Data Exchange Program (IDEP), Guided Missile Data Evaluation Program (GMDEP), and Failure Rate Data Program (FARADA).
6. Uniform Subject Index for Nuclear Power Demonstration (NPD) Project.
7. AEC Uniform System of Accounts.

As the name implies, the AEC Uniform System of Accounts was primarily developed for cost accounting and estimating purposes. However, since the breakdown in this system is by functional systems, particularly those related to the reactor plant, it has been reviewed with special interest.

A brief description of each of these programs follows.

UKAEA REACTOR FAULT REPORTING SYSTEM

Under the UKAEA Fault Reporting System⁽¹⁾ instituted in 1961, details of reactor faults and incidents which occur on UKAEA reactors are sent to the Safeguards Division of the Authority Health and Safety Branch (AHSB) located at Risley. The details are then coded and stored on punched cards according to the UKAEA data classification system for use in the analysis

of reactor fault causes and trends. This system has been in operation since September 1964 with some minor modifications of the original classification code.⁽²⁾

The UKAEA classification system is based on an 80-column punch card. Column allocation is designated as shown on Table B.1, and some samples of further breakdowns are shown in Tables B.2 through B.7. Except for those columns that are self-explanatory, description of column allocations is as follows:

Plant Type

In the United States plant type generally would be referred to as a system and subsystem level of functional equipment classification. The system and subsystem in which a fault occurred are identified in these columns. The first level breakdown in this classification is:

1. Reactor.
2. Steam Raising Units.
3. Power Plant.
4. Plant Containment.
5. Rigs and Isotope Handling.
6. Electrical Power Supplies.
7. Ancillary Equipment.

Since the classification under "Reactor" encompasses considerably more equipment than what might be normally classified at this level in the United States, this particular level is further amplified as follows:

1. Pressure Vessel.
2. Core.
3. Shield.
4. Reactivity Control Devices.
5. Heat Exchange Circuit.
6. Control Electrical System and Instrumentation Control Circuitry.

As an example, a partial coverage of the control electrical system is shown in Table B.2.

Component Type

These columns itemize the components and parts on which the fault occurred. The first-level breakdown, along with a partial coverage of the component type as shown in Table B.3, illustrates the coverage provided by component type classification.

1. Electrical.
2. Industrial Instrumentation.
3. Mechanical.
4. Chemical Plant.
5. Civil Engineering Work.
6. Component Not Identified.
7. Shielding.

Fault Importance

This portion of the data classification system deals with the safety aspects of each fault. It is basically divided into four broad categories; namely:

- A. Lack of safety.
- B. Faults or actions which reduce reactor safety.
- C. Faults or actions which do not reduce reactor safety.
- D. Events which have no safety significance whatsoever.

The definitions and details of the fault importance code are summarized completely in Table B.4. These definitions were developed during two years of negotiation with reactor operators; and although rather detailed in development, they have been proven workable. The primary reason for the extended negotiations on definition of fault classification is attributed to the fact that power reactor operators and research facility operators tended to have somewhat different attitudes when faced with a given fault. As a result of the classifications shown in Table B.4, most faults will fall in the B and C category class.

In general, assignment of a fault to one of these categories is decided as follows:

If the reactor protective system functions correctly and the resulting drift or transient is in all respects within the safe operating limit approved for the system, it is a Category C fault. If the reactor protective system functions correctly but the resulting drift or transient exceeds a safe operating limit approved for the system in any respect, it is a Category B fault.

If, in addition to the initiating event, there occurs any malfunction of protective equipment, the fault would be classed as Category B whether any operating limit is exceeded and despite any manual corrective action which has been taken by the operator (unless he takes it so quickly as to prevent a protective circuit action).

Fault Type

Columns 32 to 36 of the classification describe the nature of a fault. Fault types are generally divided into nine basic categories as follows:

1. Electrical.
2. Instrument Effects.
3. Mechanical.
4. Design Fault.
5. Human Error or Maloperation.
6. Undiagnosed Fault.
7. Chemical.
8. Radioactivity.
9. Other Faults.

Subclassifications within each basic fault-type category are illustrated by Table B.5.

PM-1 DATA EVALUATION PROGRAM

The U. S. Air Force has established a data collection and classification system for evaluating operating data obtained from land-based military nuclear power plants. The system uses a data management program that catalogs plant performance data in a master file and allows computerized information retrieval and system analysis.⁽³⁾ Although

capable of being applied to any military plant, the PM-1 nuclear power plant was chosen as the pilot plant for application of this data management program. The program is capable of producing output reports which assess the reliability, availability, safety, and performance of the plants as follows:

Reliability - Reliability of individual components and plant sub-systems.

Availability - Availability of reactor and generating equipment.

Safety - All failures having a potential safety effect.

System Performance - Performance data with respect to steam and electrical output, plant chemistry, radioactive waste production, core lifetime, and economics.

Input to the master file comes from data obtained from the power plant logs. These data are separated by type and grouped into packets of cards, each packet going to form one tape record in the master file. While all data are important in assessing plant performance, only those portions of the program which relate directly to reliability and safety are described here.

The reliability and safety data require preparation of a malfunction packet consisting of three punched cards. The first card is a header card which identifies the type of packet. The second and the third cards, column allocation of which is shown in Tables B.8 and B.9, are basically for identifying the part of the plant in which the fault occurred and the type of fault which was caused by the part malfunction.

A code designation is provided for all subsystems and components of consequence in PM-1. Code designations are also provided for all major shutdown causes and all major causes of equipment failure. In addition, all failures are categorized in accordance with their effect on plant safety. Descriptions of column allocation for each data field are shown in Tables B.8 and B.9. With the exception of those fields which are self-explanatory, the type of information required is discussed below.

Subsystem and Component Codes

All plant equipment is classified at two levels; subsystem and component. All subsystems and components are identified by a two or three alphabetic code. For example, the subsystem code for the feedwater

system is FW, while the component code for an electropneumatic transducer is EPT. Additional examples of subsystem and component codes are given in Table B.10.

Malfunction, Safety, and Shutdown Codes

As shown in Table B.11, the malfunction and safety codes are developed to designate the effect of faults on reactor operation and safety. The shutdown code relates the cause or reason for a shutdown event.

Failure Code

The failure code used in the program describes component or system faults in terms of four major categories of equipment failure. These categories are mechanical, electrical, instrumentation, and others.

The first three categories are further divided into 20 subcategories, as shown in Table B.12. In effect the subcategories are an open-ended listing of equipment failure descriptions. More terms can be added as different types of equipment failures are encountered.

A computer program has been developed to compile input data taken from PM-1 records and to generate a number of summary reports. With respect to this study the most important of these reports are the Safety Report, and the Failure Shutdown and Availability Report. Typical printouts of these reports are presented in Figures B.1 and B.2.

MARITIME ADMINISTRATION MAINTENANCE AND RELIABILITY PROGRAM

As a result of increasing costs in the construction and operation of ships subsidized by the United States, the Maritime Administration (MARAD) has developed a systematic approach for evaluating the operating data obtained from these ships. The goal of this program, the MARAD Maintenance and Reliability Program, ⁽⁴⁾ ⁽⁵⁾ is to collect data and perform detailed analyses of shipboard maintenance and repair policies, in order to identify areas where economies may be achieved.

In developing the MARAD program it was found that existing classification systems were primarily developed for filing and accounting use and were unsuitable for the objectives of the maintenance and reliability program. Furthermore, there were few sources of information concerned with ships in which the nomenclature agreed

with the program needs; and nomenclature commonly in use was found to be inconsistent. For example, complete hierarchies of systems within systems could often be found. It was necessary, therefore, to develop a new classification system.

In the new classification system, a hierarchy of ten levels was established as shown in Table B-13. The first two levels identify the ship and its environment. Levels three through ten provide the functional relationship of the elements of the ship's equipment and structure.

Between the levels the vertical relations are established on the basis of the various degrees of complexity; elements at the same level are expected to have the same degree of complexity.

The basic or fundamental levels in the equipment and structural hierarchy are Level 3-System, Level 6-Components, and Level 9-Parts. Intermediate levels are provided primarily for convenience in determining vertical relations between fundamental levels. Every system contains an element at the system level and one or more at the component level. Other elements in the intermediate levels are included to provide a complete classification of normally identifiable equipment. In classifying a system, elements at the component level are listed first; and then intermediate levels are filled, as necessary. Finally, to maximize consistency, any reference to elements within the hierarchy from system to part includes the name of their level. For example, the steam drum assembly is within the boiler component which is in the steam supply unit of the steam subsystem of the power and propulsion system.

At the system level, Level 3, each system is organized according to the ability of its element to perform, as a group, one of the necessary functions of the ship. A set of 14 general functions have been identified including one for automatic control. At the component level, Level 6, all the elements which are to be considered components under their respective systems are defined. After Level 6 is completed, Levels 5 and then 4 are completed by combining the elements into natural groupings following the appropriate definitions.

Below Level 6, the normal course would be to identify the elements at the parts level, Level 9, and then fill the intermediate Levels, 8 and 7. There are, however, an extremely large number of entries

at the parts level; and they are subject to variations reflecting manufacturers' alternative designs. Furthermore, this amount of detail was not necessary in the early stages of the MARAD program. Therefore, the components were merely separated into their assemblies at Level 7, and the classification was not carried beyond that point.

Although this classification process is reasonably straightforward, there are some complicating factors which should be mentioned. First, there are invariably entires which belong at a given level but do not exactly meet the definitions provided for that level. An example at the component level is piping. That heading is used to collect assemblies such as pipes and fittings, valves, traps, strainers, etc., into a group which together perform a specific operation.

However, piping is not a component in the usual sense of the word. The heading "Piping" at the component level, then, is a convenience heading. Other convenience headings include the various accommodation spaces of "associated equipment."

Another complication arises because there are some systems whose functions are not separable into subsystems. That is, all the units in these systems support the function of the system directly.

Finally, there are a few elements which function within one system but which are structurally or operationally within another system. In classifying these elements, each portion of the element which uniquely supports the function of a system is classified within that system.

Systems Classification Code

The code which is used with the preceding classification method is in four parts. The first is a "prefix" consisting of the registered hull number designated in the Record of the American Bureau of Shipping (ABS). This prefix allows all data for any one ship at any level to be quickly retrieved. Following the prefix, the coding method for Levels 1 and 2 consists of the MARAD design number and trade route number. For Level 3 and below a letter code is assigned to each system, each subsystem within a system, and each unit within the subsystem. A list of systems and subsystems and their identifying letters appears in Table B.14.

Each component is assigned a three-digit component index number which identifies it and also indicates whether the component is unique to a given unit, commonly occurs in several units within a particular system or can occur in any system. Some components, such as pumps, occur in several systems. Since it may be interesting to collect all data on such components, each is given a number from a specific set allotted to that component as shown by the example in Table B.15.

A second part of this code allows each particular type of component to be identified; for example, as shown in Table B.16 sectional header, bent tube, and top fired boilers can be distinguished by component type codes C, D, and E.

The third part of the code is a two-digit assembly index number, which provides information on the relation of assemblies to components, similar to that which the component index provides on the relation of components to unit.

Finally, the fourth part of the code identifies the specific component among the several identical components to which the data applies.

An illustration of the coding using the ship SS President Arthur, whose registered hull number is 264704, MARAD design number C4-S-1, and trade route number 12, follows. The code number for the steam drum assembly of the bent tube boiler on the starboard side is to be determined. The boilers are classified in the power and propulsion system, P; steam subsystem, B; and steam supply unit, B. The boilers are component 001 in their unit, and the bent tube boilers are designated component type D. The steam drum has 02 assembly designation, and as a rule the starboard boiler is numbered 01.

The complete code can be written as

264704/C4S1/12/PBB 001 D 02 01

Data Collection Program

The major obstacle in achieving the objectives originally set forth in the Maritime Administration program was the lack of adequate data. As a result, a program was established for collecting the required data in the field through direct observation and through cooperative

efforts of operators. The program specified the data to be reported, its format, and the procedures to be used. Two stepwise approaches to data collection were instituted on a trial basis; (1) initial experimental data collection program by U. S. Merchant Marine Academy cadets during their training year at sea, and (2) subsequent data collection by chief engineers or other operator personnel during the course of their normal duties.

Evaluation of the returns made it apparent that the forms needed to be consolidated and simplified to avoid the confusion. Ambiguous instructions also were identified. Given improved forms, it was concluded that at least half of the cadets and probably more would produce usable reports. Although in some instances the cadets were hampered by officers in their efforts to collect data, this difficulty was traced to inadequate communication with management--a factor which was expected to disappear after the program had become well-established.

Another result of this trial application was the observation that a large number of the cadets were obviously almost wholly dependent on the officers for much of their information and frequently seemed to act mainly as transcribers. Thus, the ship's officers might in many cases have been able to carry out the data task themselves in less time than was required for their "advisory" role. Results of the subsequent experimental data collection program using chief engineers supported such a conjecture. The use of cadets as a continuing source of information can lead to undesirable discontinuities in the data since few ships have cadets present on every voyage. As a result, reliance on random voyage samples makes it impossible to characterize events accurately whose normal cycle approaches or exceeds the normal voyage length--and a significant amount of the information required is of that character. The problem is particularly acute for reliability calculations on equipment having MTBF's on the order of a year or more. In this case, an unreported failure during a mission voyage might double the apparent time between failures; and because the total sample size is small for infrequent events, the error introduced by a missing datum is correspondingly larger.

While problems were encountered which led to revision of the data collection forms to the formats shown in Figures B.3 and B.4, the results indicated that collection of shipboard maintenance and reliability data is feasible given proper forms, instructions, indoctrination, follow-through, and encouragement from management.

Based on initial trials of the data collection program, an integrated data management system has been envisioned, as depicted by the flow chart shown in Figure B. 5.

EDISON ELECTRIC INSTITUTE (EEI) EQUIPMENT AVAILABILITY PROGRAM

The Prime Movers Committee of the Edison Electric Institute (EEI) has been collecting outage data based on equipment availability reports submitted by approximately 90 of its member utility companies for a number of years. The program covers more than 500 turbines and boilers for units having a name plate capacity of 50 megawatts or larger and with initial steam conditions of at least 800 psi or 900° F. Of the total, 91 percent of the units have a single boiler per turbine arrangement. In the near future, the institute plans to report availability and outage data in connection with nuclear units.

Outages are reported by type according to the classification shown in Table B.17. The cause or reason for each outage is classified as shown in Table B.18. The general code numbers in Table B.18 are designated 100 for boilers, 200 for turbines, 300 for generators, 400 for condensers, and 500 for unit outages not caused by any of the previous four categories. Although the list appears to be a component classification, since in many instances the names of equipment are used to describe the code designation, a closer examination reveals an intermixing of component and event data pertaining to a major piece of equipment. A typical summary of forced outages is shown in Figure B-6. Using the data collected in the EEI program analyses of availability reports ⁽⁶⁾ ⁽⁷⁾ have been prepared for use by power utility engineers engaged in design, system planning and production management, and by major equipment manufacturers. Basically these reports provide information on equipment availability and repair. As presented, the data in these reports do not lend themselves to generating component/part failure rate data.

INTERSERVICE DATA EXCHANGE PROGRAM (IDEP), GUIDED MISSILE DATA EVALUATION PROGRAM (GMDEP), AND FAILURE RATE DATA PROGRAM (FARADA)

The Interservice Data Exchange Program (IDEP) was established in 1958 for the free exchange of parts/components data among the Department of Defense ballistic missile activities. Its principal function is to reproduce and distribute test results submitted by contractors. Each

participating contractor summarizes the results of his test in a standard report summary sheet which is forwarded, with the complete test results, to the cognizant IDEP office. By multilith process the information on the standard report summary sheet is transferred to a report summary card. In addition, the test data is printed and distributed separately on 16mm roll film. A sample of a report summary card is shown in Figure B.7.

In 1959 the Navy's Guided Missile Data Evaluation Program (GMDEP), similar in purpose and intent to the IDEP, was initiated at the Fleet Missile Systems Analysis and Evaluation Group (FMSAEG), Corona, California. The significant difference between this program and IDEP is that its prime purpose was to exchange data generated by those Navy contractors engaged in the research, development, and production of guided missiles. As previously indicated, IDEP covered the interchange of ballistic missile and space system information. In July 1964, GMDEP was officially consolidated with IDEP.

Late in 1960 the Naval Ordnance Systems Command requested the Fleet Missile Systems Analysis and Evaluation Group (FMSAEG) at Corona, California, to perform a component part study associated with and as a subtask to the Navy Guided Missile Data Exchange Program (GMDEP). This study was (1) to determine whether failure rate data was available and if it could be obtained on a selected list of electrical, electronic, mechanical, electromechanical, pneumatic, hydraulic, and pyrotechnic parts/components, and (2) to develop a method for the collection, analysis, compilation, presentation, and distribution of failure rate data.

Initially, the possibility of placing failure rate data on the report summary cards being circulated in the existing IDEP and GMDEP programs was explored. However, it was found that test and failure rate data being circulated in those programs lacked sufficient analysis and summarization to facilitate the extraction of failure rates with respect to time and environment. The approach used in GMDEP and IDEP to present results of individual short-term qualification tests performed on parts/components did not lend itself to presenting a rate of failure on those parts/components.

As a result of the study, it was determined that modified or new forms and procedures would be required to obtain this information and to present it uniformly. Plans were then formulated to include as many organizations as were willing to forward a resume of failure rate information from their various in-house programs to a Failure Rate Data (FARADA)

Information Center at Corona. The Air Force, Naval Ship Systems Command, Army, and NASA also became sponsors of the FARADA program.⁽⁸⁾ Flow of FARADA information is shown schematically in Figure B.8. Qualified data which are submitted to the FARADA Information Center are screened, summarized, compiled, and published in FARADA handbooks. Figures B.9, B.10, and B.11 illustrate completed sample forms of data contribution. Use of these forms by data contributors, however, is optional since the FARADA Information Center will accept generated data from participants in whatever in-house format available. The FARADA handbooks provide reliability engineers, design engineers, and maintainability engineers with failure rate information in a convenient form.

The FARADA handbooks comprise five volumes encompassing more than 30,000 line entries of tabulated failure rate data; over 2,000 entries of failure mode distribution data; and stress curves on electronic parts/components. Each volume is updated quarterly, and the presentation of failure data is as follows:

Volume 1A	Computer printout of electrical and electronic failure rate data. See Figure B.12.
Volume 1B	Computer printout of mechanical, hydraulic, pneumatic, and pyrotechnic failure rate data. See Figure B.13.
Volume 2	Failure rate data presented as stress curves with environmental and application factors.
Volume 3	Failure rate data background information to support Volumes 1A, 1B, 2, and 4.
Volume 4	Failure mode data to implement application of the failure rate data of Volumes 1A, 1B, 2, and 3. See Figure B.14.

Although the IDEP/FARADA programs are not power plant or systems oriented, their generic code system is of value when considering collection of manufactured data.

In the FARADA component code, the first three digits are the major classification corresponding to the part/component designation. These digits are followed by three additional two digit subclass groups which identify service, function, operation, etc. A partial list of major and

subclassifications is shown in Figures B.15 and B.16. For example, from Figure B.17, the index number for a common globe valve may be 925.60.75.84.

Since several subclasses, such as service, pressure range, power rating, etc., are applicable to a number of parts/components, common subclassifications have also been used according to the breakdown given in Figure B.17. In some cases, it was necessary to break down the two digit subclasses to the point where each digit gives a subclassification description. For example, in the second subclass for the globe valve mentioned above the first numeral described the pressure range and the second numeral described the function.

UNIFORM SUBJECT INDEX FOR NUCLEAR POWER DEMONSTRATION (NPD) PROJECT

In 1958, a Uniform Subject Index (USI) was established for the Nuclear Power Demonstration (NPD) project in order to better coordinate files and accounts between different functional groups such as engineering, purchasing, accounting, operating, and maintenance. Prior to establishing this index, a careful review was made of the Hydro-Electric Power Commission (HEPC) breakdowns for hydraulic and thermal projects and the Uniform System of Accounts of the U. S. Federal Power Commission (FPC). Subjects peculiar to nuclear power stations were considered and an index was selected which required minimal changes from project to project.

The resulting USI breakdown is based on a five digit coding system using numbers rather than letters and is limited to 0 to 9 at each level. For a given system, the numbers 1 through 9 are used to represent the real physical breakdown. Alternative nonphysical breakdowns which an engineer may desire are often provided as a software breakdown in the "0" or general series. This provides further flexibility in extending the index system without affecting the breakdown based on the real physical systems.

Level 1 Breakdown

The Level 1 breakdown fundamentally reflects the major divisions for other projects in the HEPC, and is as follows:

- 0 - General
- 1 - Site and Improvement

- 2 - Buildings, Structures, and Shielding
- 3 - Steam Generation (Reactor-boiler and auxiliaries)
- 4 - Turbine-Generator and Auxiliaries
- 5 - Electrical
- 6 - Instrumentation and Control
- 7 - Common Processes and Services
- 8 - Plant Construction
- 9 - Indirect Costs

The scope of each of these major level breakdowns are expected to fit fairly well with any type of nuclear power station. Item 6 is a major exception to the FPC practice on which the USI is based. However, since Item 6 is further subdivided according to the common practice, identification becomes easier.

Shielding which does not form a part of a conventional station has been included as an extension to Item 2. The main generator which is conventionally handled as part of the turbine generator could have been included in either Item 4 or 5. It has been included under Item 4. One other exception is the circulating water system. It was considered economically advantageous to combine water supply requirements, so the circulating water system has been included under water supplies in Item 7.

Level 2 Breakdown

The Level 2 breakdown is set up to conform to a breakdown suitable for a particular type reactor. A breakdown which would be to a large extent the same for different projects employing a heavy water type of nuclear power generating station.

The Level 2 breakdown, as a general rule, corresponds to a group of related systems as shown in the example below:

- 71 Water Supply Systems
- 72 Drainage Systems
- 73 Ventilation Systems

Level 3 Breakdown

As a general rule, the Level 3 breakdown corresponds to a particular system; for example:

- 711 Intake Water System
- 712 Circulating Water System
- 713 Process Water System
- 714 Standby Water System
- 715 Domestic Water System

Level 4 and Level 5 Breakdowns

Further breakdowns into subsystems and types of equipment have been made to suit the needs of Level 3 breakout. As an example, a standard breakdown of fluid systems is shown below:

- 0 General
- 1 Heat exchangers, heaters, coolers
- 2 Pumps, fans
- 3 Valves
- 4 Tanks, receivers
- 9 Piping, ducting

Deficiency Reports

Based on an operating philosophy of minimizing paper work, deficiency reports have been relied on to collect input data for reliability analysis. Experience has shown that these reports are the best source of data and require a minimum amount of interpretation.

Deficiency reports, a sample form of which is shown in Figure B.18, are used when deficiencies are noted in equipment, design, procedures or operation to provide:

1. A means of reporting a deficiency to a work unit in order to have it corrected, and
2. A means of recording deficiencies and corrective actions, with minimum details necessary for evaluating system reliability.

Deficiency reports are handled according to the flow shown in Figure B.19. The originator completes the upper portion of the form by identifying the system, including its failure mode and shutdown requirements and describing the deficiency itself. The white original and the yellow copy are forwarded to an appropriate work unit which will take corrective action, and the pink copy is retained in the control room for information and follow-up purposes. Upon completion of the work requested, the work unit completes the lower portion of the form and forwards the yellow copy to the originator and his shift supervisor. The white copy is generally retained in the work unit files. If the work has been completed to the satisfaction of the originator and the supervisor, the pink copy is removed from the pending file and destroyed. The yellow copy is placed in the permanent file by the clerical unit for future reference and review including that by the reliability engineer. A space is provided at the bottom of the form for comments by any person during routing.

AEC UNIFORM SYSTEM OF ACCOUNTS

In the development of different nuclear power plant designs, many economic data have been submitted to AEC in proposals and studies by industrial organizations; however, direct comparison between different designs were often very difficult since a common set of ground rules for assumptions, site criteria, and format for presenting data were generally lacking. In 1962 the AEC Division of Reactor Development authorized the publication of the first edition of a Guide to Nuclear Power Cost Evaluation⁽⁹⁾ to fulfill this need.

In the Guide, a uniform system of accounts is developed for estimating and reporting construction costs for nuclear power and related transmission and general plant facilities. This system was designed by the AEC Division of Finance to provide the means for standard distribution of nuclear power plant costs and to facilitate the comparative economic analyses of various nuclear power plant concepts.

The direct cost accounts have been keyed to the Electric Plant Accounts⁽¹⁰⁾ established by the U. S. Federal Power Commission (FPC) as shown by the example in Table B.19.

The AEC system of accounts is designed to facilitate cost estimates and production cost analyses for proposed nuclear power plant concepts as well as for completed nuclear power plants. The principal difference between the AEC system of accounts and that of the FPC is that the latter is designed for use in recording costs of completed plants after the

allocation of indirect construction cost, whereas the AEC system is designed for use during the construction period prior to the allocation of indirect construction costs; and, therefore, provides separate accounts for these costs (account nos. 98 and 99).

A summary of the AEC classification of construction accounts is shown in Table B.20. An example of a detailed listing of the AEC accounts, together with a brief description of the equipment, materials, and services covered by each of the major accounts is shown in Table B.21.

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3. "Computer Program to Evaluation of Data from Military Nuclear Power Plants," AFWL TR-65-14, Westinghouse Electric Corporation, Atomic Power Division, July 1965.
4. Hanifan, D. T., R. A. Westland, L. B. Sklar, and D. A. Atkins, "Maritime Administration Maintenance and Reliability Program," Vols. I-IV, MA-3402, Dunlap and Associates, Inc., 1965.
5. Atkins, D. A. and A. W. Harbaugh, "Merchant Ship Maintenance and Reliability," Society of Naval Architects and Marine Engineers, Southern California Section, February 11, 1965.
6. "Analytical Report of Equipment Availability for the Seven-Year Period 1955-61." EEI No. 63-42, Edison Electric Institute, May 1963.
7. "Report on Equipment Availability for the Five-Year Period 1960-64," EEI No. 65-35, Edison Electric Institute, May 1965.
8. "Army, Navy, Air Force, and NASA Failure Rate Data (FARADA) Program," Revision 1, May 1966, U. S. Naval Fleet Systems Analysis and Evaluation Group, Corona, California.
9. "Guide to Nuclear Power Cost Evaluation," Kaiser Engineers, TID-7025, March 15, 1962.
10. "Uniform System of Accounts Prescribed for Public Utilities and Licenses of the Federal Power Commission," January 1, 1961.

TABLE B.1

UKAEA FAULT CLASSIFICATION SYSTEM

Data	Column Allocation
Fault Number	1 - 5
Date	
Day	6 - 7
Month	8 - 9
Year	10 - 11
Reactor Identification	12 - 13
Plant Type	14 - 21
Component Type	22 - 27
Fault Importance	28 - 31
Fault Type	32 - 36
Effect	37 - 38
Site Reference Number	41 - 45
Site Run Number	46 - 50
Time Since Start of Run	
Hours	51 - 53
Fraction of Hours	54
Time Reactor Out of Operation	
Hours	55 - 57
Fraction of Hours	58
Reactor Power at Occurrence of Fault	59 - 61
Fraction	62
Unit of Power (MW, KW, or W)	63
Whether Poisoned Out	64
Method of Shutdown	65 - 66
Mark Number of Faulty Component	67 - 68
Unused Columns	39-40, 69-74

TABLE B.3

PARTIAL LIST OF COMPONENT TYPES*

Not Applicable	0				
Electrical	1				
Control Equipment	1	1			
Switches	1	1	1		
Limit	1	1	1	1	
Micro	1	1	1	2	
Anti-Vibration	1	1	1	3	
Reset Position	1	1	1	4	
Range Selector	1	1	1	5	
Relays	1	1	2		
Contacts	1	1	2	1	
Winding	1	1	2	2	
Sealed	1	1	2	3	
Moving Coil	1	1	2	4	
Meters	1	1	3		
Frequency Meter	1	1	3	1	
Indicating Lamps	1	1	4		
Ordasign	1	1	4	1	
Alarms	1	1	4	2	
Overrun Lights	1	1	4	3	
Voltage Regulators	1	1	5		
Variacs	1	1	5	1	
Synchro Equipment	1	1	6		
Magslips	1	1	7		
Transmitters	1	1	7	1	
Receivers	1	1	7	2	
Drives	1	1	7	3	
General Equipment	1	2			
Distribution Board Links	1	2	1		
Starters	1	2	2		
Motor Starters	1	2	2	1	
Interlocks	1	2	2	1	1
U/V Solenoid	1	2	2	1	2
Auxiliary Contacts	1	2	2	1	3
Overload Protection	1	2	2	1	4
Crane Controllers	1	2	2	2	
Drum Segments	1	2	2	2	1
Commutators	1	2	3		
Components	1	2	4		
Transformers	1	2	4	1	
Rectifiers	1	2	4	2	
Suppressors	1	2	4	3	
Transducers	1	2	4	4	
Pressure	1	2	4	4	1
Circuit Protection Systems	1	2	5		
Fuses	1	2	5	1	
Heaters	1	2	6		
Switches	1	2	7		

*Code numbers left adjusted beginning with Column 22.

TABLE B.4
FAULT IMPORTANCE*

A.	Faults or actions which place the reactor in a dangerous state.	1	1	0
A.1	Faults or actions resulting in significant hazard or damage to plant.	1	1	1
A.1.1	Faults or actions resulting in significant hazard or damage to plant and injury to personnel.	1	1	1 1
A.2	Faults or actions prevented from resulting in significant hazard or damage to plant or personnel by circumstances outside those envisaged in the equipment design.	1	1	2
A.3	Faults or actions prevented from resulting in significant hazard or damage to plant or personnel by the ultimate available protection.	1	1	3
B.	Faults or actions which reduce reactor safety.	1	2	0
B.1	Failure to operate of any trip equipment which reduces reactor safety.	1	2	1
B.1.1	Failure to operate of any trip equipment which reduces reactor safety and results in personnel hazard.	1	2	1 1
B.2	Faults or actions affecting the correct functioning of important plant equipment (other than trip equipment) which reduces reactor safety.	1	2	2
B.2.1	Faults or actions affecting the correct functioning of important plant equipment (other than trip equipment) which reduces reactor safety and results in personnel hazard.	1	2	2 1
B.3	Incorrect adjustment of plant trip levels which reduces reactor safety.	1	2	3
B.3.1	Incorrect adjustment of plant trip levels with the result that the reactor actually trips at a level above the correct value, reducing reactor safety and resulting in personnel hazard.	1	2	3 1
B.4	Faults or actions which by themselves have not reduced reactor safety but have occurred so frequently as to raise doubts on the safety of the system, whether mechanical or human.	1	2	4
B.5	Error by operator in the control of important plant equipment which reduces reactor safety.	1	2	5
B.5.1	Error by operator in the control of important plant equipment which reduces reactor safety and results in personnel hazard.	1	2	5 1
C.	Faults or actions which do not reduce reactor safety.	2	0	
C.1	Faults or actions which do not reduce reactor safety when considered separately (N. B., if they occur frequently, they may come within Category B. 4).	2	1	
C.2	Reactor trip.	2	2	
C.2.1	From power.	2	2	1
C.2.2	When at shutdown.	2	2	2
C.3	Loss of operating time.	2	3	
C.3.1	Prevention of startup.	2	3	1
C.3.2	Deliberate shutdown.	2	3	2
C.4	Faults found during routine testing.	2	4	
C.5	Giving rise to high maintenance attention.	2	5	
C.6	Incorrect displayed information (recorders).	2	6	
C.7	Incorrect displayed information (electronic instruments).	2	7	
C.8	Incorrect displayed information (all other reactor displays).	2	8	
C.9	Unexpected activity levels.	2	9	
D.	Events which have no safety significance whatsoever.	3		

*Code numbers left adjusted beginning with Column 28.

TABLE B.5

PARTIAL LIST OF FAULT TYPES*

Electrical	1			
Mains Supply	1	1		
Failure	1	1	1	
Local to Component	1	1	1	1
Surge Effects	1	1	2	
Voltage Variations	1	1	2	1
Synchronization Faults	1	1	3	
Standby Supply	1	2		
Failure	1	2	1	
Surge Effects	1	2	2	
Synchronization Faults	1	2	3	
Experimental Facilities and Rigs Supply	1	3		
Failure	1	3	1	
Surge Effects	1	3	2	
Fault on Component (or Plant)	1	4		
Failure	1	4	1	
Defective	1	4	2	
Overheating	1	4	2	1
Arcing	1	4	2	2
Short Circuit	1	4	2	3
Open Circuit	1	4	2	4
Faulty Operation	1	4	2	5
No Operation	1	4	2	6
Reduced Performance	1	4	2	7
Insulation Breakdown	1	4	2	8
Adjustment	1	4	2	9
Incorrect Item	1	4	3	
Blown Fuse	1	4	4	
Damaged	1	4	5	
Timing and Sequence Faults	1	4	6	
Earth Faults	1	4	7	
Wiring	1	5		
Defective	1	5	1	
Dry Joints	1	5	1	1
Lack of Continuity	1	5	1	2
Damaged	1	5	1	3
Incorrect Item	1	5	2	
Incorrect Layout	1	5	3	
Faulty Connections	1	5	4	
Circuit Faults	1	6		
Assembly Faults	1	7		
Faults Causing Spurious Operation	1	8		
Control Systems and Instrumentation	1	8	1	
Mains Interference	1	8	1	1
Electrical Pickup	1	8	1	2
Earth Faults	1	8	1	3
Faulty Connections	1	8	1	4
Others	1	8	2	

*Code numbers left adjusted beginning with Column 32.

TABLE B.6

EFFECTS*

Reactor Power Effects	1	
Fluctuations	1	1
Overshoot	1	2
Reduction	1	3
Fuel Handling Effects	2	
Element Dropped	2	1
Element Lowered Inadvertently	2	2
Element Raised Inadvertently	2	3
Damage to Adjacent Plant or Equipment	3	
Fuel Defects	4	
Canning Failures	4	1
Fitment Failures	4	2
Element Bowing	4	3
Reactor Pressure Circuit Effects	5	
Depressurization	5	1

*Code numbers left adjusted beginning with Column 37.

TABLE B.7

MISCELLANEOUS COLUMN ALLOCATIONS*

<u>Power</u>		<u>Whether Poisoned Out</u>	
M (Megawatts)	0	P (Poisoned)	0
K (Kilowatts)	1		1
W (Watts)	2		
	3		

<u>Method of Trip</u>		<u>Reactor State</u>	
Auto Trip	0 0	Warning Only	0 0
Manual Trip	0 1	Steady	0 1
Control Shutdown	0 2	Full Power	0 2
No Shutdown	0 3	Raising Power	0 3
No Startup	0 4	Startup	0 4
Controlled Power, Reduction	0 5	δK's (Low Power)	0 5
Power Setback	0 6	Subcritical	0 6
Moderator Dumped	0 7	Experimental Run	0 7
Moderator Partially Dumped	0 8	Shutdown	0 8
	0 9	Critical	0 9
		Reducing Power	1 0
		Being Shutdown	1 1
		Partial Dumped	1 2
			1 3

*Code numbers assigned to columns as indicated in Table B.1.

TABLE B.8

PM-1 MALFUNCTION PACKET CARD NO. 2

Data	Column Allocation
Packet Card Number	1 - 2
Malfunction Packet Identification	3 - 4
Reactor Identification	5 - 9
Code Number	10 - 11
Day	12 - 13
Month	14 - 15
Year	16 - 17
Subsystem Code	18 - 20
Component Location	21 - 22
Component Code	23 - 27
Time of Occurrence or Discovery	28 - 31
Repair Time, Hours	32 - 35
Time Generator Off, Hours	36 - 39
Time Reactor Not Critical, Hours	40 - 43
Malfunction Code	44
Percent Power Cutback	45 - 46
Safety Code	47
Shutdown Code	48
Description of Shutdown	49 - 78
Packet Card Number	79 - 80

TABLE B.9
MALFUNCTION PACKET CARD NO. 3

Data	Column Allocation
Packet Card Number	1 - 2
Same as Card No. 2	3 - 17
Cost of Repair, Dollars	18 - 23
Cost of Repair by Outside Contract, Dollars	24 - 29
Failure Code	30 - 31
Description of Failure Code	32 - 78
Packet Card Number	79 - 80

TABLE B.10

PARTIAL LIST OF SUBSYSTEM AND COMPONENT CODES

SUBSYSTEM CODES

CA	Coolant Chemical Addition
CC	Coolant Charging System
CP	Coolant Purification System
CW	Cooling Water System
DB	Decontamination Building and Equipment
DC	Vital AC and DC Systems
DH	Decay Heat Removal System
DV	Coolant Discharge and Vent System
EP	Emergency Power System
ES	Extraction Steam System
FC	Fuel Cask and Cooling System
FP	Fire Protection and Alarm System
FW	Feedwater System
HC	Reactor Plant Heating and Cooling System
HV	Heating, Air Conditioning, and Ventilating Systems
IA	Instrument Air System
LS	Lighting Distribution System
MC	Main Condenser and Condensate System
MS	Main and Auxiliary Steam System

COMPONENT CODES

AB	Auxiliary Boiler	DOR	Door
AC	Air Conditioner	DRY	Dryer
AD	Air Dryer	DS	Desuperheater
AE	Air Ejector	EPT	Electropneumatic Transducer
AL	Alarm	EV	Evaporator
AM	Amplifier	EXC	Exciter
AN	Annunciator	EXT	Extinguisher
AS	Air Sampler	FA	Fan
AU	Auctioneer	FGB	Blind Flange
BA	Battery	FH	Fume Hook
BAL	Balance	FI	Filter

TABLE B.11

MALFUNCTION, SAFETY, AND SHUTDOWN CODES

MALFUNCTION CODE

01	Normal Shutdown
02	Scram
03	Power Cutback
04	None of the Above

SAFETY CODES

01	Actual External Release of Radioactivity
02	Potential External Release of Radioactivity
03	Actual Internal Release of Radioactivity
04	Potential Internal Release of Radioactivity
05	Actual Inadvertent Increase in Reactor Reactivity
06	Potential Increase in Reactor Reactivity
07	No Effect

SHUTDOWN CODES

01	Schedule for Maintenance
02	Schedule for Training or Demonstration
03	Schedule for Test
04	Refueling
05	Component Malfunction
06	Operator Error
07	Not Used
08	Other

TABLE B.12

FAILURE CODES

Mechanical	Electrical	Instrumentation
01 Leak External	21 Short Circuit	41 Electronic Tube Failure
02 Leak Internal	22 Open Circuit	42 Transistor Failure
03 Rupture or Crack External	23 Ground	43 Geiger Mueller Tube
04 Rupture or Crack Internal	24 Insulation Failure	44 BF3 Chamber Failure
05 Bearing Failure	25 Brush Failure	45 Ion Chamber Failure
06 Clog	26 Loss of Sensitivity	46 Alignment or Calibration
07 Jammed or Stuck	27 Diode Failure	47 Connectors--Terminal Fail
08 Gasket Failure	28 Relay Failure	48 Resistor Failure
09 Mechanical Linkage Failure	29 Overload Heater	49 Power Supply Failure
10 Packing	30 Coil Failure	50 Cable-Radiation Damage
11 Seal Failure	31 Contact Failure	51 Controller--M62
12 Corrosion	32 Switch Failure	52 Capacitor Failure
13 Valve Seats	33 Overload	53 D-P Cell Failure
14 Score--Stem or Shaft	34 Physical Damage	54 Transformer
15 Tube Failure	35 Power Cable	55 Drive or Torque Motors
16 Lagging	36 Control Cable	56 Clean and Adjusted
17 Adjustment and Clean	37	57 Synchro-Dr. or Rec.
18 Piping Failure	38	58 Control Cable
19	39	59
20 Mechanical--Other	40 Electrical--Other	60 Instrumentation--Other
		<u>Others</u>
		61
		62
		63
		64
		65

TABLE B.13

LEVELS OF MARAD CLASSIFICATION

LEVEL	DEFINITION	EXAMPLES (Showing functional relations in the hierarchy)		
1. Identification/Design	Identification of the ship and characterization of the design.	MARAD Design Number		
2. Environment	Characterization of the ship's environment.	Trade Route		
3. System	Collection of subsystems and/or units which together perform a major function of the ship.	Power Supply and Propulsion		
4. Subsystem	Collection of related units and components which perform a major subfunction of the system.	Steam		Drive
5. Unit	Set of one or more highly related components and assemblies which are a major portion of a subsystem.	Steam Supply		Steam Expansion
6. Component	Piece of equipment which performs some specific basic operation.	Boiler	Main Steam Piping	High Pressure Drive Turbine
7. Assembly	Set of subassemblies and/or parts which is a major part of a component and which is usually replaceable.	Steam Drum	Valves	Rotor
8. Subassembly	Connected set of parts which is a removable portion of an assembly.		Main Steam Stop Valve	
9. Part	Basic element which ordinarily cannot be further disassembled.	Drum	Stop Valve Body	Blade
10. Subpart	Specific characteristic portion of a part.		Inlet Flange	Root

TABLE B.14

SYSTEMS AND SUBSYSTEMS

System and Subsystem Letter	System and Subsystem
A	Automatic Control System
C	Communications System
CB	External Communications Subsystem
CC	Internal Communications Subsystem
E	Electrical System
EB	Generation Subsystem
EC	Distribution Subsystem
F	Fuel Oil and Ballast System
K	Cargo System
KB	Dry Cargo Subsystem
KC	Liquid Cargo Subsystem
L	Life Support System
LB	Accommodation Subsystem
LC	Life Saving Subsystem
M	Mooring System
N	Navigation System
NB	Position Subsystem
NC	Safety Subsystem
P	Power and Propulsion System
PB	Steam Subsystem
PC	Drive Subsystem
R	Preservation and Repair System
RB	Damage Control Subsystem
RC	Maintenance and Repair Subsystem
RD	Protection Subsystem
S	Steering System
SB	Main Steering Subsystem
SC	Auxiliary Steering Subsystem
T	Structural System
V	Environmental Conditioning System
VP	Accommodations Subsystem
VC	Machinery Spaces Subsystem
VD	Cargo Spaces Subsystem
VE	Refrigeration Spaces Subsystem
W	Water System
WB	Freshwater Subsystem
WC	Saltwater Subsystem

TABLE B. 15

COMPONENT AND ASSEMBLY LIST

Component Index 1 Assigned Numbers	Assembly Index 3 Assigned Numbers	Component/Assembly
240-259		Pumps
250		Pumps, Disposal
255		Pumps, Hydraulic
	01	Pump
	02	Coupling
	98	Controller
	99	Motor
260-279		Ducts
	01	Ducts and Fittings
	02	Dampers
	03	Terminals
	96	Insulation and Lagging
280-299		Fans
281		Fans, Intake
282		Fans, Exhaust
	01	Fan
	98	Controller
	99	Motor
300-319		Instruments
	95	Gauges and Thermometers
320-339		Compressors
321		Compressors, Liquid
322		Compressors, Air
	01	Compressor
	02	Condenser
	03	Coupling
	98	Controller
	99	Motor

TABLE B. 16

COMPONENT TYPE LIST (INDEX 2)

Component Type Code Index 2	Component and Type
A	Used to indicate no distinguishable types.
B	Used to indicate alternate type which is not listed.
	<u>Boilers</u>
C	Sectional Header
D	Bent Tube
E	Top Fired
	<u>Capstans</u>
C	Electric
D	Electrohydraulic
E	Steam
	<u>Compressors</u>
C	Centrifugal
D	Rotary
E	Reciprocating
	<u>Condensers and Heat Exchangers</u>
C	Single Pass
D	Double Pass
E	Multiple Pass
	<u>Cranes</u>
C	Revolving
D	Overdeck Gantry
E	Underdeck Gantry
	<u>Deaerators</u>
C	Vertical STM Jet, Direct Contact
D	Flash

TABLE B.17

EEI - TYPE OF OUTAGE

Code No.	Type of Outage	Description
1	Forced Outage	An outage which requires a major piece of equipment be taken out of service.
2	Scheduled Shutdown	An outage which can be planned in advance or for which the starting date is controllable beyond the weekend of the week during which component trouble occurred.
3	Reserve Shutdown	Shutdown in which the complete unit or its turbine, generator, or boiler could be operated, but is placed on reserve because of fuel economy or any other reason.
4	Not Used At Present	
5	Forced Partial Outage	A reduction in maximum capacity available to the system of 30 Mw or more lasting for 1 hour or more.
6	Scheduled Partial Outage	Partial outage which, by definition, not a forced partial outage.

TABLE B.18
FAILURE TYPE

<u>BOILERS</u>			
<u>Code</u>		<u>Code</u>	
100	Boiler	125	Acid Cleaning
101	Water Walls	126	Boiler Casing, Breeching and Ducts
102	Generating Tubes	127	Soot Blowers
103	Superheater	128	Boiler Circulating Pumps
104	Reheater - First	129	
105	Reheater - Second	130	Precipitator - Electrical
106	Economizer	131	Precipitator - Mechanical
107	Air Preheater - Tubular	132	Burners (including cyclones)
108	Air Preheater - Regenerative	133	Demineralizer
109	Induced Draft Fans	134	Boiler Control**
110	Forced Draft Fans	135	Miscellaneous
111	Recirculating Fans	136	Furnace Slagging
112	Desuperheaters and Attemperators	137	Superheater Fouling
113	Bypass Dampers	138	Reheater Fouling
114	Furnace Refractory	139	Air Heater Fouling
115	Safety Valves	140	Induced Draft Fan Fouling
116	Steam Valves and Piping	141	Precipitator Fouling
117	Valves and Piping - Feedwater and Blowdown	142	Wet Coal
118	Gage Glasses	143	Poor Quality Coal (low BTU)
119	Slag and Fly Ash Disposal System	144	Boiler Water Condition (silica control)
120	Stack	145	Pulverizer Capacity Limited (due to wear or outages)
121	Pulverizers	146	Ashpit Trouble
122	Stokers	147	Fly Ash Disposal Trouble
123	Fuel Handling Equipment (gas-oil-coal)		
124	Fireside Cleaning		
<u>TURBINES</u>			
200	Turbines	209	Wheels or Spindles
201	Bolting or Casing Dismantle and Reassembly	210	Buckets or Blades
202	Governors	211	Vibration of Turbine Generator Unit*
203	Control, Turbine, and Reheat Stop Valves	212	Lube Oil System and Bearings (except bearing vibration)
204	Shaft Packing	213	Turbine Control**
205	Nozzles and Nozzle Blocks	214	Miscellaneous
206	Nozzle Bolting (1st Stage)	215	Blade Fouling
207	Diaphragms	216	Shell Leaks
208	Shaft	217	Seal Leaks

TABLE B.18 (continued)

<u>GENERATORS</u>	
300 Generator	307 Generator Control**
301 Oil Leakage	308 Exciter
302 Cooling System - Air	309 Miscellaneous
303 Cooling System - Hydrogen	310 Cooling System Fouled - Water Side
304 Cooling System - Liquid	311 Cooling System Fouled - Gas Side
305 Stator (including windings, iron bushings, and terminals)	312 Hot Spots in Windings
306 Rotor (including windings, iron collector, and brush rigging)	313 Shaft Seals Leaking
	314 Hydrogen Pressure Low
<u>CONDENSERS</u>	
400 Condenser	405 Air Removal Pumps
401 Cleaning	406 Shell
402 Tube Failure (including leakage)	407 Controls for Condenser and Its Auxiliaries**
403 Condenser Cooling Water Pumps (including piping)	408 Miscellaneous
404 Condensate Pumps	409 Air Leakage
<p>*Vibration - Include all balancing of the unit as Code 211.</p> <p>**Control - Codes 134, 213, 307, and 407 are to be used when the control associated with the major piece of equipment is directly responsible for the outage or is being worked on.</p>	
<u>OUTAGES CAUSED BY OTHER THAN MAJOR EQUIPMENT</u>	
500	This code is to be used whenever there is an outage which causes the turbine and/or boiler to be unavailable but is not directly chargeable to the turbine, generator, condenser, or boiler. This code is to show outages for such incidents as operating errors, floods, earthquakes, failure of transmission lines, loss of main transformer, loss of feedwater heaters, or the failure of any equipment other than the turbine, generator, condenser, or boiler.
500 Other	503 Main Transformer Trouble
501 Feedwater Heaters - Leaking	504 Switchgear Trouble
502 Feedwater Heaters - Dirty	505 Boiler Feed Pumps (including drivers and coupling)
<p>NOTE: The boilers, turbines, generators and condensers are referred to as "Major Equipment." The coded items referred to under each piece of major equipment are referred to as "Components."</p>	

TABLE B.19

EXAMPLE OF AEC-FPC ACCOUNT NUMBER CORRELATION

Description	AEC Account Number	FPC Account Number
<u>Nuclear Production Plant</u>		
Land and Land Rights	20	320
Structures and Improvements	21	321
Reactor Plant Equipment	22	322
Turbine-Generator Units	23	323
Accessory Electric Equipment	24	324
Miscellaneous Power Plant Equipment	25	325
<u>Transmission Plant</u>		
Land and Land Rights	50	350
Clearing Land and Rights-of-Way	51	351
Structures and Improvements	52	352
Station Equipment	53	353
Towers and Fixtures	54	354
Poles and Fixtures	55	355
Overhead Conductors and Devices	56	356
Underground Conduit	57	357
Underground Conductors and Devices	58	358
Roads and Trails	59	359
<u>General Plant</u>		
Communication Equipment	97	397

TABLE B. 20

AEC CLASSIFICATION OF CONSTRUCTION ACCOUNTS
NUCLEAR POWER PLANTS

Account Number	
<u>NUCLEAR PRODUCTION PLANT</u>	
20	<u>Land and Land Rights</u>
201	Land and privilege acquisition
202	Relocating highways and railroads
203	Relocating telephone and power lines
21	<u>Structures and Improvements</u>
211	Ground improvements
212	Buildings
218	Stacks
219	Reactor containment structure
22	<u>Reactor Plant Equipment</u>
221	Reactor equipment
222	Heat transfer systems
223	Fuel handling and storage equipment
224	Fuel processing and fabricating equipment
225	Radioactive waste treatment and disposal
226	Instrumentation and control
227	Feedwater supply and treatment
228	Steam, condensate and feedwater piping
229	Other reactor plant equipment
23	<u>Turbine-Generator Units</u>
231	Turbine-generators
232	Circulating water systems
233	Condensers
234	Central lubricating system
235	Turbine plant boards, instruments and controls
236	Turbine plant piping
237	Auxiliary equipment for generators
238	Other turbine plant equipment

TABLE B. 20 (continued)

Account Number	
24	<u>Accessory Electric Equipment</u>
241	Switchgear
242	Switchboards
243	Protective equipment
244	Electrical structures
245	Conduit
246	Power and control wiring
247	Station service equipment
25	<u>Miscellaneous Power Plant Equipment</u>
251	Cranes and hoisting equipment
252	Compressed air and vacuum cleaning systems
253	Other power plant equipment
	<u>TRANSMISSION PLANT</u>
50	<u>Land and Land Rights</u>
51	<u>Clearing Land and Rights-of-Way</u>
52	<u>Structures and Improvements</u>
521	General yard improvements
522	Substation buildings
523	Outdoor substation structures
53	<u>Station Equipment</u>
531	Switchgear
532	Protective equipment
533	Main conversion equipment
534	Conduit
535	Power and control wiring
536	Station service equipment

TABLE B. 20 (continued)

Account Number	
54	<u>Towers and Fixtures</u>
55	<u>Poles and Fixtures</u>
56	<u>Overhead Conductors and Devices</u>
57	<u>Underground Conduit</u>
58	<u>Underground Conductors and Devices</u>
59	<u>Roads and Trails</u>
	<u>GENERAL PLANT</u>
97	<u>Communication Equipment</u>
	<u>DISTRIBUTIVES</u>
98	<u>Indirect Construction Costs</u>
981	Engineering, design, and inspection
982	General and administrative
983	Other indirect costs
984	Earnings and expenses during construction
985	Interest during construction
99	<u>Miscellaneous Construction Costs</u>
991	Construction inventories
992	Temporary construction facilities
993	Construction equipment and tools
994	Construction clearing accounts
	<u>CONTINGENCY</u>

TABLE B. 21

EXAMPLE OF DETAILED ACCOUNT LISTING

Account Number	
22	<u>Reactor Plant Equipment</u>
221	<u>Reactor equipment</u>
	Reactor vessel and supports, core supports and retainers within vessel, shielding, control rods including absorbers and drives, moderator and reflector, shutdown cooling facilities, and vapor containers when installed within a building.
. 1	Reactor vessel
. 11	Vessel supports
. 12	Vessel
. 13	Vessel internals, removable, including core supports and retainers, thermal shields, steam scrubbers and driers
. 2	Reactor controls
. 21	Control rods, including absorber sections
. 22	Housing, guide tubes and shrouds
. 23	Drive mechanisms or systems
. 24	Supplementary control systems
. 25	Neutron source
. 3	Reactor shielding
. 31	Thermal neutron shields including shield tanks
. 32	Biological shield
. 33	Blast shield (if other than biological shield)
. 34	Shield cooling system
. 4	Reactor auxiliary cooling and heating systems
. 41	Safety injection system
. 42	Emergency shutdown cooling system
. 43	Decay heat removal system
. 44	Component cooling system
. 45	Preheating system
. 46	Post-incident cooling system
. 47	Pressure suppression system
5	Reactor plant containers in the form of tanks installed within a building
. 51	Containers, including supports
. 52	Floors and barriers
. 53	Drainage systems
. 54	Ventilation and cooling systems
6	Moderator and reflector including cladding, if any, except fluids serving as both moderator and coolant (Account 222.6)
. 61	Moderator
. 62	Reflector
7	Reactor plant cranes and hoists
222	<u>Heat transfer systems</u>
	Reactor coolant system, intermediate coolant system, coolant charging and discharging systems, coolant sampling and purification equipment, steam generators, and superheaters
. 1	Reactor coolant system
. 11	Pumps and drives
. 12	Coolant piping and valves
. 13	External steam drums and/or separators when integral with reactor coolant system for direct cycle water reactors
. 2	Intermediate coolant system
. 21	Pumps and drives
. 22	Piping and valves
. 23	Intermediate heat exchangers
. 3	Steam generators and superheaters, including steam drums and/or separators for indirect cycle plants
. 31	Steam generators
. 32	Superheaters
. 33	Steam drums and internals
. 34	Steam separators

Taken from TID-7025

SAFETY REPORT					
COVERS PERIOD FROM 41163 to 311064					
Plant	Date	Component	Fail Type	Shutdown	Safety Hazard
PM1	41163	SUS	17	No	7
PM1	41163	SC	18	No	7
PM1	51163	MJ	12	Yes	2
PM1	51163	PP	11	No	7
PM1	51163	PP	11	No	7
PM1	51163	MJ	12	Yes	2
PM1	51163	MJ	12	Yes	2
PM1	51163	MJ	12	Yes	2
PM1	51163	MJ	12	Yes	2
PM1	51163	MJ	12	Yes	2
PM1	61163	IM	41	No	7
PM1	61163	LA	60	No	7
PM1	61163	LA	60	No	7
PM1	61163	SC	18	No	7
PM1	71163	IE	10	No	7
PM1	81163	IM	46	No	7
PM1	91163	PS	42	No	7
PM1	91163	PS	42	No	7
PM1	91163	PS	42	No	7
PM1	111163	VL	10	No	7
PM1	111163	VL	10	No	7
PM1	111163	VG	10	No	7
PM1	111163	VG	10	No	7
PM1	121163	AM	42	No	7
PM1	121163	RF	2	No	7
PM1	131163	IM	47	No	7
PM1	161163	CH	48	No	7
PM1	181163	WD	22	No	7
PM1	181163	IM	49	No	7
PM1	191163	PHM	41	No	7
PM1	191163	ND	50	No	7
PM1	201163	VL	13	Yes	5
PM1	201163	VL	13	Yes	5

FIGURE B. 1

SAMPLE SAFETY REPORT

(ALL TIME IN HOURS)

PLANT PM1
DATE 300365
PERIOD OF REPCRT 41163 TO 311064
PLANT STARTUP DATE 210262
PRESENT CORE STARTUP DATE 210262

COMP. CODE	NO. IN SUBSYSTEM	FAIL. TYPE	TOT. FAIL.	TOT. DOWN TIME	AV. DOWN TIME	TOT. CUTBACK TIME	AV. REPAIR TIME	FAIL. RATE	MAX. DOWN SHUTDOWN	CUTBACKS	SHUTDOWN	SCRAMS
SUS	6	17	1	0	0	0	7		0	0	0	0
SUS	6	20	2	0	0	0	30		0	0	0	0
SUS	6	61	1	0	0	0	165		0	0	0	0
SUS	6	40	1	0	0	0	2		0	0	0	0
TOTAL			5	0	0	0	46	.00019	0	0	0	0
RF	2	2	1	0	0	0	44		0	0	0	0
TOTAL			1	0	0	0	44	.00011	0	0	0	0
PP	1	20	1	0	0	0	33		0	0	0	0
PP	1	40	1	0	0	0	12		0	0	0	0
TOTAL			2	0	0	0	22	.00045	0	0	0	0
FL	2	20	3	0	0	0	100		0	0	0	0
TOTAL			3	0	0	0	100	.00034	0	0	0	0
DOR	7	20	1	0	0	0	6		0	0	0	0
TOTAL			1	0	0	0	6	.00003	0	0	0	0
GCS	1	20	2	0	0	0	24		0	0	0	0
TOTAL			2	0	0	0	24	.00045	0	0	0	0
TOTAL FOR SUBSYSTEM SB			14	0	0	0	48		0	0	0	0
SC	4	18	2	0	0	0	14		0	0	0	0
SC	4	20	1	0	0	0	8		0	0	0	0
SC	4	1	1	0	0	0	1		0	0	0	0

Taken from AFWL TR-65-14.

FIGURE B.2

SAMPLE FAILURE, SHUTDOWN, AND AVAILABILITY REPORT

B-45

AVAILABILITY REPORT

SHUTDOWN TYPE	NUMBER OF SHUTDOWNS	MIN. PERIOD BET. SHUTDOWNS	MAX. PERIOD BET. SHUTDOWNS	AVG. PERIOD BET. SHUTDOWNS	LONGEST SHUTDOWN	SHORTEST SHUTDOWN
7	7	1	336	53	600	8
8	6	0	0	0	51	51
1	7	8	792	218	2300	8
5	8	1	5586	978	123	7
2	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

TOTAL SHUTDOWNS	28
OVERALL MINIMUM PERIOD BETWEEN SHUTDOWNS	1
OVERALL MAXIMUM PERIOD BETWEEN SHUTDOWNS	5586
OVERALL AVERAGE PERIOD BETWEEN SHUTDOWNS	416
OVERALL LONGEST SHUTDOWN	2300
OVERALL SHORTEST SHUTDOWN	7
PLANT AVAILABILITY	.542
REACTOR AVAILABILITY	.991

SIX WORST COMPONENTS	NO. FAILURES
IM	12
IE	11
ND	11
HJ	11
AB	9
PP	8

END OF FILE

Taken from AFWL TR-65-14.

FIGURE B.2 (continued)

MAINTENANCE/REPAIR/INSPECTION REPORT

A. SHIP IDENTIFICATION

① Ship Name _____ ② Registered Hull No. _____ ③ Voyage No. _____ Prepared by _____ ④ Job No. _____

B. COMPONENT/ASSEMBLY IDENTIFICATION

⑤ Component Code _____ ⑥ Component/Assembly description _____ ⑦ Manufacturer _____ ⑧ Manufacturer's Model or Type No. _____
 ⑨ If Type Code A or B, describe type _____

C. MAINTENANCE, REPAIR, AND INSPECTION ACTIVITY DATA

Time Data	Type of Activity (Check and fill out section 13, 14, and/or 15.)
⑩ Activity Began Date _____ Time _____ ⑪ Activity Completed Date _____ Time _____ ⑫ Active Time Spent On Activity (hours) _____	⑬ Repair a. Reason for Repair: ☐ Complete failure ☐ Degraded performance ☐ Incipient failure: ☐ Excessive wear, corrosion, etc. ☐ Abnormal temp., noise, vibration, etc. ☐ Other _____ b. Condition discovered during: ☐ Operations: ☐ At sea ☐ In port ☐ Routine inspec./maint./servicing ☐ Lab or other special tests/examinations ☐ Regulatory inspection ☐ Other _____ ⑭ Regulatory Inspection a. Type of Inspection: ☐ ABS ☐ USCG ☐ Public Health ☐ Other _____ b. Ship delay due to inspection, if any, _____ hours ⑮ Routine Inspection/Maintenance/Servicing a. Reason for Inspection/Maintenance/Servicing: ☐ Company policy ☐ Manufacturer's suggested policy ☐ Chief Engineer's policy ☐ Other _____ b. Normal schedule for this inspec./maint./servicing action: Every: _____ hour(s) _____ day(s) _____ week(s) _____ month(s) _____ voyage(s) _____ year(s)

Action (Complete for repair, regulatory inspection and routine inspection/maintenance/servicing.)

⑯ Immediate Action	⑰ Subsequent Action	⑱ Type of Action (Check one or more as applicable.)	⑲ Result of Action
☐ Continue operation of affected equipment ☐ Shutdown affected equipment: ☐ Function not needed during shutdown ☐ Function needed during shutdown/switch to back-up or alternative equipment ☐ Function needed during shutdown, but no back-up or alternative equipment available	a. Location of Action: ☐ Shipboard: ☐ At sea ☐ Dockside - in port ☐ Dockside - shipyard ☐ Drydock ☐ Removed from ship to: ☐ Dockside shop/facility ☐ Contractor shop ☐ Shipyard shop ☐ Manufacturer b. Action performed by: ☐ Ship's crew ☐ Shore gang ☐ Contractor crew ☐ Shipyard crew ☐ Manufacturer	☐ Adjustment ☐ Replacement with another assembly/part: ☐ New ☐ Reconditioned ☐ Rework/Overhaul existing assembly/part: ☐ Complete or extensive reconditioning ☐ Patch or plug ☐ Rejoin (solder, weld, bolt, etc.) ☐ Other _____ ☐ Unfoul ☐ Clean ☐ Lubricate/change lubricant ☐ Disassemble/reassemble for repair/maint./service ☐ Replace/renew/add expendable element/material (filter element, chemical compound, etc.); describe _____ ☐ Open/inspect/close up ☐ Remove sample of for analysis/examination by _____ ☐ Other _____ ⑳ Describe action _____	☐ No effect of operation of affected equipment ☐ Temporary interruption of normal operations ☐ Operable, but degraded performance (less than rated operating condition) ☐ Unrepairable/inoperable (hold for arrival in port or shipyard) ☐ Temporary repair ☐ Permanent repair ㉑ Was this action a follow-up on a recent temporary repair? ☐ No ☐ Yes (Job No. _____)

㉒ What is the related preventive maintenance policy, if any? _____

㉓ What is the related inspection schedule? _____

D. FAILURE DATA (Complete for repair activities only.)

㉔ Failure Occurrence	㉕ Failure Type	㉖ Failure Cause	㉗ Effect on System	㉘ Effect on Ship's Progress
Date _____ Time _____ ㉚ Restoration to Service Date _____ Time _____ ㉛ Previous Assembly Failure Date _____	☐ Wear: ☐ Normal ☐ Abnormal ☐ Burn out ☐ Corrosion/Deterioration ☐ Fouling/Accumulation of foreign material ☐ Fracture ☐ Deformation ☐ Electrical (short, open) ☐ Other _____	☐ Normal use ☐ Improper operation ☐ Vibration ☐ Pressure build-up ☐ Environmental exposure ☐ Foreign abrasive material ☐ Inadequate preventive maintenance/servicing/cleaning: ☐ Lack of lube ☐ Other _____ ☐ Improper previous repair/installation ☐ Damage (by _____) ☐ Manufacturer's defect ☐ Poor design ☐ Other _____	☐ None ☐ Reduced to half rated performance ☐ Reduced to quarter rated performance ☐ Total loss of function ㉜ Describe failure _____ ㉝ Describe failure cause _____	☐ None ☐ Delayed (in port) How long? _____ ☐ Reduced speed (at sea) How long? _____ % reduction _____ ☐ Dead-in-the-water How long? _____

E. COMMENTS/RECOMMENDATIONS

FIGURE B. 3

SAMPLE SHIPBOARD DATA COLLECTION FORM (First of Two Sheets)

F. COST DATA

[illegible]

SAMPLE SHIPBOARD DATA COLLECTION FORM
(Second of Two Sheets)

FIGURE B. 5

MARAD MAINTENANCE AND RELIABILITY PROGRAM

A. FORCED OUTAGES				Boiler	Turbine	Generator
1. Number - - - - -	Total(a)			1,415	229	75
2. Number - - - - -	Per Unit(a)			3.2	0.5	0.2
3. Duration - - - - -	Hrs/Unit Rept'd			156	36	19
4. Duration - - - - -	Hrs/Outage			48	69	111
B. MAINTENANCE						
5. Manhours (Total)	Per Unit(b)			5,706	2,258	761
6. Manhours (Forced)	Per Unit(b)			490	97	67

BREAKDOWN OF PRINCIPAL COMPONENTS
BY SIZE AND STEAM TEMPERATURE

				SIZE - MW					TEMP. - F			
				50-89	90-129	130-199	200-389	390-599	900-955	1000-1010	1040-1060	1100-1200
TOTAL NO. OF UNITS REPORTED IN EACH CATEGORY(a)				50	124	143	119	2	16	263	153	6
CODE	NO.	% OF TOTAL	AVERAGE DURATION(c)	TOTAL FORCED OUTAGES								
<u>BOILER</u>												
101 Water Walls	310	21.9	44	4	55	128	107	14	5	102	188	13
103 Superheater	408	28.8	73	50	105	154	97	0	25	152	228	11
104 Reheater	184	13.0	42	14	50	76	45	0	7	70	102	6
TOTAL	902	63.7										
<u>TURBINE</u>												
203 Contr. Valves	54	23.6	38	1	13	14	25	1	0	21	32	0
210 Buckets & Blds.	10	4.4	553	0	1	2	5	0	2	3	6	1
211 Vibration	47	20.5	26	0	7	8	30	0	0	22	24	1
212 Oil Syst. & Brgs.	16	7.0	77	1	5	2	8	0	2	6	7	2
TOTAL	127	55.5										
<u>GENERATOR</u>												
305 Stator	6	8.0	610	0	4	1	1	0	2	3	1	0
306 Rotor	5	6.7	210	1	0	1	2	0	0	3	2	0
307 Gen. Control	7	9.3	3	0	2	1	3	0	0	5	3	0
308 Exciter	24	32.0	16	4	9	6	6	0	0	14	8	2
TOTAL	42	56.0										

NOTES:

(a) Based on total of 438 units reported.

(b) Based on total of 371 units for which manhours were reported.

(c) Total forced outage hours for each component divided by the number of outages.

Taken from EEI No. 65-35 "Report on Equipment Availability for the Five-Year Period 1960-1964," Edison Electric Institute, May 1965.

FIGURE B. 6

**ANALYSIS OF COMPONENT FORCED OUTAGES FOR THE YEAR 1964
CONVENTIONAL DRUM TYPE UNITS ONLY**

1 COMPONENT PART NAME PER GENERIC CODE Valves-Gas, NOC, 100-1000 PSIG, Relief, Pressure						2 PROGRAM OR WEAPON SYSTEM Hounddog						BD							
4. ORIGINATOR'S REPORT TITLE Design Proof Tests, Safety Relief Valves						5 ORIGINATOR'S REPORT NO. MD 63-110						3.		DAY		MO		YR	
												TEST COMPL.				9		63	
						6 TEST TYPE, ETC. Design Proof						REPT COMPL.		20		11		63	
7 THIS TEST (SUPERSEDES) (SUPPLEMENTS) REPORT NO:																			
8A PART TYPE, SIZE, RATING, LOT, ETC.				9. VENDOR				10. VENDOR PART NO.				11. IND./GOV. STD. NO.				12 TOTAL TESTS			
1 3/8" Line, 750 PSI Diaphragm Proof Pressure				BL, SIV, BRY				77-NAA-086								10			
2																			
3																			
4																(OVER)			
13. INTERNAL SPECS ETC REQ'D TO UTILIZE REPT ENCL						SENT WITH REPORT NO.						14 MIL. SPECS. STDS REFERENCED IN ISC							
A MC 284-0042						925.50.73.07-F1-01S						D MIL-E-5272B							
B												E							
C												F							
15A TEST OR ENVIRONMENT		C PER SPEC		D SPEC. PARAGRAPH METHOD CONDITION				E TEST LEVELS, DURATION AND OTHER DETAILS								F NO TESTS		G NO FAILURES	
1a Leakage		A		Para 4.5.2				Ammonia and Helium Increments of 50, 350, & 700 PSIG								10		0	
1b High Temperature		D		Para 4.1.1				Procedure I 160°F For 50 Hrs.								5		0	
1b Low Temperature		D		" 4.2.2				Procedure II - 80°F for 48 Hrs - 65°F For 24 Hrs at Ammonia Pressure 50 PSIG								5		0	
1b Life Test		A		" 4.5.8				7000 Cycles Per Para 2.6 of this report								5		0	
1c Vibration		A/D		" 4.5.7				Procedure 1, 5 to 2000 CPS at ± 10g								5		0	
1a Diaphragm Burst		A		Para 4.5.3				0-700 PSIG Per Para 2.8 of this report								10		0	
(OVER)																			
16. SUMMARY OF REPORT, NATURE OF FAILURES AND CORRECTIVE ACTIONS TAKEN: The above specimens are acceptable for the intended function. Vendor's comments are included in this report.																			
17. TESTED BEYOND VENDOR CATALOG SPECIFICATIONS		YES		NO		18. VENDOR INFORMED OF TEST RESULT BY LETTER		YES		NO		19. SIGNATURE OF CONTRACTOR		CONTRACTOR		SUBCONTRACTOR			
		☐		☒				☒		☐		MAR 5 - 1964		NAA-S&ID					

FIGURE B.7

REPORT SUMMARY SHEET

FIGURE B. 8

FARADA INFORMATION FLOW CHART

BACKGROUND INFORMATION ON FAILURE RATE DATA - FARADA PROGRAM
 11ND FMSAEG 8800 9 (10-64)

TO SUPPORT "TABULAR FAILURE RATE DATA SUMMARY"

ACTIVITY ACME Company		REPORT NUMBER OR IDENTIFICATION ABC-123	DATE 4-21-66
I. DESCRIPTION OF EQUIPMENT(S) TESTED OR UNDER SURVEILLANCE			
A. DESCRIPTION, SYSTEM TYPE, INTENDED FUNCTION AN/FSQ-7 - Large high speed digital computer for use in real-time air defense problems			
B. PRODUCTION STATUS (Production, Prototype, breadboard) Prototype			
C. AGE OF EQUIPMENT (S) PRIOR TO COMMENCEMENT OF TEST OR SURVEILLANCE 2 years		D. VINTAGE OF EQUIPMENT (Year of operational status) 1962	
II. CONDITION OF TEST (or surveillance)			
A. DATE AND DURATION 15 October 1961 through 31 December 1963			
B. ENVIRONMENT (ground, airborne, laboratory, normal field operations, accelerated life, etc.) complete word description including geographical location: Equipment housed in special environmentally controlled building at a classified location.			
C. MAINTENANCE (routine replace and repair, preventative, etc.) Some preventative maintenance in addition to routine replace and repair			
III. SYSTEM STATISTICS			
A. TOTAL SYSTEMS (number of equipments) 1 Computer			
B. TOTAL OPERATING TIME AND TIME BASE (flight hours, heater hours, equipment hours) 8500 hours of equipment operation			
C. SYSTEM MEAN TIME, TOTAL NUMBER OF FAILURES 842 Catastrophic failures Approximately 10 hours MTBF			
IV. FAILURE REPORTING SYSTEM			
A. CONTROLLED OR UNCONTROLLED, METHOD OF REPORTING, PERSONNEL Controlled; laboratory failure reports and equipment removal tags under the immediate surveillance of professional personnel			
B. DEFINITION OF FAILURE Significant removal rate - defined as the total removals minus accidental damage removals, removals due to failure of another component overload, and "no-defect-found" removals			
C. ESTIMATED PERCENT OF TOTAL FAILURES REPORTED 95 to 100%			

FIGURE B. 9

SAMPLE OF COMPLETED
 "BACKGROUND INFORMATION ON FAILURE RATE DATA" FORM

V. PART FAILURE MODES (for each part type, list failure modes and number of parts failing in each mode)

PART IDENTIFICATION	FAILURE MODE	NO OF FAILURES
Semiconductor, Diodes	Open	141
" "	Shorted	87
" "	Back Resistance Under lower Limit	22
" "	Unstable	5
" "	Total	255
Power Transistor, Silicon	Open	7

VI. PART FAILURE TIMES (list exact failure times for each failed part, where possible)

PART IDENTIFICATION	OPERATING TIME	NO OF FAILURES
Capacitor, Ceramic	7255 hours	1
Semiconductor, Diode, Germanium	825 hours	1
Power Transistor, Silicon	2000-2500 hours	3
" " "	4500-6000 hours	2
Resistor, Carbon Composition	7500-8500 hours	1

VII. SPECIAL ENVIRONMENTAL CONDITIONS (list all environments not given on "Tabular Failure Rate Data Summary")

Power surges to the AN/FSQ-7 occurred approximately 4 times per week because of the relative instability of the on-site power generators. These surges were as high as 130 percent of nominal.

VIII. ADDITIONAL INFORMATION (continue on additional sheets as required)

These data are a composite of two separate efforts of succeeding time periods (References a and b, respectively). The two groups of data were integrated into this single report since they describe the same equipment and the component failure rates were very similar.

IX. REFERENCES

(a) Doe, J.C., "A Preliminary Reliability Analysis of the AN/FSQ-7 Computer," Proceedings of the 12th National Symposium on Reliability and Quality Control, pp 372-380

(b) Mann, I.J., "The AN/FSQ-7, A Reliability Progress Report," Proceedings of the 17th RETMA Symposium of Applied Reliability, pp 75-82

11ND-PMSAEC-8800-9 (10-64) (BACK)

FIGURE B. 9 (continued)

B-55

SAMPLE

FIGURE B.10

SAMPLE OF COMPLETED
"TABULAR FAILURE RATE DATA SUMMARY" FORM

FAILURE MODE DISTRIBUTIONS
11ND-PMAEG-0000/11 (2-66)

FAILURE MODE DISTRIBUTIONS 1111D-FMSAEC-0000/11 (2-66)				FAILURE MODES BY PERCENT OF TOTAL FAILURES (5)															
PART COMPONENT DESCRIPTION (1)	SOURCE (2)	OBSERVED ENVIRONMENT INTENDED APPLICATION (3)	NUMBER OF FAILURES (4)	EXCESSIVE LEAKAGE CURRENT	SHORT	OPEN	DRIFT	INTERMITTENT	HIGH I _{cc}	B-C SHORT	B-C OPEN	LOW SVERO	HIGH HFE	ARC MECHANICAL	BRIDGING CONTACTS WILL NOT TRANSFER	RESISTANCE HIGH	LEAKING	CORRODED	EXCESSIVE WEAR
Capacitor, Fixed, Paper, MIL-C-26244		LAE/MISSILE	47	26	45	10	19												
Semiconductor, Transistor, 2N1048, Silicon - NPN, High Power		GROUND	96					5	6	46	21	13	9						
Relay, DPDT, 1/2 Size Crystal Case, Hermetically Sealed, 30VDC 2A load, 26 1/2 VDC Coil		SM/SHIPBOARD	17											41	17	24	18		
Valve, Fuel, Shutoff, Solenoid Actuation, MIL-V-0610, 35PSI, 18-30VDC		AIRCRAFT	26														67	26	7

SAMPLE

2

01111D-FMSAEC-0000/11 (2-66)

BUWEPS FAILURE RATE DATA PROGRAM

FIGURE B.11

SAMPLE OF COMPLETED
"FAILURE MODE DISTRIBUTIONS" FORM

PARTS/COMPONENTS	SOURCE	OBSERVED ENVIRONMENT/INTENDED APPLICATION	DATE OF REPORT MO-YR	FAILURE RATE-FAILURES PER MILLION OPERATING HOURS	PARTS-HOURS IN MILLIONS	NUMBER OF FAILURES	COMPONENT PART POPULATION
SEMICONDUCTORS,DIODES.1N2508,SILICON,POWER	210	GROUND	08-64	.092	43.608	4	5640
SEMICONDUCTORS,DIODES.1N251,SILICON	209	LAB,GND,SUB/SUB	09-65	.0666(C-AND-D)	209.99	14	40446
SEMICONDUCTORS,DIODES.1N251,SILICON	209	LAB,GND,SUB/SUB	09-65	.145(C1-AND-D1)	124.13	18	23544
SEMICONDUCTORS,DIODES.1N270,GERMANIUM	209	LAB,GND,SUB/SUB	09-65	.0255(C-AND-D)	117.19	3	22572
SEMICONDUCTORS,DIODES.1N276,GERMANIUM	209	LAB,GND,SUB/SUB	09-65	.0278(C-AND-D)	1469.6	41	283068
SEMICONDUCTORS,DIODES.1N276,GERMANIUM	209	LAB,GND,SUB/SUB	09-65	.0421(C1-AND-D1)	1068.2	45	202608
SEMICONDUCTORS,DIODES.1N277,GERMANIUM,GOLD-BOND	210	GROUND	08-64	.234	5463.1	1280	689724
SEMICONDUCTORS,DIODES.1N277(JAN),GERMANIUM	217	LAB/GROUND	01-65	9.53(LT)(77F)	.1049	0	27
SEMICONDUCTORS,DIODES.1N277(JAN),GERMANIUM	217	LAB(AL)/GROUND	01-65	16.4(LT)(125F)	.0609	0	15
SEMICONDUCTORS,DIODES.1N277(JAN),GERMANIUM	217	LAB(AL)/GROUND	01-65	16.4(LT)(-25F)	.0609	0	15
SEMICONDUCTORS,DIODES.1N429,SILICON	217	LAB/GROUND	01-65	15(LT)(77F)	.0667	0	20
SEMICONDUCTORS,DIODES.1N429,SILICON,REFERENCE	210	GROUND	08-64	2.36	1.6949	4	212
SEMICONDUCTORS,DIODES.1N457,SILICON,DIFFUSED	210	GROUND	08-64	.164	170.92	28	20793
SEMICONDUCTORS,DIODES.1N458,SILICON,DIFFUSED	210	GROUND	08-64	.345	14.51	5	1855
SEMICONDUCTORS,DIODES.1N459,SILICON	217	LAB/GROUND	01-65	.292(LT)(77F)	3.424	0	856
SEMICONDUCTORS,DIODES.1N459,SILICON,DIFFUSED	210	GROUND	08-64	22.8(LT)	.04387	0	5
SEMICONDUCTORS,DIODES.1N474A,SILICON,REFERENCE	210	GROUND	08-64	1.12	39.381	44	4705
SEMICONDUCTORS,DIODES.1N483B,SILICON	217	LAB/GND	01-65	3.55(LT)(77F)	.2816	0	78
SEMICONDUCTORS,DIODES.1N483B,SILICON	217	LAB	01-65	6.99(125F)	.143	1	30
SEMICONDUCTORS,DIODES.1N483B,SILICON	217	LAB	01-65	6.99(LT)(-25F)	.143	0	30
SEMICONDUCTORS,DIODES.1N538,SILICON,RECTIFIER	210	GROUND	08-64	.084	344.07	29	47321
SEMICONDUCTORS,DIODES.1N538(JAN),SILICON	217	GROUND	01-65	1.35(LT)(77F)	.7392	0	184
SEMICONDUCTORS,DIODES.1N538(JAN),SILICON	217	LAB(AL)/GROUND	01-65	14.5(LT)(125F)	.069	0	6
SEMICONDUCTORS,DIODES.1N538(JAN),SILICON	217	LAB(AL)/GROUND	01-65	14.5(LT)(-25F)	.069	0	6
SEMICONDUCTORS,DIODES.1N540,SILICON	217	LAB/GROUND	01-65	.268(LT)(77F)	3.7263	0	1028
SEMICONDUCTORS,DIODES.1N540,SILICON,RECTIFIER	210	GROUND	08-64	1.79	3.9041	7	566
SEMICONDUCTORS,DIODES.1N547(JAN),SILICON	217	LAB/GROUND	01-65	76.3(LT)(77F)	.0131	0	6
SEMICONDUCTORS,DIODES.1N629,SILICON,SWITCHING	210	GROUND	08-64	2.18	52.333	114	7580
SEMICONDUCTORS,DIODES.1N645,SILICON,RECTIFIER	210	GROUND	08-64	.055	274.5	15	34532
SEMICONDUCTORS,DIODES.1N645(USAF),SILICON	217	LAB/GROUND	01-65	9.64(LT)(77F)	.1037	0	27
SEMICONDUCTORS,DIODES.1N645(USAF),SILICON	217	LAB(AL)/GROUND	01-65	33(LT)(125F)	.0303	0	5
SEMICONDUCTORS,DIODES.1N645(USAF),SILICON	217	LAB(AL)/GROUND	01-65	33(LT)(-25F)	.0303	0	5
SEMICONDUCTORS,DIODES.1N647,SILICON	217	LAB/GROUND	01-65	2.59(LT)(77F)	.3864	0	98
SEMICONDUCTORS,DIODES.1N658,SILICON	209	LAB,GND,SUB/SUB	09-65	.413(C1-AND-D1)	9.6801	4	1836
SEMICONDUCTORS,DIODES.1N658,SILICON	217	LAB/GROUND	01-65	1.48(LT)(77F)	.6746	0	184
SEMICONDUCTORS,DIODES.1N658,SILICON	217	LAB(AL)/GROUND	01-65	4.72(LT)(125F)	.2119	0	50
SEMICONDUCTORS,DIODES.1N658,SILICON	217	LAB(AL)/GROUND	01-65	4.72(LT)(-25F)	.2119	0	50
SEMICONDUCTORS,DIODES.1N658(USA),SILICON	217	LAB/GROUND	01-65	45.5(LT)(77F)	.022	0	5
SEMICONDUCTORS,DIODES.1N658(USA),SILICON	217	LAB(AL)/GROUND	01-65	45.5(LT)(125F)	.022	0	5
SEMICONDUCTORS,DIODES.1N658(USA),SILICON	217	LAB(AL)/GROUND	01-65	45.5(LT)(-25F)	.022	0	5
SEMICONDUCTORS,DIODES.1N691,SILICON,SWITCHING	210	GROUND	08-64	.076	145.52	11	19637

SAMPLE

B-57

FIGURE B.12

TYPICAL PAGE OF FARADA COMPUTER PRINT-OUT FROM VOLUME 1A

PARTS/COMPONENTS	SOURCE	OBSERVED ENVIRONMENT/INTENDED APPLICATION	DATE OF REPORT MO-YR	FAILURE RATE- FAILURES PER MILLION OPERATING HOURS	PARTS-HOURS IN MILLIONS	NUMBER OF FAILURES	COMPONENT PART POPULATION
PUMPS	118B	AIRCRAFT	11-63	214(B)	.03267	7	150
PUMPS	138	LAB	10-63	13.5			
PUMPS	193A	GROUND/MISSILE	06-65	58.8	.017	1	9
PUMPS.AIR-TURBINE-MOTOR-DRIVEN.HYDR-PWR-SPLY	114	AIRCRAFT	02-63X	814.33(A)	.075	61	50
PUMPS.AIR-TURBINE-MOTOR-DRIVEN.HYDR-PWR-SPLY	198	AIRCRAFT	12-63	826(A)	.08478	70	50
PUMPS.ALCOHOL	61	GENERAL/AIRCRAFT	03-58	200			
PUMPS.AUXILIARY.ELECTRICAL.HYDR-PWR-SPLY	114	AIRCRAFT	06-63X	691.56(b)	.088	61	102
PUMPS.AUXILIARY.ELECTRICAL.HYDR-PWR-SPLY	114	AIRCRAFT	06-63X	1100.11(E)	.015	17	68
PUMPS.AUXILIARY.ELECTRICAL.HYDR-PWR-SPLY	198	AIRCRAFT	03-65	623(B)	.12691	79	50
PUMPS.AUXILIARY.ELECTRICAL.HYDR-PWR-SPLY	198	AIRCRAFT	03-65	834(E)	.11637	97	100
PUMPS.BOOSTER.AUXILIARY.FUEL-SYSTEM	114	AIRCRAFT	02-63X	160.17(A)	.149	24	100
PUMPS.BOOSTER.AUXILIARY.FUEL-SYSTEM	114	AIRCRAFT	06-63X	255.03(B)	.176	45	204
PUMPS.BOOSTER.AUXILIARY.FUEL-SYSTEM	114	AIRCRAFT	06-63X	97.01(E)	.031	3	136
PUMPS.BOOSTER.AUXILIARY.FUEL-SYSTEM	198	AIRCRAFT	03-65	339(B)	.25382	86	100
PUMPS.BOOSTER.AUXILIARY.FUEL-SYSTEM	198	AIRCRAFT	03-65	241(E)	.23274	56	200
PUMPS.BOOSTER.EXTERNAL.DISTRIBUTION.FUEL-SYSTEM	114	AIRCRAFT	06-63X	64.67(E)	.031	2	136
PUMPS.BOOSTER.EXTERNAL.DISTRIBUTION.FUEL-SYSTEM	198	AIRCRAFT	03-65	98.8(E)	.23274	23	200
PUMPS.BOOSTER.FUEL	17	GENERAL/AIRCRAFT	01-60	175			
PUMPS.BOOSTER.FUEL	22	GEN/AIRCRAFT	06-61	1900(B)			
PUMPS.BOOSTER.FUEL	80	AIRCRAFT	09-61	13.52	.222	3	1280
PUMPS.BOOSTER.FUEL	144	AIRCRAFT	05-64	99.99	.18969	19	366
PUMPS.BOOSTER.FUEL	196	AIRCRAFT	06-65	19.4	6.6413	129	
PUMPS.BOOSTER.FUEL ENGINE	110	AIRCRAFT	06-59	625.13	.037	23	128
PUMPS.BOOSTER.FUEL POWER-PLANT	155L	AIRCRAFT	06-65	532	.21597	115	126
PUMPS.BOOSTER.FUEL TANK, EMERGENCY	80	AIRCRAFT	09-61	10.23(LT)	.01	0	50
PUMPS.BOOSTER.FUEL-SYSTEM	114	AIRCRAFT	02-63X	33.37(A)	.299	10	200
PUMPS.BOOSTER.FUEL-SYSTEM	114	AIRCRAFT	06-63X	82.17(H)	.353	29	408
PUMPS.BOOSTER.FUEL-SYSTEM	114	AIRCRAFT	06-63X	48.5(E)	.062	3	272
PUMPS.BOOSTER.FUEL-SYSTEM	179	AIRCRAFT	12-64	91.3	.17532	16	812
PUMPS.BOOSTER.FUEL-SYSTEM	198	AIRCRAFT	03-65	51.6(E)	.46548	24	400
PUMPS.BOOSTER.FUEL-SYSTEM	198	AIRCRAFT	12-63	29.5(A)	.33912	10	200
PUMPS.BOOSTER.FUEL-SYSTEM	198	AIRCRAFT	03-65	116(B)	.50763	59	200
PUMPS.BOOSTER.GTC.AUX-POWER-PLANT	114	AIRCRAFT	02-63X	253.61(A)	.075	19	50
PUMPS.BOOSTER.GTC.AUX-POWER-PLANT	198	AIRCRAFT	12-63	236(A)	.08478	20	50
PUMPS.BOOSTER.LH2.GR-TRAIN/H2O2-DRIVEN-TURBINE	171	GROUND/MISSILE	12-64	1430000(LT)(B)	.00001	0	
PUMPS.BOOSTER.LH2.GR-TRAIN/H2O2-DRIVEN-TURBINE	171	GROUND/MISSILE	12-64	61700(LT)(A)	.00002	0	
PUMPS.BOOSTER.PYLON-TANK.FUEL-SYSTEM	198	AIRCRAFT	12-63	177(A)	.16956	30	100
PUMPS.CHARGE-SCAVENGE, CONSTANT-SPEED-DRIVE	80	AIRCRAFT	09-61	28.63(LT)	.035	0	320
PUMPS.COMPRESSOR	82	AIRCRAFT	11-61	2150	.007	15	
PUMPS.COMPRESSOR	84	AIRCRAFT	11-61	447	.114	51	
PUMPS.COMPRESSOR.RECIPROCATING	111	AIRCRAFT	02-63	1256.59	.012	15	31
PUMPS.COOLING.CONSTANT-SPEED-DRIVE	80	AIRCRAFT	09-61	28.63(LT)	.035	0	320

FIGURE B. 13

TYPICAL PAGE OF FARADA COMPUTER PRINT-OUT FROM VOLUME 1B

FAILURE MODE DISTRIBUTIONS
1980-FAHASC-0002/11 (2-66)

VALUES
(CONTINUED)

ADDITIONAL PART/COMPONENT DESCRIPTION (1)	SOURCE (2)	OBSERVED ENVIRONMENT/ INTENDED APPLICATION (3)	NUMBER OF FAILURES (5)	FAILURE MODES BY PERCENT OF TOTAL FAILURES															UNKNOWN
				CONTAMINATION	FAILED TO OPERATE	IMPROPER ADJUSTMENT	IMPROPER OPERATION	INTERMITTENT OPERATION	INTERNAL PART FAILURE	LEAKING	MECHANICAL DAMAGE	MECHANICAL INTERFERENCE	MISSING OR WRONG PART	SLOW OR SLUGGISH OPERATION	WEAR OR AGING EFFECT	OPEN			
Fuel.Shutoff.Gate	123	AIRCRAFT	40	-	-	-	5A	-	-	30	5B	-	-	-	-	-	-	-	59
Fuel.Shutoff.Gate.Motor-Actuated	123	AIRCRAFT	237	-	-	4A	-	-	-	66	-	-	-	-	-	-	-	-	26
Fuel.Shutoff.MIL-F-8615.75GPM-MAX. 0-60 PSIG	215	HELICOPTER	-	-	-	-	-	-	-	4B	-	-	-	-	-	-	-	-	-
Fuel.Shutoff.Solenoid-Actuation.MIL-V-8610. 35PSI.18-30VDC	215	HELICOPTER	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fuel.Solenoid.Dual-Pilot.MIL-F-8615.28VDC. 0-60PSIG	215	HELICOPTER	-	-	-	-	-	-	-	-	-	4A	-	-	-	-	-	-	-
Fuel/Oil.Control.Thermal-Actuation	198	AIRCRAFT	-	-	-	-	-	-	-	100	-	-	-	-	-	-	-	-	-
Fuel/Oil.Control/Shutoff.Complex-Actuation	198	AIRCRAFT	-	-	24	3	41	7	3	6	1	12	-	1	1	-	-	-	2
Fuel/Oil.Control/Shutoff.Electric-Motor/Solenoid-Actuation	198	AIRCRAFT	-	-	29	6	14	2	3	23	7	8	1	5	-	-	-	-	1
Fuel/Oil.Control/Shutoff.Manual/Mechanical-Actuation	198	AIRCRAFT	-	-	1	-	1	-	1	93	1	-	2	1	-	-	-	-	1
Fuel/Oil.Control/Shutoff.Pneumatic-Actuation	198	AIRCRAFT	-	25	-	-	50	-	-	25	-	-	-	-	-	-	-	-	-
Fuel/Oil.Shutoff.Fluid-Actuation	198	AIRCRAFT	-	-	1	-	5	-	-	77	-	2	1	-	-	-	-	-	2
Glycol.Check	80	AIRCRAFT	1	-	-	-	-	-	-	100	-	-	-	-	-	-	-	-	-
Glycol.Anti-Ice-Fluid	80	AIRCRAFT	3	-	-	-	-	-	-	33	-	-	-	-	-	-	-	-	67
H.O.Tank-Pressurization	207	GROUND/MISSILE	6	67A	-	-	-	-	-	33	-	-	-	-	-	-	-	-	-
Hydraulic.Check	80	AIRCRAFT	51	-	-	-	-	-	-	92	-	6A	-	-	-	-	-	-	2
Hydraulic.Check	191	GROUND/AIRCRAFT	2	-	-	-	-	-	-	100	-	-	-	-	-	-	-	-	-
Hydraulic.Control.Complex-Actuation	198	AIRCRAFT	-	-	-	-	-	-	6	60	1	2	-	-	-	-	-	-	1
Hydraulic.Control.Directionals	191	GROUND	46	-	-	-	-	-	-	-	-	100C	-	-	-	-	-	-	-
Hydraulic.Control.Emergency-AC-Power	80	AIRCRAFT	2	-	-	-	50F	-	-	50	-	-	-	-	-	-	-	-	-
Hydraulic.Control.Servo.Vari-Ramp	80	AIRCRAFT	9	-	-	-	-	-	-	56	-	44A	-	-	-	-	-	-	-
Hydraulic.Control/Shutoff.Electrical-Actuation	198	AIRCRAFT	-	-	21	2	17	3	6	43	2	3	1	-	-	-	-	-	2
Hydraulic.Control/Shutoff.Hydraulic-Actuation	198	AIRCRAFT	-	-	12	1	40	1	7	33	3	3	1	1	-	-	-	-	-
Hydraulic.Control/Shutoff.Manual-Actuation	198	AIRCRAFT	-	-	1	2	1	8	1	2	80	2	1	3	-	-	-	-	-
Hydraulic.Filler.Accumulator	80	AIRCRAFT	6	-	-	-	-	-	-	83	17	-	-	-	-	-	-	-	-
Hydraulic.Relay.Brake	80	AIRCRAFT	75	-	-	-	16F	-	-	48	-	7A	-	-	-	-	-	-	28
Hydraulic.Relief.Pressure	123	AIRCRAFT	370	-	-	29A	-	-	-	-	-	-	-	-	29A	-	-	-	42
Hydraulic.Relief.Pressure	123	AIRCRAFT	18	-	-	-	-	-	-	42	17A	-	-	-	8A	-	-	-	33
Hydraulic.Relief.Pressure.Arresting-Gear-Sequencing	123	AIRCRAFT	14	-	-	7A	-	-	-	86	-	-	-	-	-	-	-	-	7
Hydraulic.Relief.Pressure.Nose-Wheel	123	AIRCRAFT	17	-	-	-	-	-	-	42	17A	-	-	-	8A	-	-	-	33
Hydraulic.Relief.Pressure.Power-Control-System	123	AIRCRAFT	70	-	-	48A	-	-	-	30	-	-	-	-	-	-	-	-	22
Hydraulic.Relief.Speed-Brake	80	AIRCRAFT	3	-	-	-	-	-	-	67	-	-	-	-	-	-	-	-	33
Hydraulic.Relief.Pressure.Speed-Brake-System	123	AIRCRAFT	117	-	-	18A	-	-	-	50	5C	-	-	-	-	-	-	-	27
Hydraulic.Relief.Pressure.Thermal.Wingfold	123	AIRCRAFT	117	-	-	18A	-	-	-	50	5C	-	-	-	-	-	-	-	27
Hydraulic.Relief.Thermal-Vent	80	AIRCRAFT	5	-	-	-	-	-	-	80	-	20A	-	-	-	-	-	-	-
Hydraulic.Relief.Pressure.Utility-System	123	AIRCRAFT	70	-	-	48A	-	-	-	30	-	-	-	-	-	-	-	-	32
Hydraulic.Restrictor.Relief.Cruise-Droop	123	AIRCRAFT	4	-	-	-	-	-	-	-	-	-	-	-	50A	-	-	-	50
Hydraulic.Restrictor.Relief.Landing-Droop	123	AIRCRAFT	7	-	-	-	-	-	-	57	14A	-	-	-	14A	-	-	-	15
Hydraulic.Restrictor.Relief.Landing-Droop	123	AIRCRAFT	6	-	-	17A	-	-	-	50	-	-	-	-	-	-	-	-	33
Hydraulic.Restrictor.Relief.Landing-Droop	123	AIRCRAFT	3	-	-	34A	-	-	-	-	33A	-	-	-	33A	-	-	-	-
Hydraulic.Selector.4-Way.Solenoid-Actuation	123	AIRCRAFT	28	-	-	11A	-	-	-	32	-	-	-	-	11A	-	-	-	46

DOVEPS FAILURE RATE DATA PROGRAM

FIGURE B.14

TYPICAL PAGE OF FARADA FAILURE MODE DISTRIBUTIONS

	Accelerometers (See 852)
025	Accumulators
027	Actuators
051	Amplifiers (Electrical or Electronic)
081	Antennas
082	Inactive (See 081)
085	Attaching, Methods and Materials
091	Audio Devices
101	Batteries, Nonrechargeable
102	Batteries, Rechargeable
104	Bearings
115	Bellows
117	Brakes
121	Blowers and Fans
124	Inactive (See 511)
141	Boards, Printed Circuit
151	Inactive (See 152)
152	Capacitors, Fixed
161	Capacitors, Variable
	Choppers (See 601 Relays)
	Circuit Breakers (See 341)
170	Circuits, Evaluation of
181	Coils, Inductance, Fixed
182	Coils, Inductance, Adjustable
191	Computer and Recording Elements
201	Connectors, Electrical
232	Counters
241	Crystals
271	Delay Lines
301	Electron Tubes
303	Inactive (See 306)
306	Environmental Simulation Equipment
307	Fasteners
321	Filters, Electrical
326	Filters, Nonelectrical
331	Finishes and Surface Treatments (Materials and Processes)
336	Fittings, Tubing and Hose
337	Fluids
338	Inactive (See 337)
341	Fuses and Circuit Protective Devices
345	Gaskets and Seals
	Gears (See 511)
347	General Technical Data
358	Gyros
361	Hardware (Mechanical and Electromechanical)

FIGURE B.15

PARTIAL LIST OF MAJOR CLASSIFICATIONS
OF THE FARADA PART/COMPONENT GENERIC CODE

SERVICE, MEDIA HANDLED

.10 Cryogenic Fluids
 .20 Fuel, Exotic
 .30 Fuel, Hydrocarbon
 .40 Gas, Hot
 .50 Gas, NOC
 .60 Hydraulic Fluid
 .70 Oxidizers, NOC
 .80 Pneumatic
 .90 Oil

PRESSURE RANGE

.10 0-25 mmHg
 .20 25-35 mmHg
 .30 35-225 mmHg (70,000'-30,000')
 .40 225-760 mmHg (30,000'-Sea Level)
 .50 S. L. only
 .60 0-100 psig
 .70 100-1000 psig
 .80 1000-5000 psig
 .90 Over 5000 psig

POWER RATING

.06 Less than .1 Watt
 .08 .10-.125 Watt
 .12 .125-.25 Watt
 .14 .25-.50 Watt
 .16 .50-1 Watt
 .20 1-2 Watts
 .30 2-10 Watts
 .40 10-100 Watts
 .50 100-1,000 Watts
 .60 1-10 KW
 .70 10-100 KW
 .80 100-1,000 KW
 .90 Over 1 Megawatt

CONTACT ARRANGEMENT

.05 SPST (NC)
 .10 SPST (NO)
 .12 SPDT
 .20 DPST (NC)
 .25 DPST (NO)
 .30 DPDT
 .40 3PST (NC)
 .45 3PST (NO)
 .50 3PDT
 .60 4 PST (NC)
 .65 4PST (NO)
 .70 4PDT
 .80 6PST (NC)
 .85 6PST (NO)
 .90 6PDT
 .95 Multiple Pole

VOLTAGE RATING

.10 Under 1 MV
 .20 1-10 MV
 .30 10 MV-1 Volt
 .40 1-30 Volts
 .50 30-109 Volts
 .60 109-240 Volts
 .70 240-1,000 Volts
 .80 1-10 KV
 .90 Over 10 KV

CORE MATERIAL & CONSTRUCTION

.1 Air, Encapsulated
 .2 " , Hermetically Sealed
 .3 " , NOC
 .4 Diamagnetic, Encapsulated
 .5 " , Hermetically Sealed
 .6 " , NOC
 .7 Ferromagnetic, Encapsulated
 .8 " , Hermetically Sealed
 .9 " , NOC

FREQUENCY RANGE

.02	D. C.		
.05	60 Cycles Only		
.06	400 Cycles Only		
.07	0-3 Kc	Audio	Freq.
.10	3-30 Kc	"	"
.20	30-300 Kc	Low	"
.30	300-3,000 Kc	Medium	"
.40	3-30 Mc	High	"
.50	30-300 Mc	Very	High "
.60	300-3,000 Mc	Ultra	" "
.70	3,000-30,000 Mc	Super	" "
.80	Over 30,000 Mc	Extremely	" "

Note:

1. NOC = Not Otherwise Classified
2. Range: The Range is defined to be greater than the lower value, up to and including the larger value.
 Sample: Voltage Rating 1-10 mv
 Any voltage greater than 1 mv, up to and including 10 mv.

FIGURE B.16

FARADA COMMON SUBCLASSIFICATION

925 VALVES

925.00 Service, Media Handled (Common)

925.00.00 Pressure Range (Common)

925.00 Function

- . 1 Check
- . 2 Multifunction
- . 3 Relief
- . 4 Servo
- . 5 Shutoff
- . 6 3-way Selector
- . 7 4-way Selector

925.00.00.00 Principle of Operation

- .10 Ball
- .20 Butterfly
- .30 Flapper
- .40 Poppet
- .50 Sleeve
- .60 Slide or Gate
- .70 Spool
- .80 Globe
- .90 Needle

925.00.00.00 Actuation or Control

- . 4 Manual
- . 5 Motor
- . 6 Pilot
- . 7 Pressure
- . 8 Pyrotechnic or Explosive
- . 9 Solenoid

FIGURE B.17

EXAMPLE OF FARADA
PART/COMPONENT CLASSIFICATION CODE

Originator Sends:
 White To Work Unit
 Yellow To Control Room
 Pink To Control Room

**NPD G.S.
 DEFICIENCY REPORT
 WORK UNIT COPY**

31153
 REV. 11-88.

See - NPD G.S.
 Sm. Instruction
 No. 2.0.0.3.

TO:		SUBJECT		UNIT	
ORIGINATOR STATES - Deficiency, Description, Symptoms, Circumstances, Etc.		SYSTEM			
		DATE			
		TIME			
		FAILURE	SAFE		
			UNSAFE		
		CATEGORY	MAJOR		
			MINOR		
		SHUTDOWN REQ'D.	YES		
			NO		
		ORIGINATOR			
		SUPERVISOR			
WORK UNIT STATES - Correction Description, Results, Comments, Etc.		DATE RECEIVED			
		DATE COMPLETED			
		WORK BY			
		HOURS	REG		
			O.T.		
		DOSE MMEN.			
		PHOTOS			
		ARCHIVE NO.			
		DWG. CHANGE			
		SUPERVISOR			
OTHER COMMENTS		SHIFT SUPER. ACCEPT			
		ORIGINATOR			

No 12670

FIGURE B.18
SAMPLE DEFICIENCY REPORT

(W) - white original

(Y) - yellow copy

(P) - pink copy

FIGURE B.19

DEFICIENCY REPORT FLOW CHART

APPENDIX C

EXAMPLE OF LOADSHEET PREPARATION
AND DATA REDUCTION

APPENDIX C

EXAMPLE OF LOADSHEET PREPARATION AND DATA REDUCTION

Loadsheets preparation and data reduction for failure rate analysis will be demonstrated by the use of a simple pumping system as shown schematically in Figure C.1.

SYSTEM DESCRIPTION

The pumping system (system code 21.341) belongs in the reactor portion (system code 20) of a hypothetical power plant (I. D. No. 0123). It consists of one 50 gpm pump, one flow switch*, and three loops each containing one motor operated control valve all as listed in Table C.1. During plant operation it is assumed that the pump is operated continuously and the water flow in each loop is automatically adjusted by a motor operated valve. Automatic operation of the valves is controlled by a sensor measuring temperature or pressure. The sensor is not shown for simplicity.

Failure of any one valve in the closed position will not result in a system failure. Failure of any two valves in the closed position will result in a system failure; and failure of the pump or all three valves will result in the actuation of the low flow switch which in turn will scram the reactor plant. The flow switch is tested daily during operation.

System History

It is assumed that the pumping system has previously completed approximately five years or 43,800 hours of operation with several component failures. During the next reporting period, which is on a three-month interval shown schematically in Figure C.2, the reactor plant was operating at the beginning of January 1966, and continued operation through the month of February until a scram occurred on March 20, 1966. It was started up again on March 24, 1966, and continued operation through the end of the reporting period, March 31, 1966. During this period

* Flow switch belongs in System Code 26.121, Instrumentation and Control

there were two concurrent valve failures resulting in total loss of system performance (effect code 3) and one valve failure causing no loss of performance (effect code 1). A pump failure, which resulted in system loss (effect code 3) and plant scram, also was reported.

Although operation of the example pumping system is correlated to the reactor plant (system code 20) in Figure C.2, the operation of the turbo-generator (T/G) plant (system code 30) is also shown to demonstrate how it is treated separately. The use data of a system whose operation is related to the T/G plant would use T/G data to more accurately derive "time to failure" estimates.

LOADSHEET PREPARATION

Loadsheets are prepared in order to provide information on individual failure events as well as to enable data reduction later by either manual computation or by computer programming. The manner in which a group of line entries within each reporting period are made is as follows:

- Step 1: First make a separate line entry for reactor and T/G operating status at the beginning of the reporting period (lines 1 and 2 of Figure C.3).
- Step 2: Enter all failure events in chronological order until plant shutdown or scram occurs (lines 3, 4, 5, and 6 of Figure C.3).
- Step 3: Make a separate line entry for reactor and T/G shutdown or scram (lines 9 and 10 of Figure C.3).
- Step 4: Make a separate line entry for reactor and T/G startup (lines 9 and 10 of Figure C.3).
- Step 5: Repeat line entries starting with Step 2.
- Step 6: Finally make a separate line entry for reactor and T/G operating status at the end of the reporting period (lines 11 and 12 of Figure C.3).

Figure C.3 illustrates the completion of input data loading for a quarterly reporting period on the example system. The entries in Figure C.3 were made as follows:

- Line 1: This is the status (use code 2) of the reactor plant (system code 20) on January 1, 1966.

- Line 2: This is the status (use code 2) of the T/G plant (system code 30) on January 1.
- Line 3: Two valve failures occurred on February 4 resulting in loss of system performance (effect code 3) but no plant shutdown (use code 2). Failure mode was that of premature operation (mode code 6) caused by maintenance error (cause code 34). Recovery of the system operation was made on the same day with six hours of total repair time. This entry is for one of the valve failures.
- Line 4: This entry is for other valve failures indicated in Line 3 discussion.
- Line 5: Another valve failure occurred on February 20 with no loss of system performance (effect code 1 and use code 2); however, repair was not performed until two days later.
- Line 6: On March 20 a pump failure occurred which resulted in system loss (effect code 3) and reactor scram (use code 4). Failure mode was that of erratic operation (mode code 8) caused by high operating temperature (cause code 31). A new pump (new I.D. No. 5KY558AA1) from a different manufacturer (code 543) was installed and repair completed on March 21 with a total repair time of 20 hours.
- Line 7: Reactor scram occurred following the pump failure.
- Line 8: T/G shutdown occurred following the pump failure.
- Line 9: After remaining shut down for 3 more days another reactor startup was made on March 24.
- Line 10: T/G startup followed 4 days later on March 28.
- Line 11: The reactor plant was operating at the end of reporting period March 31.
- Line 12: The T/G plant was operating at the end of reporting period.

DATA REDUCTION

Using data presented in the input loadsheets, data reduction is possible by either manual computation or by computer programming. Two types of information that are provided in the output data sheet are as follows:

- Type 1: Listing of particular components that have failed during the reporting period. This information will provide the basis for deriving failure rates and distribution functions for components of similar kind.
- Type 2: Summary of failure rate data of all components of interest as of the end date of the reporting period. These data are carried over to the next reporting period.

A summary of failure rate data from the previous reporting periods is shown in Figure C. 4. The listing of component failures and summary of failure rate data for the current reporting period are shown in Figures C. 5 and C. 6. The output data sheet listing component failures for the reporting period is produced from information on the current input loadsheets and the previous report periods. Subsequent to this, a summary of failure rate data is generated. Components are grouped by their generic code and also by the system code in which they belong. This entire process can be handled by machine processing with component failures and failure rate information being stored on tape for data update and for special searches such as examination of failure distribution functions.

r

Component	Type	Manufacturer's Code	Plant I. D. No.	Generic Code
Pump	50 gpm, stainless steel, centrifugal	345	5C50A	221: 56.22
Flow Control Valve	1 inch, stainless steel, motor-operated gate	567	871A01T42	202: 56.24.22
Flow Control Valve	1 inch, stainless steel, motor-operated gate	567	871B01T42	202: 56.24.22
Flow Control Valve	1 inch, stainless steel, motor-operated gate	567	871C01T42	202: 56.24.22
Flow Switch	Industrial instrument	789	FS971	500: 01.40

TABLE C.1

LIST OF COMPONENTS IN A SIMPLE PUMPING SYSTEM

FIGURE C.1
SIMPLE PUMPING STATION

FIGURE C. 2
OPERATIONAL HISTORY OF A SIMPLE PUMPING SYSTEM

FIGURE C.3

INPUT LOADSHEET

ABC NUCLEAR POWER PLANT
 PLANT I.D. NO. 0123
 REPORTING PERIOD
 311065 TO 311265
 SUMMARY OF FAILURE RATE DATA

COM- PONENT I.D. NO.	NO. OF COM- PONENTS	FAILURE MODE	NO. OF FAILURES	HOUR OR CYCLE	ACCUMU- LATIVE TIME IN MILLION, HOUR OR CYCLE	FAILURE PER MILLION, HOUR OR CYCLE	STANDARD DEVIATION, HOUR OR CYCLE	ACCUMU- LATIVE REPAIR TIME, HOUR	MEAN REPAIR TIME, HOUR	STANDARD DEVIATION, HOUR
<u>COMPONENTS IN SYSTEM CODE 21341</u>										
871A01T42	1	1	1	Hour	.043780	2.3		10	10	
871B01T42	1		0	Hour	.043800			0	0	
871C01T42	1		0	Hour	.043800			0	0	
COMPONENT CODE 202562555			1	Hour	.131380	7.6				
SC50A	1	3	1	Hour	.043775	22.8		25	25	
COMPONENT CODE 2215622			1	Hour	.043775	22.8		25	25	
<u>COMPONENTS IN SYSTEM CODE 26121</u>										
FS971	1	5	2	Cycle	.001828	109		4	2	
COMPONENT CODE 5000140			2	Cycle	.001828	109		4	2	

FIGURE C.4

TYPE 2 OUTPUT DATA SHEET
PAST SUMMARY OF FAILURE RATE DATA

ABC NUCLEAR POWER PLANT
 PLANT I. D. NO. 0123
 REPORTING PERIOD
 010166 TO 310366
 LISTING OF COMPONENT FAILURES

DATE OF REPORT	COM- PONENT I. D. NO.	MANU- FACTURER'S CODE	FAILURE MODE	HOUR OR CYCLE	TIME TO FAILURE IN MILLION, HOUR OR CYCLE	ACCUMU- LATIVE TIME IN MILLION, HOUR OR CYCLE	REPAIR TIME, HOUR	DESCRIPTION OF REPAIR
<u>COMPONENTS IN SYSTEM CODE 21341</u>								
040266	871B01T42	567	6	Hour	.044640	.044640	6	Motor replaced.
040266	871C01T42	567	5	Hour	.044640	.044640	4	Contactor adjusted.
200266	871C01T42	567	5	Hour	.000384	.045024	8	Contactor adjusted.
200366	SC50A	345	8	Hour	.020696	.045696	20	Pump replaced.

FIGURE C. 5

TYPE 1 OUTPUT DATA SHEET
CURRENT LISTING OF COMPONENT FAILURES

ABC NUCLEAR POWER PLANT
 PLANT I. D. NO. 0123
 REPORTING PERIOD
 010166 TO 310366
 SUMMARY OF FAILURE RATE DATA

COM- PONENT I. D. NO.	NO. OF COM- PONENTS	FAILURE MODE	NO. OF FAILURES	HOUR OR CYCLE	ACCUMU- LATIVE TIME IN MILLION, HOUR OR CYCLE	FAILURE PER MILLION, HOUR OR CYCLE	STANDARD DEVIATION, HOUR OR CYCLE	ACCUMU- LATIVE REPAIR TIME, HOUR	MEAN REPAIR TIME, HOUR	STANDARD DEVIATION, HOUR
<u>COMPONENTS IN SYSTEM CODE 21341</u>										
871A01T42	1	1	1	Hour	.045838	21.8		10	10	
871B01T42	1	6	1	Hour	.045858	21.8		6	6	
871C01T42	1	5	2	Hour	.045810	43.6		12	6	
COMPONENT CODE 202562555			4	Hour	.177506	22.6	9.4	28	7	
SC50A	1	8	1	Hour	.045676	21.4		45	22.5	
5KY558AA1	1		0	Hour	.000168					
COMPONENT CODE 2215622			1	Hour	.045844	20.7		25	25	
<u>COMPONENTS IN SYSTEM CODE 26121</u>										
FS971	1	5	2	Cycle	.001914	105		4	2	
COMPONENT CODE 5000140			2	Cycle	.001914	105		4	2	

FIGURE C. 6

TYPE 2 OUTPUT DATA SHEET
CURRENT SUMMARY OF FAILURE RATE DATA

APPENDIX D

SELECTED FAILURE RATE DATA

APPENDIX D
SELECTED FAILURE RATE DATA

This appendix presents a list of failure rate data in Table D.1 for selected electrical, electronic, and mechanical parts or components. In Table D.2 a list of references is given for additional information on values given in Table D.1 as well as for additional failure rate data, particularly on electrical and electronic parts.

The values given in Table D.1 are provided to indicate the general level for failure rates on the parts listed. They are not necessarily the best values for a particular application since the rates must be adjusted according to the operational and environmental stresses imposed on the parts. Factors accounting for these stress factors may be found in most of the references listed in Table D.2.

As a final comment, it should be noted that the data in Table D.1 and the references cited in Table D.2 are primarily derived from equipment associated with electronic and specialized electrical systems found in military, aerospace, and nuclear reactor instrumentation systems. Data for heavy electrical and mechanical equipment found in nuclear power plants is sparse to nonexistent.

REFERENCES

1. Green, A. E. and A. J. Bourne, "Safety Assessment with Reference to Automatic Protective Systems for Nuclear Reactors, Part 3," AHSB(S)R117, UKAEA, 1966.
2. Earles, D. R., "Reliability Application and Analysis Guide," MI-60-54 (Rev. 1), The Martin Company, July 1961.
3. Military Standardization Handbook "Reliability Stress and Failure Rate Data for Electronic Equipment," MIL-HDBK-217A, Department of Defense, December 1, 1965.
4. Schmudde, A. A., "Engine-Generator Sets Meet Strict Reliability Limits," Power, April 1967.
5. McGraw-Hill Book Company, "RADC Reliability Notebook," RADC-TR-58-111, October 30, 1959.

TABLE D-1
FAILURE RATE DATA ON SELECTED
ELECTRONIC, ELECTRICAL, AND MECHANICAL EQUIPMENT

SOURCE	FAILURE RATE, Failures/10 ⁶ hr				
	AHSB(S) R 117	MI-60-54-(Rev 1)			Others*
		High	Mean	Low	
Accumulators		19.3	7.2	.4	
Actuators		13.7	5.1	.35	
Alternators	7	2.94	.7	.033	
Baffles		1.3	1.0	.12	
Batteries	1.0				
Rechargeable		14.29	1.4	.5	
Bearings					
Ball					
Heavy Duty	2.0	3.53	1.8	.072	
Light Duty	1.0	1.72	.875	.035	
Roller	5.0	1.0	.5	.02	
Sleeve	5.0	1.0	.5	.02	
Bellows	5.0	4.38	2.237	.040	
Blowers		3.57	2.4	.89	
Buzzer		1.30	.60	.05	
Circuit Breakers	2.0	.40	.1375	.045	
Thermal		.50	.3	.25	1.0 (3)
Magnetic					.5 (3)
Coils		.088	.050	.033	
Connectors, Electrical					
General, each pin	.2	.47	.2	.03	
Contactors	3	.4/c	.25/c	.1/c	
Covers					
Dust		.01	.006	.002	
Protective		.061	.038	.015	
Cylinders	.1	.81	.007	.005	
Hydraulic		.12	.008	.005	
Pneumatic		.013	.004	.002	
Diaphragms		9.0	6.00	.10	
Metal	5				
Rubber	8				
Ducts	1	1.3	.5125	.21	
Fans					
Exhaust	90	9.0	.225	.21	
Fasteners					
Bolts	.02				
Nuts	.02				
Screws	5				
Filters		.8	.3	.045	
Blockage	1				
Leakage	1				
Fuse	5	.82	.5	.30	.1 (3)
Gaskets	.5				
D-ring	.2	.03	.02	.01	
Phenolic		.07	.05	.01	
Rubber		.03	.02	.011	
Generators		2.41	.9	.40	
d. c.	9	6.27	.9	.30	
Diesel, Battery start					89 (4)
Heaters, Electrical					
Elements		.04	.02	.01	
Heat Exchangers		18.6	15.0	2.21	
Hose		3.22	2.0	.05	
Heavily Stressed	40				
Lightly Stressed	4				

* See Table D-2 for reference sources

TABLE D.1 (continued)

SOURCE	FAILURE RATE, Failures/10 ⁶ hr				
	AHSB(S) R 117	MI-60-54-(Rev 1)			Others
		High	Mean	Low	
Instruments					
Electrical		5.77	1.375	1.35	
Pressure					
Gage	10	7.8	4.0	0.135	
Sensor		6.6	3.5	1.7	
Temperature					
Bulb		3.30	1.0	0.05	
Sensor		6.4	3.3	1.5	
Meters (moving coil)	3				
Recorders	25				
Lamps		35.0	8.625	3.45	
Fluorescent	10				
Incandescent		32.0	8.0	5.20	1.0 (3)
Indicator	5				
Neon	2	18.8	10.25	4.50	.2 (3)
Motors	10	7.5	.625	.15	
Blower		5.5	.2	.05	
Electrical		.58	.3	.11	
Hydraulic		7.15	4.3	1.45	
Servo		.35	.23	.11	
Stepper	5	.71	.37	.22	
Mechanism, Power Transmittal					
Belts	40	15.0	3.875	.142	
Clutches		1.1	.4	.06	
Friction	3				
Magnetic	6	.93	.6	.45	
Slip		.94	.3	.07	
Coupling	5				
Flexible		1.348	.6875	.027	
Rigid		.049	.025	.001	
Gear		.20	.12	.0118	
Helical	10	.098	.05	.002	
Spur	1	4.3	2.175	.087	
Shafts		.62	.35	.15	
Heavily Stressed	.2				
Lightly Stressed	.02				
Rack and Pinion	2				
Mounts, Resilient	9	1.60	.875	.20	
Orifices					
Fixed		2.11	.15	.01	
Variable		3.71	.55	.045	
Pumps		24.3	13.5	2.7	
Electric Drive		27.4	13.5	2.9	
Piping					
Pipes	.2				
Pipe joints	.5				
Union and Junctions	.4				
Pressure Vessels					
General	3				
High Standard	0.3				
Regulators		5.54	2.14	.70	
Flow and Pressure		5.54	2.14	.70	
Pneumatic		6.21	2.40	.77	
Relays					
General		.48/c	.25/c	.10/c	
Each Coil	.3				
Each Contact Pair	.2				
High Speed	5				
Heavy Duty	5	.81/c	.5/c	.30/c	
Hermetically Sealed	.5	.19/c	.04/c	.02/c	
Miniature		.25/c	.06/c	.03/c	
High Speed		1.13/c	.7/c	.42/c	
Power		4.10/c	.3/c	.15/c	
P.O. Type					
General	2				
Fully Tropicallized	1				
Restrictors	5	.983	.59	.197	

TABLE D. 1 (continued)

SOURCE	FAILURE RATE, Failures/10 ⁶ hr				
	AHSB(S) R 117	MI-60-54-(Rev 1)			Others
		High	Mean	Low	
Seals					
Rotating	7	.12	.7	.25	
Sliding	3	.92	.3	.11	
Solenoids		.55	.05	.036	
Springs		.221	.1125	.004	
Heavily stressed	1				
Lightly stressed	.2				
Hair	1				
Calibration		.42	.22	.009	
Creep	2				
Breakage	.2				
Switches		.14/c	.5/c	.009/c	
General, each contact	.2				
Micro	2	.50/c	.25/c	.09/c	
Push Button	.5	.11/c	.063/c	.043/c	
Rotary	2	.660/c	.175/c	.118/c	
Thermal		.261/c	.161/c	.114/c	
Heater	1				
Contacts	1				
Toggle		.123/c	.06/c	.015/c	
General	1				
Each Pair Contact	.2				
Synchros	8	.61	.35	.09	
Tanks		.27	.15	.083	
Pressure, small		.324	.18	.10	
High Pressure, small		.144	.08	.044	
Tachometers	5	.55	.3	.25	
Transducers		45.0	30.0	20.0	
Liquid Level		3.73	2.6	1.47	
Light		6.66	4.7	2.70	
Photoelectric Cells	15				
Pressure	15	52.2	35.0	23.2	
Radioactivity					
Beta Ray		21.3	14.00	6.70	
Ion Chamber and Leads	5				
Strain					
Gage	25	20.0	12.0	7.0	
Temperature		6.4	3.3	1.5	
Thermistors		28.00	15.0	10.0	.30 (3)
Thermocouples	10				
Transformers		2.0	.2	.07	
General, each winding	.3				
Mains					
Encapsulated	5				
Oil Filled	1				
Power		2.08	1.04	.46	
Low Voltage		.60	.3	.13	
High Voltage		1.88	.94	.407	
Pulse	1.5				
Low Voltage		.235	.15	.065	
High Voltage					
Variable	1	.31	.1	.035	
A. F.	0.3	.04	.02	.01	
I. F.	1	.31	.1	.035	
AIEE Class					(3)
O					.21 - 10.00
A					.20 - 19.50
B					.22 - 12.00
H					.21 - 18.50
C					.20 - 1.00

TABLE D. 1 (continued)

SOURCE	FAILURE RATE, Failures/10 ⁶ hr				
	AHSB(S) R 117	MI-60-54-(Rev 1)			Others
		High	Mean	Low	
Valves		8.0	5.1	2.00	
Ball	.5	7.7	4.6	1.11	
Butterfly		5.33	3.4	1.33	
Check		8.10	5.0	2.02	
Control	30	19.8	8.5	1.68	
Relief		14.1	5.7	3.27	
Leakage	2				
Blockage	0.5				
Shutoff	15	10.2	6.5	1.98	
Solenoid	30	19.7	11.0	2.27	
Selector		19.7	16.0	3.70	
3-Way		7.41	4.6	1.87	
4-Way		7.22	4.6	1.81	
Vibrators	5	.80	.5	.4	
Wiring					
Joints					
Soldered	.02	.005	.004	.0002	
Wrapped	.01				
Terminals	.5	.27	.05	.041	
Wires	.1	.12	.015	.008	

TABLE D.2
REFERENCE SOURCES FOR FAILURE RATE DATA

Reference No.	Author	Title	Document Number or Publication	Date of Publication	Type of Equipment Included				
					Electronic	Electrical Light	Electrical Heavy	Mechanical Light	Mechanical Heavy
1	A. E. Green and A. J. Bourne	Safety Assessment with Reference to Automatic Protective Systems for Nuclear Reactors, Part 3	AHSB (S) R 117	1966	X	X		X	
2	D. R. Earles	Reliability Application and Analysis Guide	MI-60-54-(Rev 1)	July 1961	X	X		X	
3	Department of Defense	Reliability Stress and Failure Rate Data for Electronic Equipment	MIL-HDBK-217A	Dec 1, 1965	X	X		X	
4	A. A. Schmudde	Engine-Generator Sets Meet Strict Reliability Limits	Power (Magazine)	April 1967			X		X
5	McGraw-Hill Book Company	RADC Reliability Notebook	RADC-TR-58-111	Oct 30, 1959	X	X		X	
6	Radio Corporation of America	Reliability Stress Analysis for Electronic Equipment	TR59-416-1	Jan. 15, 1959	X	X		X	
7	R. L. Harrington and R. R. Riddick, Jr.	Reliability Engineering Applied to the Marine Industry	Marine Technology (Journal)	October 1964			X		X
8	ARINC Research Corporation	Prediction of Field Reliability for Airborne Electronic Systems	Publication No. 203-1-344	Dec 31, 1962	X	X		X	
9	D. R. Earles and M. F. Eddins	Failure Rates	Proceedings, Ninth National Symposium on Reliability and Quality Control	January 1963	X	X		X	
10	Vitro Corporation	Reliability Prediction and Measurement of Shipboard Electronic Equipments	Report No. 98	April 15, 1957	X	X		X	
11	U.S. Naval Fleet Missile Systems Analysis and Evaluation Group, Corona, California	Bureau of Naval Weapons Failure Rate Handbook (Available only qualified contractors and government agencies)	SP-63-470	Revised Quarterly	X	X	X	X	X
12	ARINC Research Corporation	Reliability Engineering (pp. 308-310)	Prentice-Hall, Inc.	1964	X	X		X	

APPENDIX E

SAFTE-I SOURCE PROGRAM LISTING

06/26/67

MAIN - EFN SOURCE STATEMENT - IFN(S) -

```

C *****
C *
C *          ** SAFTE-I **
C *
C *   SYSTEMS ANALYSIS BY FAULT TREE EVALUATION.
C *           HOLMES+MARVER, INC.
C *
C *                               APRIL 1967
C *
C *****
C
C
C MONTE CARLO FAULT TREE SIMULATION
C EXPONENTIAL FAILURE AND GAUSSIAN REPAIR
C
C SPECIFICATION STATEMENTS
C
C   DIMENSION ARRAY(90,90),XMTTF(90),XMTTR(90),TTF(90),TTR(90),XIND(90
1),DUMM(90),SIG(90),SIG1(90),SIG2(90),CONS(90),TF(90),SYSPDF(250),
2PTHCDF(20),PTHPDF(20,250),PSEUD(90),VARAY(3,500 ),K1(3),ISUM(3),
3BIN(100)
4,COMP(90)
C
C   LOGICAL X(90),Y(90),A(90),B(90),G(90),TOP
C
C
C   COMMON NTRIAL,IMX,TMAX,NOINT,SIG,SIG1,SIG2,AA,BB,CC,X,Y,A,B,G,TOP,
1ARRAY,XMTTF,XMTTR,TTF,TTR,XIND,DUMM,CONS,TF,SYSPDF,PTHCDF,PTHPDF,
2SYSCDF,NCONS,COE,ARG,DELT,DUMMY,N,IJK,WHT
3,I,J,IND,KK,PSEUD,NPTH
4,K1,ISUM,VARAY,BIN
5,COMP
C
203 READ(5,1) NTRIAL,IMX,NOINT,NCONS,NPTH
   READ(5,2) TMAX,AA,BB,CC
   READ(5,2) (XMTTF(I),I=1,IMX)
   READ(5,2) (XMTTR(I),I=1,IMX)
   READ(5,2) (SIG(I),I=1,IMX)
   READ(5,2) (CONS(I),I=1,NCONS)
   READ(5,1) (K1(I),I=1,3)
C
C NTRIAL=NUMBER OF TRIALS
C IMX=NUMBER OF COMPONENTS(MAX. 90)
C NOINT=NUMBER OF TIME INTERVALS(MAX. 250)
C NCONS=NUMBER OF SIDE CONSTRAINTS(MAX. 90)
C NPTH=NO. OF CRITICAL PATHS
C TMAX=LENGTH OF TIME BEYOND WHICH TRIAL IS TERMINATED(HOURS)
C AA=BIASING PARAMETER FO TIME TO FAILURE CALCULATIONS. VALUES OF AA GREAT
C   ER THAN 1.0 CAUSE SHOTR TTFS TO BE EMPHASIZED.
C BB=BIASING PARAMETER FOR TIME TO REPAIR CALCULATION. VALUES OF BB GREAT
C   ER THAN 1.0 CAUSE SHORT TTRS TO BE DE-EMPHASIZED.
C CC=BIASING PARAMETER FOR TIME TO REPAIR CALCULATION.VALUES OF CC GREAT
C   ER THAN 1.0 CAUSE LONG TTRS TO BE EMPHASIZED.
C XMTTF=MEAN TIME TO FAILURE(HOURS).
C XMTTR=MEAN TIME TO REPAIR(HOURS).

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06/26/67

MAIN - EFN SOURCE STATEMENT - IFN(S) -

CSIG=STANDARD DEVIATION FOR TIME TO REPAIR DISTRIBUTIONS.
CCONS=SIDE CINSTRANTS.
CK1(I)=INTERVA NOS. FOR WHICH DETAILED ERROR ANALYSIS IS PERFORMED
C

```

      WRITE(6,3)
      WRITE(6,4) NTRIAL
      WRITE(6,5) IMX
      WRITE(6,6) NOINT
      WRITE(6,7) NCONS
      WRITE(6,275) NPTH
      WRITE(6,8) TMAX
      WRITE(6,9) AA
      WRITE(6,10) BB
      WRITE(6,11) CC
      WRITE(6,3)
      WRITE(6,12)
      DO 13 I=1,IMX
      WRITE(6,14) XMTTF(I),XMTTR(I)
13  CONTINUE
      DO 15 I=1,IMX
      SIG1(I)=SIG(I)/BB
      SIG2(I)=SIG(I)*CC
15  CONTINUE
      WRITE(6,3)
      WRITE(6,16)
      DO 18 I=1,IMX
      WRITE(6,17) SIG(I),SIG1(I),SIG2(I)
18  CONTINUE
      WRITE(6,3)
      WRITE(6,19)
      DO 21 I=1,NCONS
      WRITE(6,20) CONS(I)
21  CONTINUE
      WRITE(6,401) (K1(I),I=1,3)

```

C

```

1  FORMAT(5I5)
2  FORMAT(6E12.5)
3  FORMAT(1H1)
4  FORMAT(8HONTRIAL=I5/)
5  FORMAT(5H0IMX=I5/)
6  FORMAT(7H0NOINT=I5/)
7  FORMAT(7H0NCONS=I5/)
8  FORMAT(6HOTMAX=E12.5/)
9  FORMAT(4H0AA=E12.5/)
10 FORMAT(4H0BB=E12.5/)
11 FORMAT(4H0CC=E12.5/)
12 FORMAT(27H0      MTTF      MTTR      /)
14 FORMAT(E12.5,2X,E12.5)
16 FORMAT(4H0      SIG      SIG1      SIG2      /)
17 FORMAT(E12.5,2X,E12.5,2X,E12.5)
19 FORMAT(17H0SIDE CONSTRAINTS/)
20 FORMAT(3X,E12.5)
275 FORMAT(23H0NO. OF CRITICAL PATHS=I5/)
401 FORMAT(7H0K1(I)=3I5/)

```

C
CSET SCORING ARRAYS EQUAL TO ZERO.

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MAIN - EFN SOURCE STATEMENT - IFN(S) -

```

C      DO 402 I=1,IMX
        COMP(I)=0.
402  CONTINUE
        SYSCDF=0.
        DO 258 K=1,NOINT
          SYSPDF(K)=0.
          DO 259 KM=1,NPTH
            PTHPDF(KM,K)=0.
259  CONTINUE
258  CONTINUE
        DO 260 KM=1,NPTH
          PTHCDF(KM)=0.
260  CONTINUE
        ISUM(1)=0
        ISUM(2)=0
        ISUM(3)=0
C
        DUMMY=0.
        N=349
        CALL RANDIN(DUMMY)
        IJK=0
C
C      COMPUTE TIME INTERVAL SIZE
C
        DELT=NOINT
        DELT=TMAX/DELT
C
        DO 100 KK=1,NTRIAL
          COE=1.
          ARG=0.
          WHT=1.
C
C      CALL LOGICAL VARIABLES ARE INITIALLY SET FALSE FOR EACH TRIAL
C
        CALL SETLOG
C
C      COMPUTE TIME TO FAILURE(TTF) AND TIME TO REPAIR(TTR) FOR EACH COMPONENT
C
        DO 99 I=1,IMX
          R=EXPRN(DUMMY)
          TTF(I)=XMTTF(I)*R/AA
          TF(I)=TTF(I)
          R=GAUS(N)
          IF(R)277,277,278
277  R=-R
278  R1=FLTRN(DUMMY)
          IF(R1-0.5)97,98,98
          98  XIND(I)=1.0
              TTR(I)=XMTTTR(I)+SIG2(I)*R
              GO TO 99
          97  XIND(I)=-1.0
              TTR(I)=XMTTTR(I)-SIG1(I)*R
              IF(TTR(I))96,99,99
          96  TTR(I)=0.
          99  CONTINUE

```

06/26/67

MAIN - CFN SOURCE STATEMENT - IFN(S) -

```

C
  DO 403 I=1,IMX
C
CDETERMINE IF RIGHT OR LEFT GAUSSIAN WAS USED TO COMPUTE TTR(I).
C
  IF(XIND(I))33,33,34
C
CLEFT GAUSSIAN
C
  33 COE=COE*SIG1(I)/(AA*SIG(I))
  ARG=ARG+(-(1.-AA)*TF(I)/XMTTF(I)-0.5*(TTR(I)-XMTTR(I))*(TTR(I)-
  1XMTTR(I))*(1./(SIG(I)*SIG(I))-1./(SIG1(I)*SIG1(I))))
  GO TO 403
C
CRIGHT GAUSSIAN
C
  34 COE=COE*SIG2(I)/(AA*SIG(I))
  ARG=ARG+(-(1.-AA)*TF(I)/XMTTF(I)-0.5*(TTR(I)-XMTTR(I))*(TTR(I)-
  1XMTTR(I))*(1./(SIG(I)*SIG(I))-1./(SIG2(I)*SIG2(I))))
  403 CONTINUE
C
  WHT=WHT*COE*EXP(ARG)
C
CAN INITIAL SET OT TTFS AND TTRS HAVE BEEN COMPUTED FOR TRIAL NO. KK.
CITFS ARE NOW SEQUENCED ACCORDING TO INCREASING TIME TO FAILURE AND
CSTORED IN A TWO-DIMENSIONAL ARRAY ACCORDING TO COMPONENT NUMBER AND
CORDER OF FAILURE
C
  101 CALL SEQNCE
C
CEXAMINE ARRAY
C
  J=1
C
CEXAMINE JTH FAILURE TO DETERMINE COMPONENT NUMBER.
C
  40 DO 30 I=1,IMX
  I=I
  IF(ARRAY(I,J))30,30,31
  30 CONTINUE
C
CDETERMINE IF JTH FAILURE EXCEEDS MAX.OPERATING TIME
C
  31 IF(ARRAY(I,J)-TMAX)32,32,100
C
CJTH FAILURE DOES NOT EXCEED MAX. PORATING TIME AND LOGICAL X(I)IS
CSET .TRUE.
C
  32 X(I)=.TRUE.
  35 JK=J-1
C
CEXAMINE FAILED COMPONENTS TO DETERMINE WHICH IF ANY SHOULD BE REPAIRED.
C
  38 IF(JK)36,36,37
C
CCURRENT FAILURE IS FIRST IN SEQUENCE.

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MAIN - EFN SOURCE STATEMENT - IFN(S) -

```

C
36 CALL LOGIC                                     21
   IF(TOP)GO TO 39
   J=J+1
   GO TO 40
39 CALL SUM                                       21
   GO TO 100

C
CCURRENT FAILURE IS NOT FIRST OF SEQUENCE.
C
37 DO 28 IK=1,IMX
   IK=IK
   IF(ARRAY(IK,JK))28,28,27
28 CONTINUE
27 IF(X(IK))GO TO 26
   JK=JK-1
   GO TO 38
26 IF(ARRAY(I,J)-TTF(IK)-TTR(IK))25,25,202
25 JK=JK-1
   GO TO 38

C
CIT HAS BEEN DETERMINED THAT ONE          OF THE FIRST J FAILURES DO
CNOT OVERLAP. THE NON-OVERLAPPING COMPONENT X(IK) IS
CREPAIRED. A NEW TTF AND TTR ARE COMPUTED AND SEQUENCED INTO ARRAY(I,J).
C
202 R=EXPRN(DUMMY)                                24
   TF(IK)=XMTTF(IK)*R/AA
   TTF(IK)=TTF(IK)+TTR(IK)+TF(IK)
   R=GAUS(N)                                       24
   R1=FLTRN(DUMMY)                                25
   IF(R1-0.5)22,23,23
23 XIND(IK)=1.0
   TTR(IK)=XMTTR(IK)+SIG2(IK)*R
   COE1=SIG2(IK)/(AA*SIG(IK))
   ARG1=+(-(1.-AA)*TF(IK)/XMTTF(IK)-0.5*(TTR(IK)-XMTTR(IK))*(TTR(IK)-
1XMTTR(IK))*(1./(SIG(IK)*SIG(IK))-1./(SIG2(IK)*SIG2(IK))))
   WHT=WHT*COE1*EXP(ARG1)                          26
   GO TO 200
22 XIND(IK)=-1.0
   TTR(IK)=XMTTR(IK)-SIG1(IK)*R
   IF(TTR(IK))400,410,410
400 TTR(IK)=0.
410 COE1=SIG1(IK)/(AA*SIG(IK))
   ARG1=+(-(1.-AA)*TF(IK)/XMTTF(IK)-0.5*(TTR(IK)-XMTTR(IK))*(TTR(IK)-
1XMTTR(IK))*(1./(SIG(IK)*SIG(IK))-1./(SIG1(IK)*SIG1(IK))))
   WHT=WHT*COE1*EXP(ARG1)                          26
200 CALL SETLOG                                    25
   GO TO 101
100 CONTINUE
   CALL EDIT
   GO TO 203
END

```

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SETLG - EFN SOURCE STATEMENT - IFN(S) -

SUBROUTINE SETLOG

```
C
CSETLOG SETS ALL LOGICAL VARIABLES EQUAL TO .FALSE. AT THE BEGINNING
C OF EACH TRIAL.
C
C SPECIFICATION STATEMENTS
C
      DIMENSION ARRAY(90,90),XMTTF(90),XMTTR(90),TTF(90),TTR(90),XIND(90
1),DUMM(90),SIG(90),SIG1(90),SIG2(90),CONS(90),TF(90),SYSPDF(250),
2PTHCDF(20),PTHPDF(20,250),PSEUD(90),VARAY(3,500),K1(3) ISUM(3)
3BIN(100)
4 COMP(90)
C
      LOGICAL X(90),Y(90),A(90),B(90),G(90),TOP
C
      COMMON NTRIAL,IMX,TMAX,NOINT,SIG,SIG1,SIG2,AA,BB,CC,X,Y,A,B G TOP
1ARRAY,XMTTF,XMTTR,TTF,TTR,XIND,DUMM,CONS,TF,SYSPDF,PTHCDF,PTHPDF,
2SYSCDF,NCONS,COE,ARG,DELT,DUMMY,N,IJK,WHT
3,I,J,IND,KK,PSEUD,NPTH
4,K1,ISUM,VARAY,BIN
5,COMP
C
CSET LOGICAL VARIABLES=FALSE
C
      DO 62 I=1,IMX
      X(I)=.FALSE.
      Y(I)=.FALSE.
      A(I)=.FALSE.
      B(I)=.FALSE.
      G(I)=.FALSE.
62 CONTINUE
      TOP=.FALSE.
      RETURN
      END
```


04/05/67

SEQ - EFN SOURCE STATEMENT - IFN(S) -

SUBROUTINE SEQNCE

```

C
CSEQNCE ZEROS OUT ARRAY(I,J)AND THEN ARRANGES CURRENT LIST OF TTFS
CIN ARRAY(I,J). I SUBS. DENOTES COMPONENT NUMBER AND J SUBRS. DENOTES
CSEQUENCE OF FAILURE.
C
CSPECIFICATION STATEMENTS
C
    DIMENSION ARRAY(90,90),XMTTF(90),XMTTR(90),TTF(90),TTR(90),XIND(90
1),DUMM(90),SIG(90),SIG1(90) SIG2(90),CONS(90),TF(90),SYSPDF(250),
2PTHCDF(20),PTHPDF(20,250),PSEUD(90),VARAY(3,500 ),K1(3),ISUM(3),
3BIN(100)
4,COMP(90)
C
    LOGICAL X(90),Y(90),A(90),B(90),G(90),TOP
C
    COMMON NTRIAL IMX TMAX NOINT,SIG,SIG1,SIG2,AA,BB,CC,X,Y,A,B,G,TOP,
1ARRAY,XMTTF,XMTTR,TTF,TTR,XIND DUMM CONS TF SYSPDF PTHCDF PTHPDF
2SYSCDF,NCONS,COE,ARG,DELT,DUMMY,N,IJK,WHT
3,I,J,IND,KK,PSEUD,NPTH
4,K1,ISUM,VARAY,BIN
5,COMP
C
    IJK=IJK&1
C
CSET ARRAY(I J)=0.
C
    DO 50 I=1,IMX
    DO 49 J=1,IMX
    ARRAY(I,J)=0.
49 CONTINUE
50 CONTINUE
C
CPLACE TTF(I) LIST IN DUMM(I).
C
    DO 51 I=1,IMX
    DUMM(I)=TTF(I)
51 CONTINUE
C
CPLACE DUMM(I) IN ARRAY(I,J) IN ORDER OF INCREASING TIME TO FAILURE
C
    DO 52 J=1,IMX
    J=J
    I=1
53 IF(DUMM(I))54,54,55
54 I=I&1
    GO TO 53
55 DUM1=DUMM(I)
    IJ=1
56 K=I&1
    IF(K-IMX)57,57,58
57 IF(DUMM(K))59,59,60
59 I=I&1
    GO TO 56
60 DUM2=DUMM(K)

```

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	SEQ	-	EFN	SOURCE STATEMENT	-	IFN(S)	-
				IF (DUM1-DUM2)59,59,61			
61				DUM1=DUM2			
				IJ=K			
				GO TO 59			
58				ARRAY(IJ,J)=DUM1			
				DUMM(IJ)=0.			
52				CONTINUE			
				RETURN			
				END			

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LOGIC1 - EFN SOURCE STATEMENT - IFN(S) -

SUBROUTINE LOGIC

```

C
C DRESDEN EMERGENCY POWER SYSTEM
C
C THE FUNCTION OF LOGIC IS TO EXAMINE CURRENT COMPONENT FAILURES AND
C DETERMINE IF THE UNDESIRE EVENT HAS OCCURED.
C
C SPECIFICATION STATEMENTS
C
C   DIMENSION ARRAY(90,90),XMTTF(90),XMTTR(90),TTF(90),TTR(90),XIND(90
C   1),DUMM(90),SIG(90),SIG1(90),SIG2(90),CONS(90),TF(90),SYSPDF(250),
C   2PTHCDF(20),PTHPDF(20,250),PSEUD(90),VARAY(3,500 ),K1(3),ISUM(3),
C   3BIN(100)
C   4,COMP(90)
C
C   LOGICAL X(90),Y(90),A(90),B(90),G(90),TOP
C
C   COMMON NTRIAL,IMX,TMAX,NOINT,SIG,SIG1,SIG2,AA,BB,CC,X,Y,A,B,G,TOP,
C   1ARRAY,XMTTF,XMTTR,TTF,TTR,XIND,DUMM,CONS,TF,SYSPDF,PTHCDF,PTHPDF,
C   2SYSCDF,NCONS,COE,ARG,DELT,DUMMY,N,IJK,WHT
C   3,I,J,IND,KK,PSEUD,NPTH
C   4,K1,ISUM,VARAY,BIN
C   5,COMP
C
C   A(1)=X(1).OR.X(2)
C   A(2)=X(3).OR.X(4)
C   A(3)=A(1).OR.A(2)
C   A(4)=X(5).OR.X(6)
C   A(5)=A(3).OR.A(4)
C   A(12)=X(13).OR.A(5)
C   A(13)=X(14).OR.X(15)
C   A(14)=A(12).OR.A(13)
C   A(15)=X(16).OR.A(14)
C   A(16)=X(17).OR.A(15)
C
C   A(6)=X(2).OR.X(7)
C   A(7)=X(8).OR.X(9)
C   A(8)=A(6).OR.A(7)
C   A(9)=X(10).OR.A(8)
C   A(10)=X(11).OR.A(9)
C   A(11)=X(12).OR.A(10)
C
C   B(1)=A(11).AND.A(16)
C   A(18)=X(19).OR.X(20)
C   A(19)=A(18).OR.B(1)
C
C   A(20)=X(23).OR.X(24)
C   A(21)=X(21).OR.X(22)
C   A(22)=A(20).OR.A(21)
C
C   A(23)=X(25).OR.X(26)
C   A(24)=X(27).OR.X(28)
C   A(35)=X(38).OR.X(39)
C   A(25)=X(29).OR.A(35).OR.A(24)
C   A(26)=A(23).OR.A(25)

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LOGIC1 - EFN SOURCE STATEMENT - IFN(S) -

C B(2)=A(19).AND.A(22).AND.A(26)

A(31)=X(34).OR.X(35)
A(29)=X(32).OR.X(33)
A(30)=A(9).OR.A(29)
A(17)=X(18).OR.A(15)
A(27)=X(30).OR.X(31)
A(28)=A(17).OR.A(27)
B(3)=A(28).AND.A(30)
A(32)=A(31).OR.B(3)

C A(33)=X(36).OR.X(37)
A(34)=A(20).OR.A(33)

C A(36)=X(40).OR.X(41)
A(37)=A(25).OR.A(36)
B(4)=A(32).AND.A(34).AND.A(37)

C B(5)=B(2).AND.B(4)

C A(38)=X(42).OR.X(43)
A(39)=A(38).OR.B(2)
A(40)=X(44).OR.A(39)
A(41)=X(45).OR.X(46)
A(42)=A(40).OR.A(41)
A(43)=X(47).OR.A(42)
A(44)=X(48).OR.X(49)
A(45)=A(43).OR.A(44)

C A(52)=X(56).OR.X(57)
A(46)=X(50).OR.X(51)
A(47)=A(46).OR.B(4)
A(48)=X(52).OR.A(47)
A(49)=X(53).OR.X(54)
A(50)=A(48).OR.A(49)
A(51)=A(50).OR.A(55)
A(53)=A(51).OR.A(52)

C B(6)=A(45).AND.A(53)

C B(7)=B(5).AND.B(6)

C TOP=B(7)
IND=1
RETURN
END

04/28/67

SUBROUTINE SUM

C
C THE PURPOSE OF SUM IS TO TO RECORD TRIAL WEIGHT IN THE APPROPRIATE
CARAYS AT THE END OF EACH TRIAL.

C
C SPECIFICATION STATEMENTS

C
C DIMENSION ARRAY(90,90),XMTTF(90),XMTTR(90),TTF(90),TTR(90),XIND(90
1),DUMM(90),SIG(90),SIG1(90),SIG2(90),CONS(90),TF(90),SYSPDF(250),
2PTHCDF(20),PTHPDF(20,250),PSEUD(90),VARAY(3,500),K1(3),ISUM(3),
3BIN(100)
4,COMP(90)

C
C LOGICAL X(90),Y(90),A(90),B(90),G(90),TOP

C
C COMMON NTRIAL,IMX,TMAX,NOINT,SIG,SIG1,SIG2,AA,BB,CC,X,Y,A,B,G,TOP,
1ARRAY,XMTTF,XMTTR,TTF,TTR,XIND,DUMM,CONS,TF,SYSPDF,PTHCDF,PTHPDF,
2SYSCDF,NCONS,COE,ARG,DELT,DUMMY,N,IJK,WHT
3,I,J,IND,KK,PSEUD,NPTH
4,K1,ISUM,VARAY,BIN
5,COMP

C
C TIME=ARRAY(I,J)
CHECK=DELT
DO 255 K=1,NOINT
K=K
IF(TIME-CHECK)256,256,257
257 CHECK=CHECK+DELT
255 CONTINUE
256 SYSPDF(K)=SYSPDF(K)+WHT
SYSCDF=SYSCDF+WHT
PTHPDF(IND,K)=PTHPDF(IND,K)+WHT
PTHCDF(IND)=PTHCDF(IND)+WHT
DO 260 I=1,3
IF(K-K1(I))253,253,260
253 ISUM(I)=ISUM(I)+1
IF(ISUM(I)-500)254,254,260
254 IND=ISUM(I)
VARAY(I,IND)=WHT
260 CONTINUE

C
C COMPONENT I IS RESPONSIBLE FOR CATASTROPHIC FAILURE

C
C 1 COMP(I)=COMP(I)+WHT
RETURN
END

04/05/67

EDIT1 - EFN SOURCE STATEMENT - IFN(S) -

SUBROUTINE EDIT

```

C
CTHE PURPOSE OF EDIT IS TO PERFORM THE NECESSARY OPERATIONS ON ARRAY
CCONTENTS AT END OF RUN TO ENABLE INTERPRETATION IN TERMS OF FAILURE
CFREQUENCY&CUMULATIVE FAILURES.
C
CTHIS SUBROUTINE LOOKS AT THE DETAILED STATISTICAL ERRORS IN THE CUMU-
CLATIVE FAILURE DISTRIBUTIONS FOR SELECTED OPERATING TIMES
C
CSPECIFICATION STATEMENTS
C
    DIMENSION ARRAY(90,90),XMTTF(90),XMTTR(90),TTF(90),TTR(90),XIND(90
1),DUMM(90),SIG(90),SIG1(90) SIG2(90),CONS(90),TF(90),SYSPDF(250),
2PTHCDF(20),PTHPDF(20,250),PSEUD(90),VARAY(3,500 ),K1(3),ISUM(3),
3BIN(100)
4,COMP(90)
C
    LOGICAL X(90),Y(90),A(90),B(90),G(90),TOP
C
    COMMON NTRIAL,IMX,TMAX,NOINT,SIG,SIG1,SIG2,AA,BB,CC,X,Y,A,B,G,TOP,
1ARRAY,XMTTF,XMTTR,TTF,TTR,XIND,DUMM,CONS,TF,SYSPDF,PTHCDF,PTHPDF,
2SYSCDF,NCONS,COE,ARG,DELT,DUMMY,N,IJK,WHT
3,I,J,IND,KK,PSEUD,NPTH
4,K1,ISUM,VARAY,BIN
5,COMP
C
    TRIAL=NTRIAL
    DELT1=DELT*TRIAL
    SYSCDF=SYSCDF/TRIAL
    WRITE(6,261)
    WRITE(6,262)SYSCDF
    DO 263 I=1,NOINT
    SYSPDF(I)=SYSPDF(I)/DELT1
    DO 264 J=1,NPTH
    PTHPDF(J,I)=PTHPDF(J,I)/DELT1
264 CONTINUE
263 CONTINUE
    DO 265 J=1,NPTH
    PTHCDF(J)=PTHCDF(J)/TRIAL
265 CONTINUE
    WRITE(6,266)
    WRITE(6,267)(SYSPDF(I),I=1,NOINT)
    SYSPDF(1)=SYSPDF(1)*DELT
    DO 450 I=2,NOINT
    SYSPDF(I)=SYSPDF(I-1)&SYSPDF(I)*DELT
450 CONTINUE
    WRITE(6,261)
    WRITE(6,451)
    WRITE(6,267)(SYSPDF(I) I=1,NOINT)
    WRITE(6,261)
    WRITE(6,268)
    WRITE(6,269)
    DO 270 I=1,NPTH
    WRITE(6,271)I,PTHCDF(I)
270 CONTINUE

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EDIT1 - EFN SOURCE STATEMENT - IFN(S) -

```

211 CONTINUE
    SUM1=SUM1/TRIAL
    SUM2=SUM2/TRIAL
    VAR2=SUM1-SUM2*SUM2
    IF(VAR2)111,111,212
111 DEV2=0.
    GO TO 213
212 DEV2=VAR2**0.5
213 WRITE(6,214) VAR2
    WRITE(6,215) DEV2
    IF(DEV1)223,223,224
223 WRITE(6,225)
    RETURN
224 DO 218 KI=1,48
    BIN(KI)=0.
218 CONTINUE
    DO 219 J=1,IND
    VARAY(I,J)=VARAY(I,J)/(TRIAL*XMEAN*0.25*DEV1)
    WRITE(6,229) VARAY(I,J)
    CHECK=XMEAN-5.75*DEV1
    DO 220 KI=1,48
    KI=KI
    IF(CHECK-VARAY(I,J))221 222 222
222 BIN(KI)=BIN(KI)&VARAY(I,J)
    GO TO 219
221 CHECK=CHECK&0.25*DEV1
220 CONTINUE
219 CONTINUE
    WRITE(6,226) K1(I)
    CHECK1=XMEAN-5.75*DEV1
    CHECK2=XMEAN-6.0*DEV1
    CHECK3=CHECK2&0.125*DEV1
    WRITE(6,227)
    DO 228 KI=1,48
    EXACT=1.0/(DEV1*2.508)
    EXACT=EXACT*EXP(-CHECK3*CHECK3/(2.0*VAR1))
    WRITE(6,229) CHECK2,CHECK1,BIN(KI),EXACT
    CHECK1=CHECK1&0.25*DEV1
    CHECK2=CHECK2&0.25*DEV1
    CHECK3=CHECK3&0.25*DEV1
228 CONTINUE
200 CONTINUE
C
261 FORMAT(1H1)
262 FORMAT(43HOPROBABILITY OF SYSTEM FAILURE BEFORE TMAX=E12.5/)
266 FORMAT(25HOSYSTEM FAILURE FREQUENCY/)
267 FORMAT(5E12.5)
268 FORMAT(50HOPROBABILITY OF DISCRETE PATH FAILURES BEFORE TMAX/)
269 FORMAT(24HO PATH NO. PROBABILITY/)
271 FORMAT(16,6X,E12.5)
273 FORMAT(26HOFailure FREQUENCY OF PATH I4/)
281 FORMAT(7HOASTEP=E12.5)
451 FORMAT(25HOCUMULATIVE FAILURE DIST./)
453 FORMAT(33HOCUMULATIVE FAILURE DIST.OF PATH I4/)
C
225 FORMAT(14HOEFF.ST.DEV.=0/)

```

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EDIT1 - EFN SOURCE STATEMENT - IFN(S) -

```

DO 272 I=1 NPTH
WRITE(6,261)
WRITE(6,273) I
WRITE(6,267) (PTHPDF(I,J),J=1,NOINT )
PTHPDF(I,1)=PTHPDF(I,1)*DELT
DO 452 J=2,NOINT
PTHPDF(I,J)=PTHPDF(I,J-1)&PTHPDF(I,J)*DELT
452 CONTINUE
WRITE(6,261)
WRITE(6,453) I
WRITE(6,267) (PTHPDF(I,J) J=1,NOINT)
272 CONTINUE
XIIJK=IJK
ASTEP=XIIJK/TRIAL
WRITE(6,281) ASTEP
WRITE(6,261)
WRITE(6,500)
500 FORMAT(30HOCOMP. ID      NO. OF FAILURES  //)
DO 501 I=1,IMX
I=I
COMP(I)=COMP(I)/TRIAL
WRITE(6,502) I,COMP(I)
501 CONTINUE
502 FORMAT(I6,6X,E12.5)
C
CSTATISTICAL ERROR ANALYSIS OF CUMULATIVE FAILURE DIST. FOR SELECTED
COPERATING TIMES.
C
DO 200 I=1,3
WRITE(6,261)
SUM=0.
IF(K1(I)) 200,200,201
201 IND=ISUM(I)
DO 202 J=1,IND
SUM=SUM&VARAY(I,J)
202 CONTINUE
XMEAN=SUM/TRIAL
VAR1=0.
DO 203 J=1,IND
VAR1=VAR1&(VARAY(I,J)-XMEAN)**2.
203 CONTINUE
VAR1=VAR1/(TRIAL-1.)
IF(VAR1) 208,208,209
208 DEV1=0.
GO TO 210
209 DEV1=VAR1**0.5
210 WRITE(6,204) K1(I)
WRITE(6,216) ISUM(I)
WRITE(6,205) XMEAN
WRITE(6,206) VAR1
WRITE(6,207) DEV1
SUM1=0.
SUM2=0.
DO 211 J=1,IND
SUM1=SUM1&VARAY(I,J)*VARAY(I,J)
SUM2=SUM2&VARAY(I,J)

```


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EDIT1 - EFN SOURCE STATEMENT - IFN(S) -

```
204 FURMAT(30HOERROR ANALYSIS FOR INTERVAL I5//)
205 FORMAT(16HOEFF.MEAN VALUE= E12.5/)
206 FORMAT(14HOEFF.VARIANCE= E12.5/)
207 FORMAT(24HOEFF.STANDARD DEVIATION= E12.5/)
214 FORMAT(18HOMON.CAR.VARIANCE= E12.5/)
215 FORMAT(17HOMON.CAR.ST.DEV.= E12.5/)
216 FORMAT(24HOND.OF NON-ZERO SAMPLES= I5/)
226 FORMAT(37HONORMALIZED SAMPLE DIST.FOR INTERVAL I5/)
227 FORMAT(57HO          INTERVAL          SAMPLE          EXACT
1          //)
229 FORMAT(2E13.5 3X 2E12.5)
RETURN
END
```

DEMO RAN1
ASSEMBLED TEXT.

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\$TEXT RAN1

RAN10001

BINARY CARD (NOT PUNCHED)

00000	1	00000	0	00005	10001	RNGEN SAVE(1,2,4)
00001	0774	00	2	00000	10000	
00002	0774	00	1	00000	10000	
00003	0774	00	4	00000	10000	
00004	0020	00	4	00001	10000	
00005	0634	00	4	05000	10011	
00006	0634	00	4	00545	10001	
00007	0634	00	4	00003	10001	
00010	0634	00	1	00002	10001	
00011	0634	00	2	00001	10001	
00012	4520	00	0	00066	10001	NZT IX&2
00013	0020	00	0	00123	10001	TRA NFE
00014	0600	00	0	00066	10001	STZ IX&2
00015	0500	60	4	00003	10000	CLA* 3,4
00016	0100	00	0	00137	10001	TZE BLO
00017	0621	00	0	00064	10001	STA IX
00020	0534	00	4	00064	10001	LXA IX,4
00021	0534	00	2	00547	10001	LXA =25,2
00022	1	00001	4	01001	10011	LOP TXI *&1,4,1

BINARY CARD (NOT PUNCHED)

00023	0500	00	4	01000	10011	CLA *,4
00024	0340	00	0	00067	10001	CAS IX&3
00025	0020	00	0	01002	10011	TRA *&2
00026	0020	00	0	00022	10001	TRA LOP
00027	0601	00	0	00067	10001	STO IX&3
00030	0760	00	0	00003	10000	SSP
00031	0601	00	2	00123	10001	STO BUF&1,2
00032	2	00002	2	00022	10001	TXI LOP,2,2
00033	0634	00	4	00064	10001	SXA IX,4
00034	0534	00	1	00547	10001	LXA =25,1
00035	0534	00	2	00547	10001	LXA =25,2
00036	0560	00	0	00122	10001	LDQ BUF
00037	0500	00	0	00070	10001	CLA WS
00040	4320	00	0	00550	10001	LP1 ANA =03000015
00041	0400	00	0	00550	10001	ADD =03000015
00042	4734	00	4	00000	10000	PDX 0,4
00043	0621	00	0	01003	10011	STA *&3
00044	0500	00	0	00070	10001	CLA WS
00045	4765	00	0	00022	10000	LP2- LGR 18

BINARY CARD (NOT PUNCHED)

00046	4773	00	0	00000	10000	RQL 0
00047	4763	00	0	00022	10000	LGL 18
00050	0400	00	2	00123	10001	ADD BUF&1,2
00051	2	00001	2	01002	10011	TXI *&2,2,1
00052	0534	00	2	00547	10001	LXA =25,2
00053	2	00001	4	00045	10001	TXI LP2,4,1
00054	0140	00	0	01001	10011	TQV *&1
00055	0162	00	0	01002	10011	TQP *&2
00056	0760	00	0	00006	10000	COM
00057	0760	00	0	00003	10000	SSP

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ASSEMBLED TEXT.			
00060	0601 00 1 00123	10001	STO BUF&1,1
00061	0601 00 0 00070	10001	STO WS
00062	2 00001 1 00040	10001	TIX LP1,1,1
00063	0020 00 0 00137	10001	TRA BLO
00064	000000000000	10000	IX DEC 0,25,15,0
00065	000000000031	10000	
00066	000000000017	10000	
00067	000000000000	10000	
00070	314261527645	10000	WS OCT 314261527645,0
BINARY CARD (NOT PUNCHED)			
00071	000000000000	10000	
00072	212372516470	10000	OCT 212372516470,254626046356,234404214246,234070206046
00073	254626046356	10000	
00074	234404214246	10000	
00075	234070206046	10000	
00076	052556470063	10000	OCT 052556470063,317302262367,074030426135,062537664126
00077	317302262367	10000	
00100	074030426135	10000	
00101	062537664126	10000	
00102	330654014044	10000	OCT 330654014044,056476235564,256546754666,377116552640
00103	056476235564	10000	
00104	256546754666	10000	
00105	377116552640	10000	
00106	354476611273	10000	OCT 354476611273,220737153554,144403454231,037272626023
00107	220737153554	10000	
00110	144403454231	10000	
00111	037272626023	10000	
00112	057012270401	10000	OCT 057012270401,156527204220,246321541143,356113317526
00113	156527204220	10000	
BINARY CARD (NOT PUNCHED)			
00114	246321541143	10000	
00115	356113317526	10000	
00116	340261252715	10000	OCT 340261252715,221724170022,000164101035,030701073715
00117	221724170022	10000	
00120	000164101035	10000	
00121	030701073715	10000	
00122	253477371574	10000	BUF OCT 253477371574
00123	0500 00 0 00065	10001	NFE CLA IX&1
00124	0100 00 0 00020	10001	TZE LUP-2
00125	0734 00 1 00000	10000	PAX 0,1
00126	0500 00 1 00123	10001	CLA BUF&1,1
00127	0771 00 0 00011	10000	ARS 9
00130	0430 00 0 00551	10001	ADD =1.0
00131	0302 00 0 00551	10001	FSB =1.0
00132	1 77777 1 01001	10011	TXI *&1,1,-1
00133	0634 00 1 00065	10001	SXA IX&1,1
	00134		RETURN RNGEN,0
BINARY CARD (NOT PUNCHED)			
00137	0500 00 0 00547	10001	BLO CLA =25
00140	0020 00 0 00125	10001	TRA NFE&2
00141	1 00000 0 00146	10001	GAUS SAVE 1,2,4
00142	0774 00 2 00000	10000	
00143	0774 00 1 00000	10000	

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ASSEMBLED TEXT.					
00144	0774	00 4	00000	10000	
00145	0020	00 4	00001	10000	
00146	0634	00 4	05000	10011	
00147	0634	00 4	00545	10001	
00150	0634	00 4	00144	10001	
00151	0634	00 1	00143	10001	
00152	0634	00 2	00142	10001	
00153	4520	00 0	00162	10001	NZT G&2
00154	0020	00 0	00160	10001	TRA G
00155	0600	00 0	00162	10001	STZ G&2
00156	0500	00 4	00003	10000	CLA 3,4
00157	0621	00 0	00163	10001	STA G&3
00160	0074	00 4	02000	10011	G TSX RNGEN,4
00161	0020	00 0	01003	10011	TRA *G3
BINARY CARD (NOT PUNCHED)					
00162	0000	00 0	00017	10000	HTR 15
00163	0000	00 0	00000	10000	HTR 0
00164	0601	00 0	00177	10001	STO X
00165	0601	00 0	00200	10001	STO X&1
00166	0302	00 0	00552	10001	FSB =0.5
00167	0120	00 0	00203	10001	TPL G2
00170	0600	00 0	00200	10001	STZ X&1
00171	0500	00 0	00177	10001	CLA X
00172	0601	00 0	00201	10001	STO X&2
00173	0300	00 0	00552	10001	FAD =0.5
00174	0601	00 0	00177	10001	STO X
00175	0760	00 0	00002	10000	CHS
00176	0020	00 0	00205	10001	TRA G3
00177	000000000000		10000	X	DEC 0,0,0,0
00200	000000000000		10000		
00201	000000000000		10000		
00202	000000000000		10000		
00203	0601	00 0	00201	10001	G2 STO X&2
00204	0502	00 0	00177	10001	CLS X
BINARY CARD (NOT PUNCHED)					
00205	0300	00 0	00551	10001	G3 FAD =1.0
00206	0131	00 0	00000	10000	XCA
00207	0260	00 0	00177	10001	FMP X
00210	0601	00 0	00202	10001	STO X&3
00211	0500	00 0	00177	10001	CLA X
00212	4300	00 0	00553	10001	UFA =0232000000000
00213	4773	00 0	00010	10000	RQL 8
00214	0774	00 1	00011	10000	AXT 9,1
00215	0763	00 0	00001	10000	G4 LLS 1
00216	0760	00 0	00001	10000	LBT
00217	0020	00 1	00233	10001	TRA H,1
00220	2 00001	1 00215	10001		TIX G4,1,1
00221	0020	00 0	00404	10001	TRA I9
00222	0020	00 0	00236	10001	TRA I1
00223	0020	00 0	00256	10001	TRA I2
00224	0020	00 0	00274	10001	TRA I3
00225	0020	00 0	00300	10001	TRA I4
00226	0020	00 0	00323	10001	TRA I5
00227	0020	00 0	00347	10001	TRA I6&1

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ASSEMBLED TEXT.					
BINARY CARD (NOT PUNCHED)					
00230	0020 00 0 00346	10001		TRA 16	
00231	0020 00 0 00400	10001		TRA 17	
00232	0020 00 0 00402	10001		TRA 18	
00233	000000000000	10000	H	DEC 0,0,0	
00234	000000000000	10000			
00235	000000000000	10000			
00236	4754 00 0 00000	10000	I1	PXD 0,0	
00237	0763 00 0 00003	10000		LLS 3	
00240	0734 00 2 00000	10000		PAX 0,2	
00241	0560 00 0 00177	10001		LDQ X	
00242	4600 00 0 00234	10001		STQ H&1	
00243	0260 00 0 00177	10001		FMP X	
00244	0131 00 0 00000	10000	G5	XCA	
00245	0260 00 2 00544	10001		FMP B3,2	
00246	0601 00 0 00233	10001		STO H	
00247	0560 00 0 00234	10001		LDQ H&1	
00250	0260 00 2 00513	10001		FMP B2,2	
00251	0300 00 0 00233	10001		FAD H	
00252	0300 00 2 00462	10001		FAD B1,2	
BINARY CARD (NOT PUNCHED)					
00253	4520 00 0 00200	10001		NZY X&1	
00254	4760 00 0 00003	10000		SSM	
	00255			RETURN GAUS	
00256	4754 00 0 00000	10000	I2	PXD 0,0	
00257	0763 00 0 00002	10000		LLS 2	
00260	0734 00 2 00000	10000		PAX 0,2	
00261	0500 00 0 00201	10001		CLA X&2	
00262	0241 00 0 00202	10001		FDP X&3	
00263	4600 00 0 00234	10001		STQ H&1	
00264	000000000000	00010		CALL SQRT(X&3)	
00264	0074 00 4 04000	10011			
00265	1 00001 0 01003	10011			
00266	0 00545 0 00232	10100			
00267	0 00000 0 00202	10001			
00270	0601 00 0 00202	10001		STO X&3	
00271	0500 00 0 00201	10001		CLA X&2	
00272	0241 00 0 00202	10001		FDP X&3	
00273	1 00010 2 00245	10001		TXI G5&1,2,8	
00274	4754 00 0 00000	10000	I3	PXD 0,0	
BINARY CARD (NOT PUNCHED)					
00275	0763 00 0 00002	10000		LLS 2	
00276	0734 00 2 00000	10000		PAX 0,2	
00277	1 00004 2 00261	10001		TXI I2&3,2,4	
00300	4754 00 0 00000	10000	I4	PXD 0,0	
00301	0763 00 0 00001	10000		LLS 1	
00302	0734 00 2 00000	10000		PAX 0,2	
00303	0530 00 0 00201	10001		CLA X&2	
00304	0241 00 0 00202	10001		FDP X&3	
00305	4600 00 0 00234	10001		STQ H&1	
00306	000000000000	00010		CALL SQRT(X&3)	
00306	0074 00 4 04000	10011			
00307	1 00001 0 01003	10011			
00310	0 00545 0 00251	10100			

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ASSEMBLED TEXT.					
00311	0 06030 0 00202	10001			
00312	0601 00 0 00202	10001		STO X&3	
00313	000000000000	00010		CALL SQRT(X&3)	
00313	0074 00 4 04000	10011			
00314	1 00001 0 01003	10011			
00315	0 00545 0 00253	10100			
BINARY CARD (NOT PUNCHED)					
00316	0 00000 0 00202	10001			
00317	0601 00 0 00202	10001		STO X&3	
00320	0500 00 0 00201	10001		CLA X&2	
00321	0241 00 0 00202	10001		FDP X&3	
00322	1 00020 2 00245	10001		TXI G5&1,2,16	
00323	4754 00 0 00000	10000	15	PXD 0,0	
00324	0763 00 0 00001	10000		LLS 1	
00325	0734 00 2 00000	10000		PAX 0,2	
00326	000000000000	00010		CALL SQRT(X&3)	
00326	0074 00 4 04000	10011			
00327	1 00001 0 01003	10011			
00330	0 00545 0 00263	10100			
00331	0 00000 0 00202	10001			
00332	0601 00 0 00202	10001		STO X&3	
00333	0500 00 0 00201	10001		CLA X&2	
00334	0241 00 0 00202	10001		FDP X&3	
00335	4600 00 0 00234	10001		STQ H&1	
00336	000000000000	00010		CALL SQRT(X&3)	
00336	0074 00 4 04000	10011			
BINARY CARD (NOT PUNCHED)					
00337	1 00001 0 01003	10011			
00340	0 00545 0 00270	10100			
00341	0 00000 0 00202	10001			
00342	0601 00 0 00202	10001		STO X&3	
00343	0500 00 0 00201	10001		CLA X&2	
00344	0241 00 0 00202	10001		FDP X&3	
00345	1 00022 2 00245	10001		TXI G5&1,2,18	
00346	0765 00 0 00001	10000	16	LRS 1	
00347	0765 00 0 00001	10000		LRS 1	
00350	4754 00 0 00000	10000		PXD 0,0	
00351	0763 00 0 00002	10000		LLS 2	
00352	0734 00 2 00000	10000		PAX 0,2	
00353	000000000000	00010		CALL SQRT(X&3)	
00353	0074 00 4 04000	10011			
00354	1 00001 0 01003	10011			
00355	0 00545 0 00302	10100			
00356	0 00000 0 00202	10001			
00357	0601 00 0 00202	10001		STO X&3	
00360	0500 00 0 00201	10001		CLA X&2	
BINARY CARD (NOT PUNCHED)					
00361	0241 00 0 00202	10001		FDP X&3	
00362	4600 00 0 00234	10001		STQ H&1	
00363	000000000000	00010		CALL SQRT(X&3)	
00363	0074 00 4 04000	10011			
00364	1 00001 0 01003	10011			
00365	0 00545 0 00307	10100			

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ASSEMBLED TEXT.			
00366	0 00000 0 00202	10001	
00367	0601 00 0 00202	10001	STO X&3
00370	000000000000	00010	CALL SQRT(X&3)
00370	0074 00 4 04000	10011	
00371	1 00001 0 01003	10011	
00372	0 00545 0 03311	10100	
00373	0 00000 0 00202	10001	
00374	0601 00 0 00202	10001	STO X&3
00375	0500 00 0 00201	10001	CLA X&2
00376	0241 00 0 00202	10001	FDP X&3
00377	1 00024 2 00245	10001	TXI G5&1,2,20
00400	0774 00 2 00003	10000	17 AXT 3,2
00401	0020 00 0 00353	10001	TRA 16&5
BINARY CARD (NOT PUNCHED)			
00402	0774 00 2 00004	10000	18 AXT 4,2
00403	0020 00 0 00353	10001	TRA 16&5
00404	0774 00 2 00005	10000	19 AXT 5,2
00405	0500 00 0 00424	10001	CLA 88
00406	0601 00 0 00233	10001	STO H
00407	0020 00 0 03415	10001	TRA 191
00410	000000000000	00010	CALL SQRT(X&3)
00410	0074 00 4 04000	10011	
00411	1 00001 0 01003	10011	
00412	0 00545 0 00326	10100	
00413	0 00300 0 00202	10001	
00414	0601 00 0 00202	10001	191 STO X&3
00415	0500 00 0 00201	10001	CLA X&2
00416	0241 00 0 00202	10001	FDP X&3
00417	0260 00 2 00432	10001	FMP 88&6,2
00420	0300 00 0 00233	10001	FAD H
00421	0601 00 0 00233	10001	STO H
00422	2 00001 2 00410	10001	TXI 19&4,2,1
00423	0020 00 0 00253	10001	TRA G5&7
BINARY CARD (NOT PUNCHED)			
00424	603677741204	10000	88 DEC -6.9990618,1.6687811E-08,-6.4184731E-04
00425	147436543423	10000	
00426	566520406447	10000	
00427	176772760277	10000	DEC 0.24754369,-6.4510401,22.172394
00430	603634673535	10000	
00431	205542604201	10000	
00432	577475323755	10000	DEC -0.3099746,-0.5916167,-0.7765925,-0.8109274,-0.7713425
00433	600456720611	10000	
00434	600615473041	10000	
00435	600637143601	10000	
00436	600612732636	10000	
00437	573542457223	10000	DEC -0.0216426,-0.0715735,0.0634248,0.0123036,0.2762601
00440	575445124404	10000	
00441	175403623344	10000	
00442	172623124117	10000	
00443	177432707666	10000	
00444	176645730301	10000	DEC 0.2060169,0.1548084,0.1167513,0.0766115,0.0431227
00445	176475030277	10000	
00446	175736155162	10000	

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ASSEMBLED TEXT.				
BINARY CARD (NOT PUNCHED)				
00447	175471631754	10000		
00450	174541205555	10000		
00451	173603721413	10000	DEC	0.0236761,0.0124941,-0.0421306,-0.3968161
00452	172631320156	10000		
00453	574531104427	10000		
00454	577626255727	10000		
00455	600512060767	10000	DEC	-0.6447181,-0.8246707,-0.9600543,-1.0655321,-1.1506400
00456	600646166364	10000		
00457	600753430363	10000		
00460	601420615331	10000		
00461	601446441673	10000		
00462	601470523300	10000	B1	DEC -1.2218275
00463	573571401050	10000	DEC	-0.0230469,-0.0317972,-0.0400265,-0.0421472,-0.0386395
00464	574404315134	10000		
00465	574507713236	10000		
00466	574531212127	10000		
00467	574474421636	10000		
00470	576672434030	10000	DEC	-0.2150912,-0.2348252,-0.0170209,-0.0123672,-0.0746127
00471	576740730043	10000		
BINARY CARD (NOT PUNCHED)				
00472	572510272634	10000		
00473	572625177137	10000		
00474	575461472131	10000		
00475	575566150676	10000	DEC	-0.0913586,-0.1075076,-0.1229990,-0.1444770,-0.1713646
00476	575670263617	10000		
00477	575767633463	10000		
00500	576447710036	10000		
00501	576536750635	10000		
00502	576620137066	10000	DEC	-0.1954032,-0.2156801,-1.2315805,-0.2454071,0.4752560
00503	576673605433	10000		
00504	601473222403	10000		
00505	576766457776	10000		
00506	177746523011	10000		
00507	201405763775	10000	DEC	1.0233459,1.4563484,1.8114948,2.1140442
00510	201564646377	10000		
00511	201717574176	10000		
00512	202416462000	10000		
00513	202460710477	10000	B2	DEC 2.3819675
00514	202627055173	10000	DEC	3.1803778,3.5303623,3.7827146,3.8338347,3.7687329
BINARY CARD (NOT PUNCHED)				
00515	202703705646	10000		
00516	202744137770	10000		
00517	202752566142	10000		
00520	202742313534	10000		
00521	202431000165	10000	DEC	2.1953160,2.2842329,1.7392134,1.8152241,1.0041019
00522	202444303372	10000		
00523	201675172134	10000		
00524	201720545033	10000		
00525	201401045342	10000		
00526	201434371014	10000	DEC	1.1112749,1.2034196,1.2834617,1.3838077,1.4932303
00527	201464046472	10000		
00530	201510441711	10000		
00531	201542202343	10000		

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ASSEMBLED TEXT.

00532	201576210535	10000	
00533	201624200555	10000	DEC 1.5791070,1.6470113,2.9161072,2.2306061,1.7068558
00534	201645505041	10000	
00535	202565206001	10000	
00536	202435411001	10000	
00537	201664751002	10000	

BINARY CARD (NOT PUNCHED)

00540	201512074002	10000	DEC 1.2895203,0.9432983,0.6443520,0.3754978
00541	200742757773	10000	
00542	200511721005	10000	
00543	177600404773	10000	
00544	175771257726	10000	B3 DEC 0.1233749
00545	000000000000	10000	*LOIR
00546	512145016060	10000	
00547	000000000031	10000	*LORG
00550	000003000015	10000	
00551	201400000000	10000	
00552	200400000000	10000	
00553	232000000000	10000	

00000 01111 END

DEMO	RDMCB	02/17/67	PAGE	40
ASSEMBLED TEXT.				
\$TEXT RDMCB		RDMC0001		
* RANDOM NUMBER PACKAGE				
* CALLING SEQUENCES FOR THE RANDOM NUMBERS				
* R = FLTRN(DUMMY)				
* R = SFLRN(DUMMY)				
* R = EXPRN(DUMMY)				
* CALL AZIRN(SINE,COSINE)				
* CALL POLRN(SINE,COSINE)				
* CALL GTISO(X,Y)				
* R = RNMAX(XMAX)				
* R = FISRN(DUMMY)				
* CALL RANDIN(CONS)				
PCC				
ENTRY RANDM				
ENTRY GENRA				
ENTRY FLTRN				
ENTRY SFLRN				
ENTRY EXPRN				
ENTRY AZIRN				
ENTRY POLRN				
ENTRY GTISO				
ENTRY RNMAX				
ENTRY FISRN				
ENTRY RANDIN				
BINARY CARD (NOT PUNCHED)				
00000	343277244615	10000	GENRA OCT	343277244615
00001	343277244615	10000	RANDM OCT	343277244615
* FLOATING POINT RANDOM NUMBER GENERATOR				
00002	0560 00 0 03000	10011	FLTRN LDQ	RANDM
00003	0200 00 0 02000	10011	MPY	GENRA
00004	4600 00 0 03000	10011	STQ	RANDM
00005	0500 00 0 00352	10001	CLA	=0170000000100
00006	4763 00 0 00034	10000	LGL	28
00007	0300 00 0 00352	10001	FAD	=0170000000100
00010	0140 00 4 00001	10000	TOV	1,4
* SIGNED RANDOM NUMBER GENERATOR				
00011	0560 00 0 03000	10011	SFLRN LDQ	RANDM
00012	0200 00 0 02000	10011	MPY	GENRA
00013	4600 00 0 03000	10011	STQ	RANDM
00014	4773 00 0 00001	10000	RQL	1
00015	0500 00 0 00353	10001	CLA	=0200
00016	0763 00 0 00033	10000	LLS	27
00017	0300 00 0 00352	10001	FAD	=0170000000100
00020	0020 00 4 00001	10000	TRA	1,4
* CHOOSE FROM AN EXPONENTIAL DISTRIBUTION				
00021	0600 00 0 00054	10001	EXPRN STZ	E..INT
00022	0560 00 0 03000	10011	E....A LDQ	RANDM
BINARY CARD (NOT PUNCHED)				
00023	0200 00 0 02000	10011	MPY	GENRA
00024	4600 00 0 00051	10001	STQ	E....X
00025	4600 00 0 00053	10001	E....B STQ	E....Z
00026	0200 00 0 02000	10011	MPY	GENRA
00027	4600 00 0 00052	10001	STQ	E....Y

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ASSEMBLED TEXT.							
00030	0500	00 0	00053	10001	CLA	E....Z	
00031	0040	00 0	00041	10001	TLQ	E....C	
00032	4600	00 0	03000	10011	STQ	RANDOM	
00033	0500	00 0	00051	10001	CLA	E....X	
00034	0771	00 0	00010	10000	ARS	8	
00035	0400	00 0	00354	10001	ADD	=02000000000000	
00036	0300	00 0	00054	10001	FAD	E..INT	
00037	4100	00 4	00001	10000	TNZ	1,4	
00040	0020	00 0	00022	10001	TRA	E....A	
00041	0200	00 0	02000	10011	E....C MPY	GENRA	
00042	0500	00 0	00052	10001	CLA	E....Y	
00043	0040	00 0	00025	10001	TLQ	E....B	
00044	4600	00 0	03000	10011	STQ	RANDOM	
00045	0500	00 0	00054	10001	CLA	E..INT	
BINARY CARD (NOT PUNCHED)							
00046	0300	00 0	00355	10001	FAD	=1.	
00047	0601	00 0	00054	10001	STO	E..INT	
00050	0020	00 0	00022	10001	TRA	E....A	
00051	0 00000	0 00000	10000		E....X		
00052	0 00000	0 00000	10000		E....Y		
00053	0 00000	0 00000	10000		E....Z		
00054	0 00000	0 00000	10000		E..INT		
* SINE AND COSINE OF RANDOM AZIMUTHAL ANGLE (0 TO 2PI)							
00055	0634	00 4	00100	10001	AZIRN SXA	A....A,4	
00056	0074	00 4	05000	10011	A....B TSX	SFLRN,4	
00057	0601	00 0	00110	10001	STO	A...R1	FIRST RANDOM NUMBER
00060	0131	00 0	00000	10000	XCA		
00061	0260	00 0	00110	10001	FMP	A...R1	
00062	0601	00 0	00112	10001	STO	A.R1SQ	R1**2
00063	0074	00 4	04000	10011	TSX	FLTRN,4	
00064	0601	00 0	00111	10001	STO	A...R2	SECOND RANDOM NUMBER
00065	0131	00 0	00000	10000	XCA		
00066	0260	00 0	00111	10001	FMP	A...R2	
00067	0601	00 0	00113	10001	STO	A.R2SQ	R2**2
00070	0300	00 0	00112	10001	FAD	A.R1SQ	
BINARY CARD (NOT PUNCHED)							
00071	0601	00 0	00107	10001	STO	ASUMSQ	R1**2&R2**2
00072	0402	00 0	00355	10001	SUB	=1.	
00073	0120	00 0	00056	10001	TPL	A....B	
00074	0560	00 0	00110	10001	LDQ	A...R1	
00075	0260	00 0	00111	10001	FMP	A...R2	
00076	0361	00 0	00356	10001	ACL	=00010000000000	
00077	0241	00 0	00107	10001	FDP	ASUMSQ	
00100	0774	00 4	00000	10000	A....A AXT	*,4	
00101	4600	60 4	00003	10000	STQ*	3,4 SINE PHI	$E-2*R1*R2/(R1**2&R2**2)$
00102	0500	00 0	00113	10001	CLA	A.R2SQ	
00103	0302	00 0	00112	10001	FSB	A.R1SQ	
00104	0241	00 0	00107	10001	FDP	ASUMSQ	
00105	4600	60 4	00004	10000	STQ*	4,4 COSINE PHI	$(R1**2-R2**2)/(R1**2&R2**2)$
00106	0020	00 4	00001	10000	TRA	1,4	
00107	0 00000	0 00000	10000		ASUMSQ		
00110	0 00000	0 00000	10000		A...R1		
00111	0 00000	0 00000	10000		A...R2		
00112	0 00000	0 00000	10000		A.R1SQ		

00113 0 00000 0 00000 10000 A.R2SQ
* SINE AN D COSINE OF RANDOM POLAR (0,P1)

BINARY CARD (NOT PUNCHED)

00114	0634	00 4	00135	10001	POLRN SXA	P....A,4
00115	0074	00 4	04000	10011	P....B TSX	FLTRN,4
00116	0601	00 0	00147	10001	STO	P...R1
00117	0131	00 0	00000	10000	XCA	
00120	0260	00 0	00147	10001	FMP	P...R1
00121	0601	00 0	00151	10001	STO	P.R1SQ
00122	0074	00 4	04000	10011	TSX	FLTRN,4
00123	0601	00 0	00150	10001	STO	P...R2
00124	0131	00 0	00000	10000	XCA	
00125	0260	00 0	00150	10001	FMP	P...R2
00126	0601	00 0	00152	10001	STO	P.R2SQ
00127	0300	00 0	00151	10001	FAD	P.R1SQ
00130	0601	00 0	00153	10001	STO	P....E
00131	0560	00 0	00147	10001	LDQ	P...R1
00132	0260	00 0	00150	10001	FMP	P...R2
00133	0361	00 0	00356	10001	ACL	=00010000000000
00134	0241	00 0	00153	10001	FDP	P....E
00135	0774	00 4	00000	10000	P....A AXT	** ,4
00136	4600	60 4	00003	10000	STQ*	3,4

BINARY CARD (NOT PUNCHED)

00137	0260	00 0	00357	10001	FMP	=1.5396
00140	0402	00 0	00153	10001	SUB	P....E
00141	4120	30 0	10000	10011	TMI	POLRN
00142	0500	00 0	00152	10001	CLA	P.R2SQ
00143	0302	00 0	00151	10001	FSB	P.R1SQ
00144	0241	00 0	00153	10001	FDP	P....E
00145	4600	60 4	00004	10000	STQ*	4,4
00146	0020	00 4	00001	10000	TRA	1,4
00147	0 00000	0 00000	10000		P...R1	
00150	0 00000	0 00000	10000		P...R2	
00151	0 00000	0 00000	10000		P.R1SQ	
00152	0 00000	0 00000	10000		P.R2SQ	
00153	0 00000	0 00000	10000		P....E	
					* GTISO	GETS RANDOM ISOTROPIC VECTOR
00154	0634	00 4	00210	10001	GTISO SXA	G....A,4
00155	0074	00 4	04000	10011	G....B TSX	FLTRN,4
00156	0601	00 0	00231	10001	STO	G....Z
00157	0131	00 0	00000	10000	XCA	
00160	0260	00 0	00231	10001	FMP	G....Z
00161	0601	00 0	00234	10001	STO	G...ZSQ

BINARY CARD (NOT PUNCHED)

00162	0074	00 4	05000	10011	TSX	SFLRAN,4
00163	0131	00 0	00000	10000	XCA	
00164	0260	00 0	00236	10001	FMP	G..CON
00165	0601	00 0	00227	10001	STO	G....X
00166	0131	00 0	00000	10000	XCA	
00167	0260	00 0	00227	10001	FMP	G....X
00170	0601	00 0	00232	10001	STO	G...XSQ
00171	0074	00 4	05000	10011	TSX	SFLRAN,4
00172	0131	00 0	00000	10000	XCA	

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ASSEMBLED TEXT.			
00173	0260 00 0 00236	10001	FMP G...CON
00174	0601 00 0 00230	10001	STO G....Y
00175	0131 00 0 00000	10000	XCA
00176	0260 00 0 00230	10001	FMP G....Y
00177	0601 00 0 00233	10001	STO G..YSQ
00200	0300 00 0 00232	10001	FAD G..XSQ
00201	0601 00 0 00232	10001	STO G.XYSQ
00202	0300 00 0 00234	10001	FAD G..ZSQ
00203	0601 00 0 00235	10001	STO G....D
00204	0131 00 0 00000	10000	XCA
BINARY CARD (NOT PUNCHED)			
00205	0260 00 0 00235	10001	FMP G....D
00206	0402 00 0 00231	10001	SUB G....Z
00207	0120 00 0 00155	10001	TPL G....B
00210	0774 00 4 00000	10000	G....A AXT **4
00211	0500 00 0 00231	10001	CLA G....Z
00212	0400 00 0 00356	10001	ADD =01000000000
00213	0241 00 0 00235	10001	FDP G....D
00214	4600 00 0 00231	10001	STQ G...ZD
00215	0260 00 0 00227	10001	FMP G....X
00216	0601 60 4 00003	10000	STO* 3,4
00217	0560 00 0 00230	10001	LDQ G....Y
00220	0260 00 0 00231	10001	FMP G....ZD
00221	0601 60 4 00002	10000	STO* 2,4
00222	0500 00 0 00234	10001	CLA G..ZSQ
00223	0302 00 0 00232	10001	FSB G.XYSQ
00224	0241 00 0 00235	10001	FDP G....D
00225	4600 60 4 00004	10000	STQ* 4,4
00226	0020 00 4 00001	10000	TRA 1,4
00227	0 00000 0 00000	10000	G....X
BINARY CARD (NOT PUNCHED)			
00230	0 00000 0 00000	10000	G....Y
00231	0 00000 0 00000	10000	G....Z
00232	0 00000 0 00000	10000	G..XSQ
00233	0 00000 0 00000	10000	G..YSQ
00234	0 00000 0 00000	10000	G..ZSQ
00235	0 00000 0 00000	10000	G....D
	00232		G.XYSQ SYN G..XSQ
	00231		G...ZD SYN G....Z
00236	200537736000	10000	G...CON OCT 200537736000
			* MAXWELL BULTZMANN
00237	0634 00 4 00273	10001	RNMAX SXA M....A,4
00240	0074 00 4 06000	10011	TSX EXPRN,4
00241	0601 00 0 00305	10001	STO M....X
00242	0520 00 0 00301	10001	ZET M..BIN
00243	0020 00 0 00276	10001	TRA M.FLOP
00244	0074 00 4 04000	10011	M....C TSX FLTRN,4
00245	0601 00 0 00302	10001	STO M.R1SQ
00246	0131 00 0 00000	10000	XCA
00247	0260 00 0 00302	10001	FMP M.R1SQ
00250	0601 00 0 00302	10001	STO M.R1SQ
00251	0074 00 4 04000	10011	TSX FLTRN,4
00252	0601 00 0 00303	10001	STO M.R2SQ

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ASSEMBLED TEXT							
BINARY CARD (NOT PUNCHED)							
00253	0131	00 0	00000	10000	XCA		
00254	0260	00 0	00303	10001	FMP	M..R2SQ	
00255	0601	00 0	00303	10001	STO	M..R2SQ	
00256	0300	00 0	00302	10001	FAD	M..R1SQ	
00257	0601	00 0	00304	10001	STO	MSUMSQ	
00260	0402	00 0	00355	10001	SUB	=1.	
00261	0120	00 0	00244	10001	TPL	M....C	
00262	0074	00 4	06000	10011	TSX	EXPRN,4	
00263	0241	00 0	00304	10001	FDP	MSUMSQ	
00264	4600	00 0	00304	10001	STQ	MSUMSQ	
00265	0260	00 0	00302	10001	FMP	M..R1SQ	
00266	0601	00 0	00301	10001	STO	M..BIN	
00267	0560	00 0	00304	10001	LDQ	MSUMSQ	
00270	0260	00 0	00303	10001	FMP	M..R2SQ	
00271	0300	00 0	00305	10001	M....B FAD	M....X	
00272	0131	00 0	00000	10000	XCA		
00273	0774	00 4	00000	10000	M....A AXT	**.,4	
00274	0260	00 4	00003	10000	FMP*	3,4	
00275	0020	00 4	00001	10000	TRA	1,4	
BINARY CARD (NOT PUNCHED)							
00276	0500	00 0	00301	10001	M..FLOP CLA	M..BIN	
00277	0600	00 0	00301	10001	STZ	M..BIN	
00300	0020	00 0	00271	10001	TRA	M....B	
00301	000000000000			10000	M..BIN DEC	0	
00302	0 00000	0 00000		10000	M..R1SQ		
00303	0 00000	0 00000		10000	M..R2SQ		
00304	0 00000	0 00000		10000	MSUMSQ		
00305	0 00000	0 00000		10000	M....X		
* WATT FISSION SPECTRUM							
00306	0634	00 4	00330	10001	FISRN SXA	F....A,4	
00307	0074	00 4	05000	10011	TSX	SFLRAN,4	
00310	0601	00 0	00336	10001	STO	F...MU	
00311	000000000000			00010	CALL	RNMAX(F....T)	
00311	0074	00 4	12000	10011			
00312	1 00001	0 01003		10011			
00313	0 00350	0 00353		10100			
00314	0 00000	0 00332		10001			
00315	0601	00 0	00335	10001	STO	F..VSQ	
00316	000000000000			00010	CALL	SQRT(F..VSQ)	
00316	0074	00 4	15000	10011			
BINARY CARD (NOT PUNCHED)							
00317	1 00001	0 01003		10011			
00320	0 00350	0 00355		10100			
00321	0 00000	0 00335		10001			
00322	0131	00 0	00000	10000	XCA		
00323	0260	00 0	00333	10001	FMP	F...2F	
00324	0131	00 0	00000	10000	XCA		
00325	0260	00 0	00336	10001	FMP	F...MU	
00326	0300	00 0	00335	10001	FAD	F..VSQ	
00327	0300	00 0	00334	10001	FAD	F..FSQ	
00330	0774	00 4	00000	10000	F....A AXT	**.,4	
00331	0020	00 4	00001	10000	TRA	1,4	
00332	275631711716			10000	F....T DEC	1.846E&18	

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ASSEMBLED TEXT.					
00333	237741405150	10000	F...2F DEC	2.0196F69	
00334	274704761114	10000	F..FSQ DEC	1.020E&18	
00335	0 00000 0 00000	10000	F...VSQ		
00336	0 00000 0 00000	10000	F...MU		
00337	0500 60 4 00003	10000	RANDIN CLA*	3,4	
00340	0100 00 0 00345	10001	TZE	R....A	
00341	076C 00 0 00003	10000	SSP		
BINARY CARD (NOT PUNCHED)					
00342	0601 60 4 00003	10000	STO*	3,4	
00343	0601 00 0 03000	10011	STO	RANDM	
00344	0020 00 4 00001	10000	TRA	1,4	
00345	0500 00 0 03000	10011	R....A CLA	RANDM	
00346	0601 60 4 00003	10000	STO*	3,4	
00347	0020 00 4 00001	10000	TRA	1,4	
00350	000000000000	10000	*LDIR		
00351	512444232260	10000			
00352	170600000100	10000	*LORG		
00353	000000000200	10000			
00354	200600000000	10000			
00355	201400000000	10000			
00356	001000000000	10000			
00357	201612106347	10000			
	00000 01111		END		

APPENDIX F

TENTATIVE GUIDELINES FOR RELIABILITY
ANALYSIS OF CONTAINMENT
ISOLATION VALVE SYSTEMS

APPENDIX F

TENTATIVE GUIDELINES FOR RELIABILITY ANALYSIS OF CONTAINMENT ISOLATION VALVE SYSTEMS

Assessment of isolation valve system reliability can be based on the assumption that at least one isolation valve must close or remain closed on each piping penetration; and, subsequently, these valves must maintain a certain degree of leak tightness. The question then arises, "should one consider all penetrations or only particularly critical penetrations?" This consideration is especially important for containments with a large number of penetrations. For example, the Dresden-3 drywell or primary containment system is penetrated by approximately 488 pipes or tubes and 61 electrical or instrumentation cartridges. Of the piping penetrations, 370 are control rod-drive hydraulic lines which terminate outside the drywell in the control rod hydraulic system.

To attack the problem of assessing isolation valve reliability, the penetrations and the associated valves have been classified according to importance by the degree of separation they afford between potentially radioactive systems and the atmosphere or the secondary containment. These classes in order of decreasing importance are:

1. Penetrations open to containment and terminating in systems not sealed to atmosphere.
2. Penetrations open to primary coolant system and terminating in systems not sealed to atmosphere.
3. Penetrations originating in systems separated from primary coolant or containment atmosphere by one or more impermeable membranes and terminating in systems not sealed to atmosphere.
4. Penetrations open to containment and terminating in sealed systems.
5. Penetrations open to primary coolant system and terminating in sealed systems.
6. Penetrations originating and terminating in sealed systems.

These penetration classes are summarized in Table F.1 along with isolation valve classifications based on normal valve status, i.e., normally open and normally closed valves.

With the preceding breakdown the most critical isolation valves are normally open valves on Class 1 penetrations; e.g., containment ventilation lines which communicate with the atmosphere during normal operation. Such lines are used in some early power reactor designs (e.g., Shippingport and Dresden-1) but are not included in recent facilities. As developed, the classification system says that isolation valve reliability is most important on lines which do not require a second order failure (i.e., rupture of a sealed system) to result in leakage to the atmosphere, and that lines which require a third order failure, i.e., rupture of two sealed systems, are the least important. Using this ranking, the isolation valve reliability model can be simplified to focus on the more important lines with knowledge that other lines have even less probability of becoming a leakage path, since they will require second or third order failures to become significant.

TABLE F. 1
PENETRATION CLASSIFICATION

Class Designation	Terminates Within Containment In	Terminates Outside Containment In
1	Line open to containment atmosphere	Line or apparatus not sealed to atmosphere
2	Line open to primary coolant system	Line or apparatus not sealed to atmosphere
3	Equipment separated from primary coolant or containment atmosphere by one impermeable membrane	Line or apparatus not sealed from atmosphere
4	Line open to containment atmosphere	Equipment separated from atmosphere by one impermeable membrane
5	Line open to primary coolant system	Equipment separated from atmosphere by one impermeable membrane
6	Equipment separated from primary coolant or containment atmosphere by one impermeable membrane	Equipment separated from atmosphere by one impermeable membrane
<u>Valve Classification</u>		
<u>Description</u>		
NO	Valves open during normal plant operation includes check valves on in-flowing lines.	
NC	Valve closed during normal plant operation includes check valves on stagnant lines.	

APPENDIX G

GLOSSARY

APPENDIX G

GLOSSARY

This glossary is a reference for definitions of reliability terms and phrases which are used throughout this report. For broader coverage of reliability nomenclature, the reader is referred to handbooks, reports, and texts such as those listed at the end of this appendix.

Progress is closely associated with the ability to communicate especially in technical fields. At the beginning new concepts and ideas are expressed in many different ways, but in time they are amalgamated into a single word or phrase which greatly increases the understanding between different groups of people. As concepts, ideas, and philosophies change, old words take on new meanings. So it is with the words included in this glossary; they reflect present concepts and ideas, but as the field progresses, these words will acquire new meanings.

Automatic Reliability Mathematical Model (ARMM) - A general purpose computer program for deriving and solving a mathematical model of the reliability of complex systems based on a sequential application of the conditional probability theorem (Bayes' Theorem) to the probability of system failure. The program can handle up to a maximum of 300 functions and 500 components and has a built-in capability to handle dependent components, standby components, and mutually exclusive failure modes.

Component - A self-contained unit which performs a distinctive function in the overall operation of a system and which can be disassembled, re-assembled, or replaced. For example, count rate amplifier, high voltage power supply, centrifugal pump, and solenoid operated valve.

Confidence Level - The probability that a given statement is correct or the chance that a given value lies within a stated numerical range. For example, a stated reliability of 99 percent at a confidence level of 75 percent means there is a 75 percent probability that the actual reliability is at least 99 percent (lies between 99 and 100 percent).

Derating - The process, in design or test, of employing a component which will carry a greater load, or is more accurate, or will provide a larger output than is necessary for the application.

Derating Factor - A numerical measure of the design margin provided by derating. If a pump with a design head of 500 feet is used where only a 250-foot head is required, the derating factor becomes 2.

Degradation - A gradual deterioration in performance, strength, resistance, etc.

Environmental Stress - The stress or load imposed on a component by a given set of environmental conditions. Conditions which determine environmental stress include humidity, power, pressure, temperature, and voltage. Variations in these conditions tend to affect the failure rate of equipment.

Exponential Failure Density Function - A failure density function which represents the probability of failure in a population composed of units experiencing a constant failure rate. It is of the form

$$f(t) = \lambda e^{-\lambda t}$$

Exponential Failure Distribution - The distribution describing the probability of failure before time t in a population with a constant failure rate. It is of the form

$$F(t) = 1 - e^{-\lambda t}$$

Failure - The occurrence of any condition which renders an item incapable of operating within its specified performance parameters.

Failure Cause - That which made the component fail the way it did. Cause description usually involves several levels which are difficult to identify. If an amplifier fails, the immediate cause may be a malfunctioning diode. However, the basic cause may be conditions or events such as a mis-application of the diode in the circuitry or inadequate inspection of the diodes employed in assembling the amplifier.

Failure Data - A collection of discrepancy and malfunction data derived from field and test experience.

Failure Density Function, $f(t)$ - The probability that a unit will fail per unit time at time t . Thus

$$f(t) = \frac{dF(t)}{dt}$$

sometimes called the failure frequency function.

Failure Distribution Function, F(t) - The probability that a unit will fail by time t. Thus

$$F(t) = \int_0^t f(t) dt$$

This is sometimes called the cumulative distribution function and is also recognized as the unreliability function.

Failure Effect - What happened to the system when a component failed the way it did.

Failure Event - Occurrence of failure as related to point in time.

Failure Mode - The physical description of the manner in which a component failed. For example, a valve failed to open; a pump failed to continue operation; and a bistable amplifier trip unit operated prematurely.

Failure Rate, λ - The probability of failure per unit time in a given time interval. For an exponential failure distribution (constant failure rate), the failure rate is the reciprocal of the mean time between failures for reparable components and the mean time to failure for irreparable components. Failure rate is normally expressed in number of failures per million hours.

Fault Tree - A graphical presentation of a fault tree analysis which displays the sequential arrangement of events interconnected by logic operators (or gates) that ultimately lead to an undesired event.

Fault Tree Analysis - The analysis of a functional system to establish the logical sequence of events leading to an undesired event. The analysis includes a detailed understanding of system design and operation, the construction of a fault tree, and the mathematical simulation of fault tree logic to establish the likelihood of and individual failure contributions to an undesired event.

Malfunction - Any occurrence of unsatisfactory performance. It need not constitute a failure if readjustment of operator controls can restore an acceptable operating condition.

Mean Life, θ - The arithmetic average of the life times of all items considered. It is equivalent to

$$\theta = \int_0^{\infty} t f(t) dt$$

Mean Time Between Failure, MTBF - The average time between failures which can be expected for a reparable component during the portion of its life cycle in which the exponential failure distribution applies.

Mean Time to Failure, MTTF - The average or mean life of an irreparable component.

Mean Time to Repair, MTTR - The average time to repair a failed component including detection of failure, definition of corrective action, performance of corrective action, and testing before return to service.

Normal Distribution - Same as Gaussian distribution. A distribution defined by

$$f(t) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(t-\theta)^2}{2\sigma^2}}, \quad -\infty < t < +\infty$$

where

σ = standard deviation

Operating Error - An error that is traceable principally to some human action or inaction occurring in any activity subsequent to design and fabrication.

Operating Time - The time period between turn-on and turn-off of a system, subsystem, or component during which operation is as specified. Total operating time is the summation of all operating time periods.

Performance - Operation with some degree of effectiveness.

Population - The total collection of items from a common source.

Probability of Failure, $P(\bar{A})$ - The likelihood that A will fail during a specified period of time under a given environment.

Probability of Success, P(A) - The complement of the probability of failure. Thus

$$P(A) = 1 - P(\bar{A})$$

Random Failure - Any failure which occurs by chance, in an accidental, casual, or haphazard manner. Sometimes called chance failure.

Redundancy - The existence of more than one means of performing a function in order to prevent an overall failure in the event that all but one of the means fail. Parallel redundancy is the application of two or more means of performing a function, all of which are functioning at the same time but each of which is capable of performing the function in the event of a failure to the other means. Standby redundancy applies where there is an alternate means of performing a function which is held in abeyance until a failure of the primary means is sensed and the alternate means is actuated to perform the same function.

Reliability, R(t) - The probability of performing a required function under specified conditions for at least a given length of time t. For exponential failure distribution

$$R(t) = e^{-\lambda t}$$

System - A combination of components joined together to perform a specific operational function or functions. For example, reactor coolant system, reactor control system, and safety injection system.

Systems Analysis by Fault Tree Evaluation (SAFTE-1) - A Monte Carlo fault tree simulation program capable of handling exponential distribution for component failure and normal distribution for component repair.

Unreliability - The complement of reliability, namely, $1 - R(t)$.

Use Data - Data which describe the accumulated use by which successful operation of a plant or system is measured.

Wearout - The point at which the continued operation and repair of a component becomes uneconomical due to the increasing frequency of failures.

Weibull Failure Density Function - Failure density function of the form

$$f(t) = \beta \alpha t^{\beta-1} e^{-\alpha t^\beta}$$

where

α = Scale parameter

β = Shape parameter

If $\beta = 1$, $f(t)$ becomes exponential function
and α is equivalent to failure rate, λ .

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APPENDIX H

RELIABILITY ESTIMATES WITH CONFIDENCE LEVELS

APPENDIX H

RELIABILITY ESTIMATES WITH CONFIDENCE LEVELS

In estimating component and system reliabilities the question arises, "what is the potential error associated with reliability estimates made from available reliability data?" That is, one wishes to know the probability that the probability estimate is correct. In safety applications confidence level estimates are generally one-sided and state the probability that the reliability is at least the level estimated, or the failure rate is equal to or lower than the value used. Confidence levels can be readily estimated for failure rates or reliabilities of either single components or simple systems. For complex systems, the problem of assigning a confidence level to a system reliability estimate, based on component reliabilities and confidence levels, is not as straightforward. The problem here is that the failure distribution function for the system is not necessarily the same as that for the components nor is it easily obtainable.

This appendix presents analytical methods for determining component failure rates or reliabilities at specified confidence levels. In addition, two techniques are discussed for using component data in estimating system reliabilities with certain confidence levels.

COMPONENT LIFETIMES

An infinitely large component sample size would allow one to predict the true value of a measured parameter with 100 percent confidence. For the finite or particularly small sample size, an estimate of the mean life with a certain confidence level is all that can be obtained. The methods outlined in the following discussion can be used to correlate the accuracy of an estimate with the size of the sample from which it is obtained. These methods are separated, for clarity, into two classes - standby and operating.

Standby Components

Following Roberts⁽¹⁾, let us consider a population whose individual units have an exponential failure distribution with mean life of θ_0 . Then the reliability (probability of successful operation) to time t for each unit is

$$R(t) = e^{-t/\theta_0} . \quad (1)$$

Hence the failure probability is

$$F(t) = 1 - R(t) = 1 - e^{-t/\theta_0}. \quad (2)$$

If n such units are tested for a certain time t , the probability that c or fewer units fail is

$$Q = \sum_{i=0}^c \frac{n!}{i!(n-i)!} [F(t)]^i [R(t)]^{n-i}. \quad (3)$$

The confidence level P then can be determined from

$$P \cong 1 - Q. \quad (4)$$

For the case of no failures, which is of importance in this study, Equation (4) yields

$$P \cong 1 - [R(t)]^n. \quad (5)$$

Equation (5) is readily solved for P , given t and n . However, for $c \geq 1$, Equation (4) does not have a simple representation, and the relation of c , t , n , and P must be obtained numerically.

Numerical Computation - If P is specified, c and t can be chosen and an iterative approach used to obtain n from the equality given by Equation (4). Hence for some n we write

$$Q_n = \sum_{i=0}^c \frac{n!}{i!(n-i)!} [F(t)]^i [R(t)]^{n-i}.$$

Now assuming a truncated Taylor series of the form

$$1 - P \approx Q_n + \frac{dQ_n}{dn} \Delta n,$$

this yields as a correction for n

$$\Delta n = \frac{(1 - P) - Q_n}{\frac{dQ_n}{dn}}. \quad (6)$$

Thus if n is used for the j^{th} iterate, then $(n+\Delta n)$ should be used in the $(j+1)^{\text{st}}$ iterate.

Using Stirling's formula for $n!$ and neglecting terms in $\frac{1}{n}$

$$\frac{dQ_n}{dn} = Q_n \left[\ln R(t) - \frac{F(t)}{R(t)} \right] - \left[\frac{F(t)}{R(t)} \right]^{c+1} \frac{n^c}{c!} [R(t)]^n$$

This expression is used in calculating the denominator of Equation (6). Using this method, Figure H. 1 was obtained for the 75 percent confidence level case.

Example - As an example of the use of Figure H. 1 in obtaining lifetime estimates, consider the following problem. All components in an emergency cooling system are tested periodically. The most critical components are tested by conducting functional tests prior to each reactor startup. Other components are tested annually. These tests are assumed to show that the component can or cannot perform adequately under accident conditions.

Functional tests were conducted 24 times with an average testing interval of 38.4 days. An estimate will be made for the mean time to an unsafe failure of a certain component with an associated confidence level P of 75 percent. For a component with no reported failures during the entire operating period, $c = 0$ and $n = 24 - 1 = 23$. We find from Figure H. 1 $\frac{t}{\theta_0} \cong 0.060$ and θ_0 is, therefore,

$$\theta_0 \cong \frac{38.4}{0.060} = 640 \text{ days}$$

which is equivalent to a failure rate λ of

$$\lambda \cong \frac{1}{640 \times 24} = 65 \times 10^{-6} \text{ hr}^{-1}.$$

Since there are several components generically and operationally similar, the test data from these components may be pooled together. For two similar components with no reported failure, $c = 0$ and $n = 23 \times 2 = 46$. At a confidence level of $P = 0.75$, θ_o becomes

$$\theta_o \cong \frac{38.4}{0.030} = 1,280 \text{ days}$$

or

$$\lambda \cong 32.6 \times 10^{-6} \text{ hr}^{-1}.$$

Thus doubling the number of components has doubled the lifetime estimate at the same confidence level.

Suppose the second component failed once during the entire period. Then for $c = 1$ and $n = 46$

$$\theta_o \cong \frac{38.4}{0.060} = 640 \text{ days}$$

or

$$\lambda \cong 65 \times 10^{-6} \text{ hr}^{-1}.$$

Similar estimates can be made for annually tested components. In this example, annual tests were conducted five times with an averaged testing interval of 324.5 days. For a component tested annually with no failure reported during the entire period, $c = 0$, $n = 5 - 1 = 4$, and

$$\theta_o \cong \frac{324.5}{0.34} = 954 \text{ days}$$

or

$$\lambda \cong 44 \times 10^{-6} \text{ hr}^{-1}.$$

Operating Components

Consider n similar components which operate for a time t . The point estimate of the mean life of these components, θ_o , when c failures occur, is

$$\theta_o = \frac{nt}{c}, \quad (7)$$

Confidence Level - An alternative estimate⁽²⁾ of θ_o can be made based on the chi-square (χ^2)* distribution. In this case, it can be specified with a certain confidence that θ_o will lie between two numbers, the upper and lower confidence level estimates. For a given confidence level P

$$\frac{2nt}{\chi_{\frac{Q}{2}, 2c+2}^2} \cong \theta_o \cong \frac{2nt}{\chi_{1 - \frac{Q}{2}, 2c}^2} \quad (8)$$

where

$$Q = 1 - P.$$

Equation (8) is useful provided $c \geq 1$.

In reliability analysis, a one-sided estimate of the mean lifetime is often of particular interest. That is, the minimum value of θ_o can be specified at a given confidence level. Thus

$$\theta_o \cong \frac{2nt}{\chi_{Q, 2c+2}^2} \quad (9)$$

This expression holds for $c \geq 0$.

A family of curves for operating time nt versus $\frac{1}{\theta_o}$ is plotted in

Figure H. 2 for 0 to 6 failures with 75 percent confidence level. Note that $\frac{1}{\theta_o}$ is equivalent to failure rate λ .

Example - Consider a system which has been operated 17,604 hours and which contains six similar pumps with no reported failures. Entering Figure H. 2 with $c = 0$ and $nt = 6 \times 17,604 = 105,624$ hours, the failure rate is estimated to be

$$\frac{1}{\theta_o} = \lambda \cong 13.3 \times 10^{-6} \text{ hr}^{-1}.$$

DISCUSSION

It can be shown that the method used for the lifetime estimates of standby components is equivalent to that used for continuously operating

*The values of χ^2 are obtained from probability tables.

components. In fact, many continuously operating components can be considered as standby in that they are cyclically monitored by an operator or operate cyclically and therefore can be treated in the manner for standby components.

Example

Consider the previous example in which six pumps operated for 17,604 hours with no failure and yielded

$$\lambda = 13.3 \times 10^{-6} \text{ hr}^{-1}$$

according to the continuous method.

Treating each hour as a successful test, i. e., pump operation is monitored once each hour

$$n = 6 \times 17,604 = 105,624 \text{ tests}$$

$$c = 0$$

$$t = 1 \text{ hour.}$$

Extrapolating from Figure H. 1

$$\frac{t}{\theta_o} = 13.3 \times 10^{-6}$$

or

$$\lambda = \frac{1}{\theta_o} = 13.3 \times 10^{-6} \text{ hr}^{-1}.$$

Similarly if each day is treated as a successful test

$$n = 105,624/24 = 4,401 \text{ tests}$$

$$c = 0$$

$$t = 24 \text{ hours.}$$

We find from Figure H. 1

$$\frac{t}{\theta_o} = 0.000316$$

or

$$\lambda = \frac{1}{\theta_o} = \frac{0.000316}{24} = 13.2 \times 10^{-6} \text{ hr}^{-1}.$$

The difference is due to round-off.

SYSTEM LIFETIMES

Confidence level estimates for individual components are quite simply obtained for either operating or nonoperating components. Similar estimates of confidence are difficult for the reliability of a system when based on the probabilistic behavior of components. In fact, such analytical estimates are presently limited to a narrow class of system models and probability distributions. This difficulty results from the fact that system reliability is strongly dependent on the structure of the system functional logic as well as component reliability.

Takenaga⁽³⁾ has analyzed systems composed of 10 components in series with all components assumed to have exponential failure distributions. He has found, for example, for a set of components all having failure rate estimates at the same confidence level, that the system confidence level behaves as follows:

<u>Component Confidence Level</u>	<u>System Confidence Level</u>
40%	13.5%
50%	31.3%
60%	62.35%
70%	90.0%
80%	99.9%

Failure data are given in Reference (3). Another method for estimating the confidence level on system reliability with serially arranged components having exponential failure distributions is given in Reference (4).

Kniss⁽⁵⁾ has investigated simple systems which contain components in parallel as well as in series. He obtains system confidence levels by generating random values of the component confidence levels and using these to generate random values of the system reliability. His results agree with those obtained by alternative analytical methods in three simple cases.

Of course, if a system were constructed, then data on its reliability characteristics could be easily obtained through testing the system. However, it should be possible to predict system reliability based on a knowledge of its components and structure. The two approaches mentioned above are attempts to solve this problem. The latter approach appears promising since one is not restricted to analyzing serial systems. However, this technique may become costly for complex systems. Further work in this area is needed.

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FIGURE H. 1

LIFETIME ESTIMATE FOR STANDBY COMPONENTS
AT 75 PERCENT CONFIDENCE LEVEL

FIGURE H. 2

LIFETIME ESTIMATE FOR OPERATING COMPONENTS
AT 75 PERCENT CONFIDENCE LEVEL