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# Common-Cause Failure Database and Analysis System: Overview

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Prepared for
U.S. Nuclear Regulatory Commission

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# ABSTRACT

This volume of the Common Cause Failure Database and Analysis System report presents an overview of common cause failure methods for use in the U.S. commercial nuclear power industry. It summarizes how data (on common cause failure events) are gathered, evaluated, and coded. It then describes the process for estimating probabilistic risk assessment (PRA) common cause failure parameters. It also references other volumes of this report for specific details.

Equipment failures that contribute to common cause failure events are identified through searches of Licensee Event Reports (LERs) and Nuclear Plant Reliability Data System (NPRDS) failure reports. Once common cause failure events are identified by reviewing reports of equipment failures, INEEL staff enter the event information into a personal computer data analysis system (CCF system) using the method presented in this and companion volumes. The events stored in the CCF system are used for common cause failure PRA parameter estimations using common cause failure quantification methods.

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# EXECUTIVE SUMMARY

The U.S. Nuclear Regulatory Commission's (NRC's) Office for Analysis and Evaluation of Operational Data (AEOD) and the Idaho National Engineering and Environmental Laboratory (INEEL) have developed and maintain a common cause failure (CCF) database for the U.S. commercial nuclear power industry. Previous studies documented methods for identifying and quantifying CCFs. This report extends previous methods by introducing a method for identifying CCF events, a collection of events from industry failure data, and a computerized system for quantifying probabilistic risk assessment (PRA) parameters and uncertainties.

A CCF event consists of component failures that meet four criteria: (1) two or more individual components fail or are degraded, including failures during demand, in-service testing, or deficiencies that would have resulted in a failure if a demand signal had been received; (2) components fail within a selected period of time such that success of the PRA mission would be uncertain; (3) component failures result from a single shared cause and coupling mechanism; and (4) a component failure occurs within the established component boundary.

Two data sources are used to select equipment failure reports to be reviewed for CCF event identification: the Nuclear Plant Reliability Data System (NPRDS), which contains component failure information, and the Sequence Coding and Search System (SCSS), which contains Licensee Event Reports (LERs). These sources served as the developmental basis for the CCF data collection and analysis system. The CCF data collection and analysis system consists of (1) CCF event identification methodology, (2) event coding guidance, and (3) a software system to estimate CCF parameters.

The CCF event identification process includes reviewing failure data to identify CCF events and counting independent failure events. The process allows the analyst to consistently screen failures and identify CCF events. The CCF event coding process provides guidance for the analyst to consistently code CCF events. Sufficient information is recorded to ensure accuracy and consistency. Additionally, the CCF events are stored in a format that allows PRA analysts to review the events and develop understanding of how they occurred.

A software system stores CCF events, independent failure counts, and automates PRA parameter estimations. The system employs two quantification models: the alpha factor and the multiple Greek letter. These models are used throughout the nuclear industry. In addition, these parameter estimations can be used in a PRA to estimate basic event probability and uncertainty.

This report is presented in four volumes: Overview, Event Definition and Classification, Data Collection and Event Coding, and Software Reference Manual.

Specific terms and acronyms are used throughout this report. The specific terms used are found in the glossary at the back of each volume. A list of acronyms follows the executive summary.

# ACRONYMS

| | |
|---|---|
| AEOD | Nuclear Regulatory Commission's (NRC's) Office for the Analysis and Evaluation of Operational Data |
| CCCG | common cause component group |
| CCF | common cause failure |
| INEEL | Idaho National Engineering and Environmental Laboratory |
| LER | Licensee Event Report |
| MGL | multiple Greek letter |
| MLE | maximum likelihood estimate |
| NPRDS | Nuclear Plant Reliability Data System |
| NRC | Nuclear Regulatory Commission |
| ORNL | Oak Ridge National Laboratory |
| PC | personal computer |
| PRA | probabilistic risk assessment |
| SCSS | Sequence Coding and Search System |

# Common Cause Failure Database and Analysis System Volume I—Overview

## 1. INTRODUCTION

A general conclusion from probabilistic risk assessments (PRAs) of commercial nuclear power plants is that common cause failures (CCFs) are significant contributors to the unavailability of safety systems. Efforts in past years to improve understanding and modeling of CCF events have produced several models, procedures, computer codes, and databases. Some efforts have collected limited amounts of data for use in CCF analyses. Most of these efforts used operational experience data prior to 1984.

Until recently, lack of CCF event data was a major problem, though significant progress was made with the publication of *Classification and Analysis of Reactor Operating Experience Involving Dependent Events*, EPRI NP-3967.[1] Two known deficiencies of EPRI NP-3967 are the limited time frame for the study, and the lack of details regarding independent events. In the area of data classification, analysis, and model parameter estimation, the detailed procedures of *Procedures for Treating Common Cause Failures in Safety and Reliability Studies*, NUREG/CR-4780, Volumes 1 and 2,[2] and *Procedure for Analysis of Common Cause Failures in Probabilistic Safety Analysis*, NUREG/CR- 5801,[3] have been viewed as too time consuming, despite wide acceptance of the basic approach.

In response to these deficiencies, the Idaho National Engineering and Environmental Laboratory (INEEL) staff and the Nuclear Regulatory Commission's (NRC) Office for Analysis and Evaluation of Operational Data (AEOD ) have developed a CCF data collection and analysis system that includes a method for identifying CCF events, coding and classifying those events for use in CCF studies, and a computer system for storing and analyzing the data. The system is based, in part, on previous CCF methods and models. The data collection effort added a substantial number of CCF events for use in CCF analyses above the previous industry efforts to collect CCF data. The generic data generated from these past studies have been divided by component type, with no allowance given for differences that might exist between systems. The current data collection effort has separated the data by system. The principal products of this CCF data collection and analysis system (CCF system) project are the method for identifying and classifying CCF events, the CCF database containing both CCF events and independent failure counts, and the CCF parameter estimation software.

Documentation of this project is presented in four volumes: Overview, Event Definition and Classification,[4] Data Collection and Event Coding,[5] and Software Reference Manual.[6]

The database contains common cause failure events from 1980 through 1995. Table 1 shows the number of records examined and the number of CCF events found. It also shows that CCF events are rare. Approximately 5 percent of all failures involve some degree of common cause, and only 0.7 percent of all failures result in complete CCFs (events in which all redundant components completely fail). A more detailed display of the data in the database is in Table 2 of section 4 of this volume.

**Table 1.** Number of events analyzed.

| | |
|---|---|
| Total number of records examined | 31,910 |
| Total number of LERs examined | 11,884 |
| Total number of NPRDS records examined | 20,026 |
| CCF events found | 1,533 |
| From LERs | 673 |
| From NPRDS | 860 |
| Complete CCF events (events in which all redundant components are failed) | 235 |

The computer software produced for this project uses the impact vector method introduced in Reference 2 and further refined in Reference 3. The basic information needed for understanding and coding a CCF event is based on the physical characteristics of the event, and is recorded in the following fields in the database: a component degradation parameter for each component in the specified group of similar components, the timing factor (which is a measure of the time between the failures), and the shared cause factor (which measures the analyst's uncertainty about a shared cause). These are defined and explained later in this volume, and further in Volumes 2[4] and 3.[5] Project objectives are (1) development of a comprehensive database of CCF events using several data sources such as Licensee Event Reports (LERs)—contained in the Sequence Coding and Search System maintained by Oak Ridge National Laboratory—and the Nuclear Plant Reliability Data System (NPRDS) maintained by the Institute of Nuclear Power Operations, and (2) automation of the data analysis and parameter estimation procedures of References 2 and 3.

The INEEL staff, INEEL contractor staff, and AEOD staff developed a method for identifying CCF events and a personal computer-based system for storing and analyzing CCF events. This volume presents an overview of the CCF data analysis process, CCF software features, and a summary of general insights regarding CCF events.

# 2. OVERVIEW OF THE CCF DATA ANALYSIS PROCESS

The first task of the CCF event database effort was to develop specific guidance for data analysts to use in identification of CCF events. For this project the definition of a CCF event is (from Reference 2) "a subset of dependent failures in which two or more component functional fault states exist at the same time, or within a short interval, as a result of a shared cause." The basic characteristics of a CCF event were translated into engineering terms with examples to illustrate the definitions and concepts. The initial CCF event search and screening criteria included similar components, failure of components within a short time interval, and multiple failures resulting from a shared cause. All of these characteristics must be present for an event to be considered a CCF event candidate.

The use of the term "shared cause" implies the presence of a coupling mechanism that renders the multiple components susceptible to failure from the same cause. Examples of coupling mechanisms are multiple identical components with the same defective design (hardware), a calibration procedure that specifies an incorrect set point for several relief valves (operational), and contamination of emergency diesel generator (EDG) fuel oil that disables all EDGs (environmental). The time interval is a concern because multiple failures that do not occur within the PRA mission time will not prevent successful operation of the safety system during an accident condition.

Failure of shared equipment (e.g., common cooling water or AC power systems) is not considered a CCF event because these events are usually modeled explicitly in the reliability logic models. In order for the CCF database to be a complete compilation of dependent events, however, these dependent failure events are coded and included in the CCF database. Another convention adopted in the initial effort of this project is that similar failures within a short time interval in different power plants of a multiple unit power plant site are not considered a CCF event. This is because an individual plant design typically does not rely on use of systems from another unit. Exceptions to this are the EDGs and ultimate heat sinks. In cases where similar failures (e.g., all four EDGs at a two-unit site with the same defective design) are detected at multiple plants, a CCF event is entered into the database for each unit affected. These concepts and definitions are documented in detail in Volume 2.

Figure 1 demonstrates the major steps in the CCF data analysis process. The numbers in parentheses after each block in Figure 1 are references to the steps in the detailed procedure in Volume 3. The same numbers are given after the section titles in the remainder of this section.

In summary, the CCF data analysis process consists of six activities: identification of analysis boundaries, data collection, failure data review and coding, data entry, independent QA verification, and CCF parameter estimation. Each activity is discussed below in the following sections.

## 2.1 Identification of Analysis Boundaries (1)

The initial step in the process is to identify the boundaries of the analysis, including the plant systems and components to be analyzed, operational event boundaries, and data search strategies. Initially, a list of components for analysis was developed by identifying the components that are risk important in several PRAs. The list includes such components as batteries, auxiliary feedwater system pumps, and emergency diesel generators. Currently, only mechanical and electrical components typically modeled in PRAs are being considered.

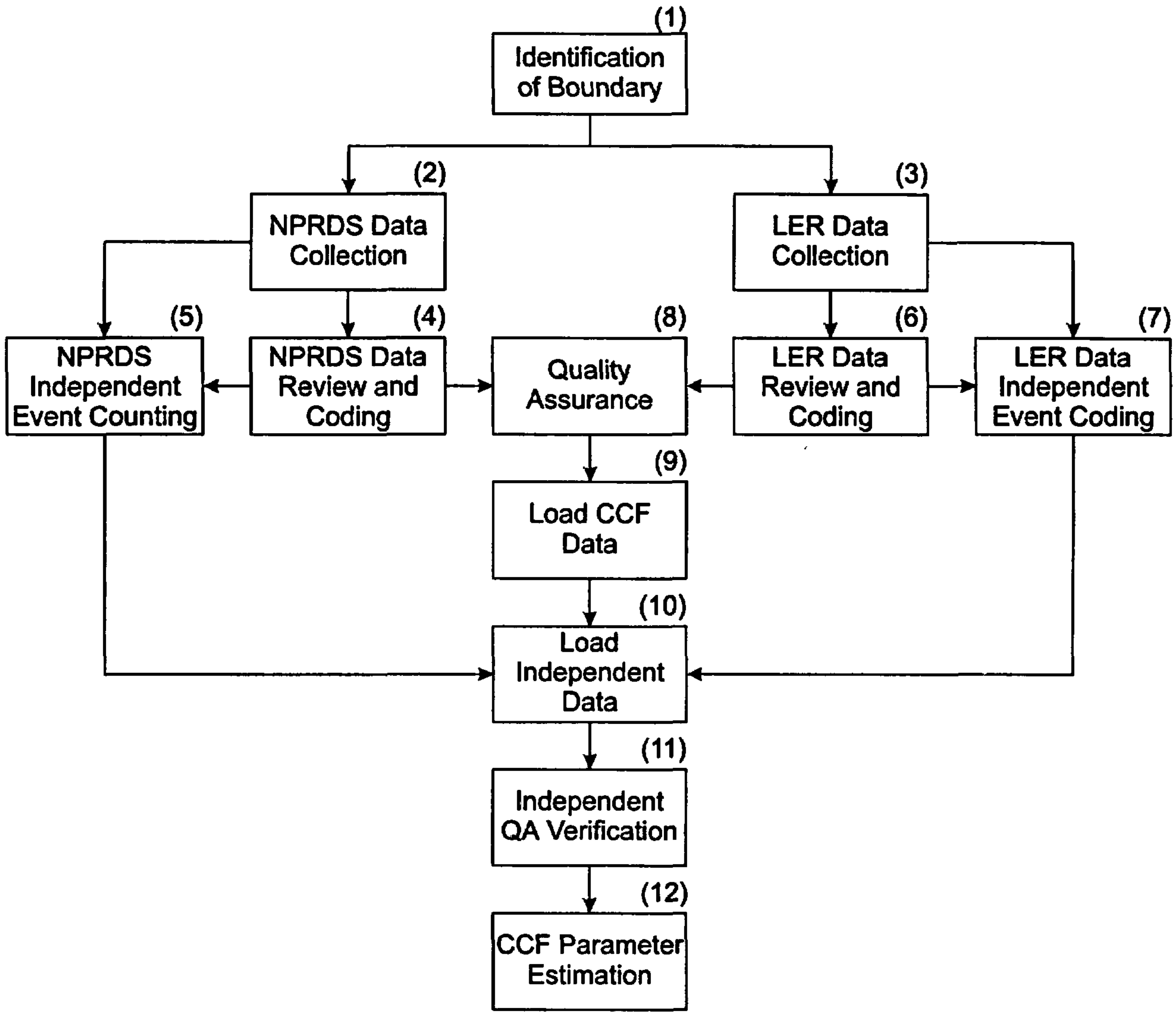



**Figure 1.** CCF data analysis process.

The staff identified the system success criteria by defining system and component failure modes. These are descriptions of how the system and components within the system are required to operate and accomplish their (safety or PRA-specific) mission. The failure modes defined initially were those that correspond primarily to the ones used in PRAs. For example, the safety function of a pump is to start on specific demand criteria, then to run for a given length of time (mission time). Pump failure to start includes events such as the motor circuit breaker not racked in and a successful start of the pump motor without achieving rated pressure and flow. Pump failure to run events include erratic speed control, lubrication system problems, or high vibration that may prevent operation for the full duration of mission time. As the data review progressed, analysts recognized that other failure modes, not typically used in PRA applications, such as failure to stop, exist in the operational data, and that it would be useful to capture this information in the database. Specific definitions of these additional failure modes, using operational data as examples, were documented to aid the data analysts in their review of the events. Analysts determined the failure modes for both the CCF events and the independent failures.

The component and system combinations are referred to as a common cause component group (CCCG). The number of components in a CCCG is referred to as the size of the group, the CCCG size, or the redundancy level. Each CCCG (e.g., EDGs, auxiliary feedwater air-operated valves) is unique in the application of system and component boundaries, definition of failure, and the applicable failure modes. Prior to performing any data searches and downloads, the analysts established the CCCG boundaries and defined the applicable failure modes to ensure that the data were properly collected and consistently analyzed. For example, the auxiliary feedwater (AFW) pump boundary includes the driver (motor and circuit breaker, or turbine and turbine governor) and the mechanical portion of the pump. All records containing failures of these subcomponents were obtained. Examples of possible failure events for each component set were given to the data analyst to assist in determining the applicability of the reported failure event to the CCF study. When a licensee reported a component degradation, the analyst had to determine the effect of the degradation on the actual operability of the component. For example, failure of one indicator light on a valve position indicator was determined not to be a failure of the valve. Conversely, an incorrectly positioned pump circuit breaker that would have prevented a successful pump start was considered a failure, even though the deficiency was identified prior to an actual demand.

The component boundaries are defined the same as the components modeled in most PRA studies. Component boundaries are defined prior to the date review so that each data analyst can consistently identify failure reports that should be included within a single component analysis. While identifying the component boundaries, the analyst identifies all components (including subcomponents) or portions of the system to be considered during the analysis.

When establishing component boundaries, the analyst considers CCF issues that affect groups of similar components being evaluated. During the analysis, the system being evaluated is first partitioned into components. Component partitions are based on factors that can cause a CCF event. For example, pumps are partitioned into pumps and drivers because CCF events may be different for pumps and drivers. The drivers are further partitioned into turbines and motors for the same reason. This partitioning is performed because some CCF events may affect only one type of subcomponent, while other CCF events occur across subcomponent boundaries. For example, failures that result in a loss of motive force for pump drivers are not the same as the failures that result in the pumps losing suction. Likewise, failures that result in the failure of motive force for the steam turbine generally are not similar to the failures that result in a loss of electrical power for a motor.

Prior to reviewing the failure records for identification of CCF events, it is necessary to understand the system configuration at each plant. Understanding the configuration enables the analyst to properly interpret the event and determine the impact of the reported failure on the system and component operability with respect to the PRA mission. The system configurations were determined using data in the *Nuclear Power Plant System Sourcebooks,*[7] plant final safety analysis reports, plant drawings, and other available sources. The system configuration analysis consists of identifying the number of trains involved, the number of each type component (CCCG), and component configuration.

Once preparations are completed, the following information is recorded for quality assurance documentation:

- A description of component boundaries. The description includes a list of parts (subcomponents and groups of similar components) analyzed with the CCCG.

- A description of failure modes used during the analysis.

- A description of relevant operational events, and definitions of failures and non-failures.

- Time boundaries for the data set and the date of the download. Currently the NPRDS data span the period from January 1, 1984, through December 31, 1995. (There are some NPRDS events, both CCF and independent, used in this data collection effort that occurred prior to 1984, but were not entered into NPRDS until after 1984.) The LER data span the period from January 1, 1980, through December 31, 1995.

- Any special limitations on data used during the download such as the following:

  - Exclude incipient failure reports, because they are inconsistently reported by licensees.

  - Exclude nonsafety-related failure reports.

- The size of the CCCG. If it is unknown, an assumption is made and explained.

- Any special situations that should be considered for a particular plant.

- Testing frequency for components of interest.

Using the above established system descriptions, boundaries of the component and system of interest, failure events, and applicable failure modes, the data are downloaded and prepared for analyst review. The INEEL staff downloads the NPRDS data, and the ORNL staff downloads the SCSS data in the form of LER numbers and LER abstracts for transmittal to the INEEL.

## 2.2 Data Collection (2 and 3)

The next step is to perform searches for CCF events using available data sources. The sources of component failure data most readily available to the NRC are the NPRDS failure reports and LERs downloaded from SCSS. The NPRDS data reports contain detailed information about the failure of a single component; thus, they must be considered in groups of two or more records with specific characteristics to constitute CCF events. Conversely, LERs contain information about more complex plant events, and, due to the reporting criteria, often contain information about multiple simultaneous failures in a single report. INEEL staff developed database search strategies using the basic characteristics of a CCF event as described above. For the initial data collection and evaluation phase of the project, INEEL staff reviewed data from 1980 through 1995.

The staff collected NPRDS failure reports for CCCGs of interest. Once collected, the failure reports were grouped by failure date and plant docket for consideration as potential CCF events. All failure reports that fall within one and a quarter surveillance testing interval are considered to be potential CCF events, because of the possibility of the failure states to exist, undetected, until the next component is tested. Volume 3[5] further discusses the timing factor.

The SCSS search algorithm has four basic parts: (1) any actual or potential failures of multiple components within one system coded on the same step of the SCSS matrix, (2) any actual or potential failure of a system train linked to a failure in another train of the same system, (3) any actual or potential failure of a component with at least one or more actual or potential failures of the same type of component in the same system coded afterward in the SCSS matrix, and (4) any fabrication/manufacturing deficiency resulting in an actual or potential failure within the system. The LERs retrieved using the four parts of the algorithm are combined into one group, resulting in the total number of potential CCF events for the system or component of interest.

Once the CCF search algorithm is completed, an algorithm for searching for independent events is developed to complement the CCF searches.

This is done by retrieving LERs on actual or potential failures or degradations of the component and/or system of interest that were not retrieved by any of the four elements of the CCF search algorithm. Similar to the NPRDS event grouping by failure date, the LERs are also grouped by date to facilitate identification of potential CCF events. Further discussion of the SCSS and NPRDS search details is contained in Volume 3.[5]

## 2.3 Event Analysis

The outputs from search strategies are potential CCF events and events that could represent independent failures. Data analysts read the LER abstracts and NPRDS report narratives of potential CCF events to determine when the criteria for a CCF event are satisfied. All failure events not included in a CCF event are considered for inclusion in the independent failure event databases. The coded LER CCF events and independent failures are compared to coded NPRDS CCF events and independent failures. All duplicates are removed from the NPRDS CCF data and independent NPRDS failure counts.

### 2.3.1 NPRDS and LER Data Review and Coding (4 and 6)

Once the NPRDS and LER data are grouped by plant docket and failure start date, potential CCF events are identified. The data analysts read the LER abstracts and the NPRDS failure narratives to identify CCF events. The criteria presented in Volume 2[4] are used to identify CCF events. As the CCF events are identified, INEEL staff complete the data coding in accordance with the guidance provided in Volume 3.[5] Failures not included in a CCF event are coded and entered into the independent failure databases (one for each CCCG).

### 2.3.2 NPRDS and LER Independent Event Counting (5 and 7)

Valid failures that are not coded as CCF events during the CCF event analysis are considered to be independent failure events. Independent failure events are counted because the counts are used in the denominator in the overall CCF parameter estimation, as described in Volume 2.[4] Independent failure event data must be provided by system, component, failure mode, and docket. This information is determined for each independent failure identified during the data review, for both the NPRDS and the LER data. Once this information has been identified, the independent failure data are counted by docket, failure mode, component, and system.

### 2.3.3 Quality Assurance (8)

A quality assurance verification plan was developed to ensure consistency and accuracy in the data analysis and CCF event coding. The two-step quality assurance verification plan includes (1) INEEL review, by both a second data analyst and a PRA analyst, and (2) independent quality assurance verification, by a subcontractor not at the INEEL. A discussion of the review by a second data analyst follows; independent quality assurance verification is discussed in Section 2.5.

A second INEEL data analyst evaluates every coded CCF event to ensure both proper identification of the CCF event and verification of coding accuracy. Any differences between the first and second codings are resolved by the two data analysts prior to data entry. A PRA analyst at the INEEL performs another review to ensure that appropriate PRA concepts are considered during data coding.

## 2.4 Load CCF and Independent Data (9 and 10)

A database management system has been developed for the CCF data. The CCF database system was constructed using the SAGE-ST software.[8] Using the CCF database system, CCF event data are entered into the CCF database by CCF event and by independent event counts. Accuracy of data entry is verified following by a second data analyst reviewing the entered data. Independent failure event data (e.g., failure mode, component) are entered into the independent failure databases, and the data entry is verified.

## 2.5 Independent QA Verification (11)

The independent QA verification activity is a full review of coded CCF events and CCF identification and coding methods by recognized CCF experts outside the INEEL. The independent QA verification ensures that coded CCF events are actually CCF events and that the CCF event coding is correct and consistent.

The following steps constitute the independent QA verification:

- Copies of coded events, supporting documentation, and printouts of CCF parameter estimates are transmitted to the personnel doing the independent QA verification.

- The independent QA personnel review the events and identify potential changes. The proposed changes are transmitted back to the INEEL CCF database staff for resolution prior to entry into the CCF database.

## 2.6 CCF Parameter Estimation (12)

After independent event count and CCF event information have been entered into the CCF database and quality assurance verification completed, the next step is the estimation of CCF parameters using the software developed for performing quantifications. Detailed guidance on the use of the CCF software for parameter estimations is in Volume 4[6].

The parameter estimation software developed for this project uses the impact vector method described in Reference 2 and the approach introduced in Reference 3 for evaluating the event impact vector based on physical characteristics of the event. These characteristics include component degradation parameter, timing factor, and shared cause factor. In addition, the software allows the user to modify the generic event impact factors for plant-specific applications, including mapping the impact vectors to account for differences in CCCG size between the plant in which the event occurred and the plant for which the data are being modified. Other software features include parameter estimations for both alpha factor and multiple Greek letter (MGL) models.

# 3. CCF SOFTWARE AND PARAMETER ESTIMATES

The CCF database system was developed for the personal computer. It contains the CCF events in a searchable database and options to estimate CCF parameters. It provides a number of capabilities to users with different interests and levels of expertise in CCF event analysis. The CCF system has two main options, allowing users to perform either generic analyses or plant-specific analyses of CCF events included in the database. The parameter estimation process is a two-step process: (1) search of the CCF database to obtain only the events of interest, usually sorted by system, component, and failure mode, and (2) use of the CCF system software to perform calculations using the selected events.

Descriptions of the two parameter estimation options, generic and specific, follow:

1. Generic (data from multiple plants are pooled) analysis of CCF events included in the database. Generic analysis includes a qualitative analysis of causes and severity of CCF events and a quantification of generic CCF parameters (alpha factor and multiple Greek letter models). These can be used in risk and reliability studies or other applications such as trending of industry performance with respect to a single class of failures.

2. Plant-specific analysis of CCF events. This option allows users to specialize (modify) the CCF events in the database for application to a specific plant by considering design and operational differences between the plant where the event occurred and the plant of interest (target plant), and to estimate CCF parameters that reflect the specific features of the plant being studied. This is recommended in Reference 2 as the preferred approach for plant-specific analyses.

The data included in the CCF system are the result of review and classification of LER and NPRDS data to identify and characterize CCF events in terms of their causes, the functional state of components affected in each event, and mechanisms responsible for propagation of the failure or degraded state beyond a single component failure. The event classification approach is summarized in Volume 2,[4] and the detailed coding guidance for evaluating each event in terms of the attributes needed for quantification is provided in Volume 3.[5]

Flexibility is built into the CCF system to enable the PRA analyst to add or remove CCF events from a set, provided by the database search capability, in recognition that a precise definition of a CCF may vary from one PRA study to another. All events identified as dependent events in the LER and NPRDS data are included in the CCF database, but some are shared equipment dependencies, modeled explicitly in PRAs. The events in the database, therefore, include more events than those which might be appropriate for use in a given PRA or other studies.

The classification of events (both CCFs and independent failure data) represents the best judgment of experienced analysts who have applied a set of carefully designed rules to ensure consistency and minimize subjectivity. The PRA analyst, however, can modify various attributes of the events in a copy of the database, leaving the original database intact as a reference point. This type of modification requires a relatively high degree of experience and is not expected to be the primary application of the CCF system.

While in the CCF system, an analyst may search the CCF database to obtain information on various aspects of the CCF data, such as the distribution of proximate causes (collectively or component by component). The software allows the user to specify a subset of the attributes of the events as the search criteria to obtain a subset of the database having those attributes. This enables the user to develop a statistical base for the study of generic differences among different classes of plants or systems, as well as a trend of CCF events by plant or across the industry.

Figure 2 contains the major steps in the CCF parameter estimation process. Steps 13 through 15 in Figure 2 are a more detailed breakdown of step 12 in Figure 1. The same numbers follow the titles for the remaining sections.

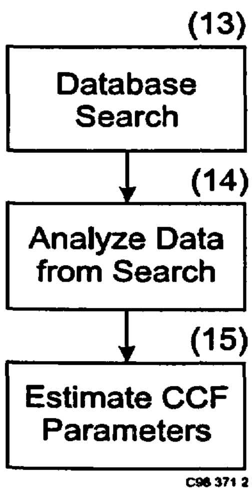



**Figure 2.** Software process flow diagram.

## 3.1 Search Database (13)

The CCF events that have been entered into the database cover a large range of systems and components and vary in importance from a PRA perspective. Searches for CCF events to be included in parameter estimations can be structured to prevent inclusion of events irrelevant to an individual study. For example, prior to searching for AFW pump events, which include either motor-driven pump CCF events, turbine-driven pump CCF events, or CCF events that include both pump types, the analyst must decide to include either all pump types, searching for motors, turbines, and pumps, or only one pump type, then perform the CCF database search accordingly.

Using the search option, the PRA analyst can select the data fields of interest (system, component, failure mode, shared cause factor, cause, type, etc.), search the database on the basis of the coded event information entered in those fields, and identify the events whose fields meet the specified search criteria. For example, to search the database for the auxiliary feedwater pumps that fail to start on demand and the events that are important from a PRA perspective, the search criteria would specify the system code for auxiliary feedwater, component code for motor-driven pumps, turbine-driven pumps, motors, turbines, and pumps, failure mode of failure to start, and event type of CCF. A search using these criteria would identify all events coded with the field information meeting these criteria. Following the search, the events are saved in an "application" for analysis. Volume 4[6] discusses the mechanics of the process.

## 3.2 Analyze Data from Search (14)

Once the analyst selects the events to be included in the analysis, using the CCF software to obtain the parameter estimations is straightforward; the CCF database system performs all calculations. Due to the relative rarity of CCF events in operational experience, CCF events from similar plants can be pooled together to obtain enough data for use in reliability and risk studies; these are the "generic" estimations. The analysis uses CCF data that involve degradations, as well as those involving total failures. The data from any search can be saved for future reference and can be used with either the generic or plant-specific software options.

All CCF event data obtained in the search and saved (discussed in Section 3.1) can be reviewed for applicability for specific studies. Some events may be coded in a manner that does not reflect the PRA analyst's perception of the events. Each event can be reviewed to give the PRA analyst an opportunity to modify or delete the event from consideration in the specific application. The data fields that can be modified are component degradation level, timing factor, shared cause factor, and average impact vector. The software system defaults to "not modifying" the data. This does not modify the event information in the original database. Once the PRA analyst has determined and entered the data modifications, the software calculates the average impact vector for the selected set of CCF events. During sensitivity studies, the average impact vector values can be changed and saved for calculating parameter estimates.

Additionally, the PRA analyst may want to analyze the CCF data for applicability to a particular plant, using the plant-specific option. In this case, some data may not be applicable because of a difference in plant configuration or in shared cause factors between the original event and the target plant. As in the generic option, event data can be modified or an event may be deleted from the analysis. The fields that can be modified are cause, shock type, component degradation level, shared cause factor, map up factor, event type, timing factor, shared cause factor, average impact vector, and application specific impact vector. Once the PRA analyst has determined and entered the applicability of an event, the software calculates the specific impact vector. Similar to the average impact vector values, the specific impact vector values can be modified and stored for use in parameter estimations.

## 3.3 Estimate CCF Parameters (15)

Once event data are prepared for parameter estimation (Section 3.2), the final analytical step is to perform the parameter estimation using either of the two different quantification methods (generic or specific). In both options, the models are selected (alpha factor or multiple Greek letter, or both) and the calculations performed. The output of the parameter estimations is displayed in several ways: tabular, graphically, electronically for transfer to other software applications. Uncertainty calculations are also provided. Figure 3 displays an example of output from the CCF system showing summary results of an EDG analysis, including generic estimates of the CCF frequency parameters for the failure-to-start mode.

The parameter estimation software uses the impact vector approach. Reference 2 and Volume 2[4] discuss the use of event impact vectors. This method classifies the individual CCF events according to the level of their impact on the overall CCF effect on the PRA study and the associated uncertainties in numerical terms, using the assessments from the event coding. These impact vectors represent the certainty that each event represents a CCF event. They are based on the component degradation factor, the timing factor, and the shared cause factor, discussed briefly in Section 2. Once the individual event impact vectors are determined, the average impact vector for the CCCG of interest (e.g., EDGs) is calculated. The independent event counts are included in the CCF database, sorted by system, component, failure mode, source (LER or NPRDS), and docket. The user has the option of modifying the independent event value if there is uncertainty about the number provided, or if there are additional assumptions or information to be used in the analysis.

The generic analysis portion of the database includes an estimation of CCF parameters, from pooled plant data, which can be used in risk and reliability studies, or other applications such as trending of industry performance with respect to specific types of failures. CCF data are used in the Accident Sequence Precursor (ASP) program, safety system reliability studies, and for resolution of NRC Generic Issues.

The plant-specific analysis option of the CCF software allows the PRA analyst to modify event coding to adjust CCF event data for design or operational differences between the plant where the actual CCF event occurred and the plant to which the data are applied. The software allows the analyst to review each event and modify various attributes of the event or delete the event from consideration in parameter estimations. Two adjustment factors, the cause applicability factor and the shared cause factor applicability, can be used to reflect the analyst's interpretation of the differences between the two plants. The changes are saved in a copy of the database for the particular application for use at a later time, while the data in the original database are not changed. As with the generic estimations, the analyst may use the independent events that are in the CCF database, by individual plant, or the analyst may choose another value, based on knowledge of the target plant. Additionally, the software includes the capability to adjust the size of the CCCG, using mapping factors, so that an event that occurred at a plant with n similar components may be applied to a plant that has m such components.

Special Quantification Report

| | | | |
|---|---|---|---|
| Application: | EDG_FS | Unadjusted Independent Events: | 764 |
| Component: | EDG | Total Common Cause Events: | 55 |
| Failure Mode: | FS | Average Event CCCG: | 2.83 |

| CCCG Size | Adjusted Ind. Events | Count Summary | | Alpha Factors | | MGL Factors | |
|---|---|---|---|---|---|---|---|
| 2 | 522.96 | N1 | 30.0822 | α1 | 0.9683328 | 1-Beta | 9.68E-001 |
| | | N2 | 18.0860 | α2 | 3.16E-002 | Beta | 3.16E-002 |
| 3 | 784.45 | N1 | 24.0867 | α1 | 0.9620172 | 1-Beta | 9.62E-001 |
| | | N2 | 17.2720 | α2 | 2.05E-002 | Beta | 3.79E-002 |
| | | N3 | 14.6510 | α3 | 1.74E-002 | Gamma | 4.58E-001 |

Note: "Staggered" testing on MGL Calculations? Y

**Figure 3.** Parameter estimation example.

# 4. GENERAL INSIGHTS FROM ANALYSIS OF CCF DATA

The CCF database developed in this project is a rich source of information on various aspects of common cause failure. Exploring the full potential of the database merits a dedicated activity and is outside the scope of the current effort, which has focused on building the infrastructure for such analyses. Nevertheless, some general observations have been made on the character of CCF events, including their causes and shared cause factors, and frequency of occurrence. Some of these insights are summarized in this section.

Table 2 lists the systems, component types, and failure modes for which CCF events have been collected and entered into the database. It also contains the number of CCF events for each system and component combination and the number of independent failure events. This table is an expansion of Table 1 (Section 1), providing a more detailed list of the component data that have been reviewed. Table 2 only shows the event counts for failure modes that are relevant to PRA studies, whereas Table 1 includes all events for all failure modes. Other failure modes, such as failure to close for reactor trip breakers, were found in the source data; these events were coded and entered into the CCF database, even though they are not likely to be used in PRA studies.

Basic information about the nature of CCF events is displayed in Figures 4 and 5, which illustrate the distribution of CCF event proximate causes and shared cause factors, respectively. This information provides a general picture of the types of events that may be expected to occur, and what design features might be most susceptible to CCF events. These figures also illustrate the different characteristics of partial CCF events and complete CCF events (events with timing factor, shared cause factor, and component degradation values for each component in the CCCG =1.0). Figures 6, 7, and 8 display the number of CCF events by year of occurrence.

A general review of the actual events and the distributions provided in Figures 4 and 5, reveals the following insights regarding CCF events:

- A major contributor to CCF events is programmatic maintenance practices. The frequency of scheduling has been a factor in the numerous wearout-caused and aging-caused events. Additionally, the quality of the maintenance, both in the procedures and in performance of the maintenance activities, is a key factor. Similar events have occurred at different plants—lubrication of circuit breakers (too much, too little, or too long between lubrications), improperly set torque and limit switches on MOVs that are reported as misadjustments and not setpoint drift. This indicates that there are maintenance practices that need to be reviewed to reduce common cause failure potential.

- Another contributor is design problems. Many of the design-related events resulted from a design modification, indicating that perhaps the modification review processes were not rigorous and resulted in CCF susceptibilities.

- Human errors related to procedures caused a small percentage of the total events, but the impact of the individual events is usually greater, since human errors have overridden the programmatic controls. This is illustrated by comparing Figure 4b with Figure 4a, which shows that human error causes a larger portion of complete CCF events than partial CCF events. Examples of events caused by human error are all EDG day tanks simultaneously drained for a chemistry surveillance, two pump breakers racked out as the plant changed modes from shutdown to power.

- A vast majority of the CCF events are not due to multiple failures in response to an operational demand, but result from a "condition of equipment." The most common is inspection or surveillance test of one component revealing a deficiency that prompts the licensee to inspect/test the redundant component, resulting in the discovery that the same defective condition exists on both components. This demonstrates that detection of failures during the testing and surveillance program prevents CCF events from occurring during demand situations.

- The CCF database contains several examples where both CCF and independent events recur at some, but not all, plants, perhaps indicating ineffective root cause analysis and corrective action. Examples of repeated events are water in compressed air systems, pump seal wearout, and turbine governor misadjustment. Additionally, not all plants experience the same type of recurring event. This indicates that plant-to-plant variability exists in the CCF parameters that might cause the CCF parameter estimates for some plants to be higher than the industry average for certain component and system combinations. Thus, it is very important to perform plant-specific CCF parameter estimations for plant-specific PRAs and reliability studies.

With respect to quantification of common cause failures, the overall conclusion is that, based on the evaluation of over 15 years of operating experience data, CCF parameters for similar components vary among systems and failure modes. Table 3 displays maximum likelihood estimates (MLE) for both EDG failure modes, fail to start and fail to run. Tables 4 and 5 display the MLEs for both the alpha factors ($\alpha_2$) and beta factors for several component and system combinations. These results illustrate that the parameter estimates vary for different failure modes within the same component group, and that they also vary between different systems for the same component.

Another useful observation is that common cause failure parameters of different components are available. Figure 9 shows the component-to-component variability of the mean $\alpha_2$ for various system and component combinations. It also shows a beta distribution fit to these data. The equation for this beta distribution is:

$$\pi(\alpha) \propto \frac{\Gamma(A+B)}{\Gamma(A)(B)} \alpha^{A-1} (1-\alpha)^{B-1}$$

where A = 2.0291, B = 45.707.

$$\alpha_{5\%} = 0.0079$$
$$\alpha_{95\%} = 0.0984$$
$$\alpha_{mean} = 0.0425$$

**Table 2.** Component types and systems analyzed for CCF events (1980–1995).

| Component Type | PRA-relevant Failure Modes | Systems Analyzed for the Component Type | No. of CCF Events for System and Component Type | No. of Independent Failures for System & Component Type | Total No. of CCF Events for Component Type | Total Number of Independent Failures for Component Type |
|---|---|---|---|---|---|---|
| Air-Operated Valves | Fail to Open | Auxiliary Feedwater (PWR) | 42 | 197 | 191 | 505 |
| | Fail to Close | High Pressure Injection (BWR) | 2 | 28 | | |
| | Fail to Remain Closed | Isolation Condenser (BWR) | 1 | 9 | | |
| | | Main Steam Isolation (BWR & PWR) | 146 | 271 | | |
| Batteries/Chargers | No, High Output | DC Power (BWR & PWR) | 60 | 1,260 | 60 | 1,260 |
| Check Valves | Fail to Open | Auxiliary Feedwater (PWR) | 59 | 201 | 147 | 556 |
| | Fail to Close | High Pressure Injection (BWR/PWR) | 23/21 | 84/145 | | |
| | Fail to Remain Closed | Low Pressure Injection (BWR/PWR) | 23/21 | 88/38 | | |
| Circuit Breakers | Fail to Open | DC Power (BWR & PWR) | 8 | 112 | 116 | 989 |
| | Fail to Close | AC Power (BWR & PWR) | 82 | 746 | | |
| | Fail to Remain Closed | Reactor Trip Breakers (fail to open only) (PWR) | 26 | 131 | | |
| Emergency Diesel Generators | Fail to Start, Run | Emergency Power (BWR & PWR) | 131 | 1,346 | 131 | 1,346 |
| Heat Exchangers | Fail to Transfer Heat | Containment Spray (PWR) | 10 | 14 | 18 | 29 |
| | | Residual Heat Removal (BWR/PWR) | 8 | 15 | | |
| Motor-Operated Valves | Fail to Open | Auxiliary Feedwater (PWR) | 27 | 422 | 192 | 2,568 |
| | Fail to Close | Containment Spray (PWR) | 15 | 250 | | |
| | Fail to Remain Closed | High Pressure Injection (BWR/PWR) | 11/40 | 369/292 | | |
| | | Isolation Condenser (BWR) | 2 | 44 | | |
| | | Low Pressure Injection (BWR/PWR) | 61/23 | 492/470 | | |
| | | Pressurizer (PWR) | 7 | 155 | | |
| | | Refueling Water Storage Tank (PWR) | 6 | 74 | | |
| Pumps | Fail to Start | Auxiliary Feedwater (PWR) | 51 | 919 | 280 | 3,507 |
| | | Emergency Service Water (BWR & PWR) | 141 | 1,184 | | |
| | | High Pressure Injection (BWR/PWR) | 2/42 | 343/481 | | |
| | | Low Pressure Injection (BWR/PWR) | 9/25 | 148/362 | | |
| | | Standby Liquid Control (BWR) | 10 | 70 | | |
| Relief Valves | Fail to Open | BWR Primary System | 37 | 237 | 115 | 976 |
| | Fail to Close | Pressurizer (PWR) | 22 | 334 | | |
| | Fail to Remain Closed | Steam Generator (PWR) | 56 | 405 | | |
| Safety Valves | Fail to Open | Pressurizer (PWR) | 6 | 119 | 38 | 280 |
| | Fail to Close | Steam Generator (PWR) | 32 | 161 | | |
| | Fail to Remain Closed | | | | | |
| Strainers | Fail to Allow Flow | Containment Spray (PWR) | 1 | 0 | 39 | 162 |
| | | Emergency Service Water (BWR & PWR) | 36 | 162 | | |
| | | Suppression Pool (BWR) | 2 | 0 | | |

**Table 3.** Emergency diesel generator CCF parameter estimations.

| | Fail to Start | | | Fail to Run | | |
|---|---|---|---|---|---|---|
| | CCCG=2 | CCCG=3 | CCCG=4 | CCCG=2 | CCCG=3 | CCCG=4 |
| **Alpha Factor** | **Alpha Factor Parameter Estimations** | | | | | |
| $\alpha_1$ | 0.968333 | 0.957241 | 0.950567 | 0.961131 | 0.939467 | 0.954343 |
| $\alpha_2$ | 3.16E-2 | 2.45E-2 | 1.04E-2 | 3.88E-2 | 3.66E-2 | 1.18E-2 |
| $\alpha_3$ | — | 1.82E-2 | 1.58E-2 | — | 2.38E-2 | 2.38E-2 |
| $\alpha_4$ | — | — | 1.31E-2 | — | — | 1.82E-2 |
| **MGL Parameter** | **MGL Parameter Estimations** | | | | | |
| **1-Beta** | 9.68E-1 | 9.57E-1 | 9.60E-1 | 9.61E-1 | 9.39E-1 | 9.46E-1 |
| **Beta** | 3.16E-2 | 4.27E-2 | 3.94E-2 | 3.88E-2 | 6.05E-2 | 5.38E-2 |
| **Gamma** | — | 4.25E-1 | 7.35E-1 | — | 3.94E-1 | 7.80E-1 |
| **Delta** | — | — | 4.52E-1 | — | — | 4.33E-1 |
| **Adj. Independent Events** | 522.96 | 784.45 | 1,045.9 | 450.98 | 676.47 | 901.96 |

**Fail to Start**
Number of Independent Failure Events: 764
Number of Common Cause Failure Events: 55

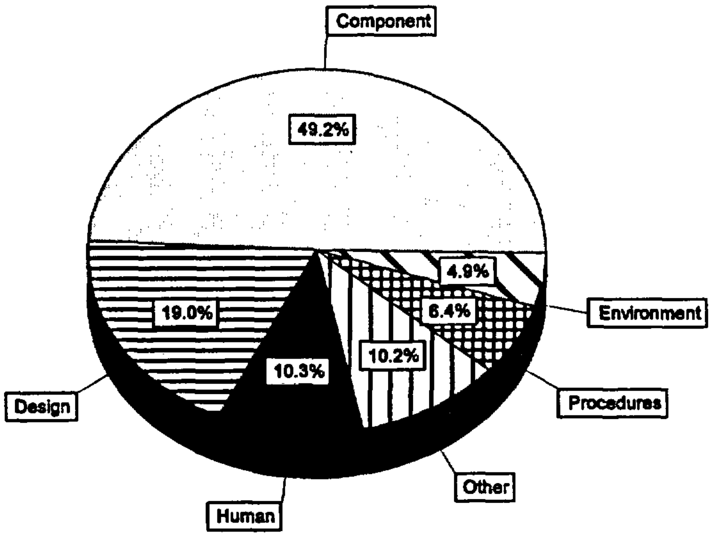
**Fail to Run**
Number of Independent Failure Events: 587
Number of Common Cause Failure Events: 76

**Table 4.** Alpha and beta factors for motor operated valves (CCCG=6).

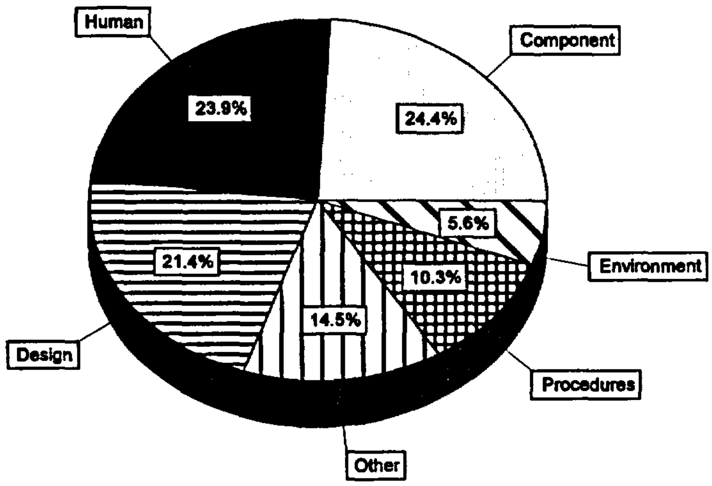
| System | Alpha Factor ($\alpha_2$) | | Beta Factor ($\beta$) | |
|---|---|---|---|---|
| | Fail to Open | Fail to Close | Fail to Open | Fail to Close |
| Auxiliary Feedwater - PWR | 1.50E-2 | 2.33E-2 | 3.27E-2 | 6.28E-2 |
| High Pressure Safety Injection - PWR | 2.21E-2 | 3.12E-2 | 5.95E-2 | 3.76E-2 |
| Low Pressure Safety Injection - PWR | 1.21E-2 | 9.28E-3 | 1.65E-2 | 1.65E-2 |
| Low Pressure Coolant Injection - BWR | 1.27E-2 | 1.90E-2 | 3.39E-2 | 4.60E-2 |

**Table 5.** Alpha and beta factors for pumps.

| System | CCCG | Alpha Factor ($\alpha_2$) | | Beta Factor ($\beta$) | |
|---|---|---|---|---|---|
| | | Fail to Start | Fail to Run | Fail to Start | Fail to Run |
| Emergency Service Water- BWR & PWR | 6 | 3.23E-2 | 8.92E-3 | 8.38E-2 | 3.54E-2 |
| Auxiliary Feedwater - PWR | 4 | 1.25E-2 | 1.23E-2 | 4.79E-2 | 2.31E-2 |
| High Pressure Safety Injection - PWR | 3 | 2.18E-2 | 1.61E-2 | 5.28E-2 | 2.56E-2 |
| Low Pressure Safety Injection - PWR | 2 | 6.31E-2 | 5.34E-2 | 6.31E-2 | 5.34E-2 |
| Low Pressure Coolant Injection - BWR | 4 | 3.14E-2 | 6.40E-3 | 3.17E-2 | 6.40E-3 |
| Standby Liquid Control - BWR | 2 | 9.80E-2 | 3.24E-2 | 9.80E-2 | 3.24E-2 |

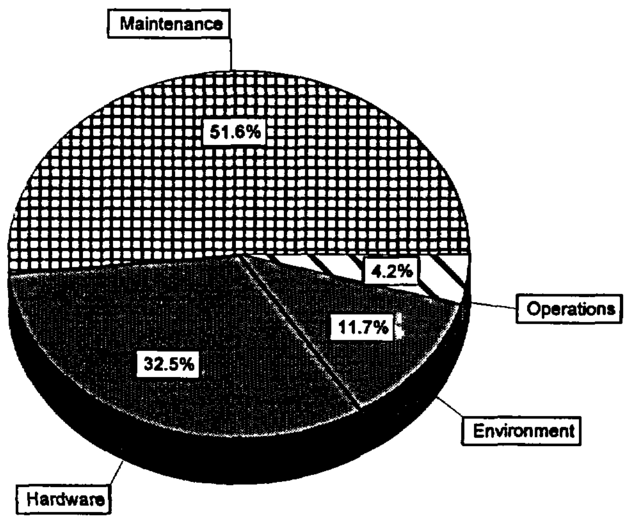



a. Distribution of causes of complete and partial CCF events.

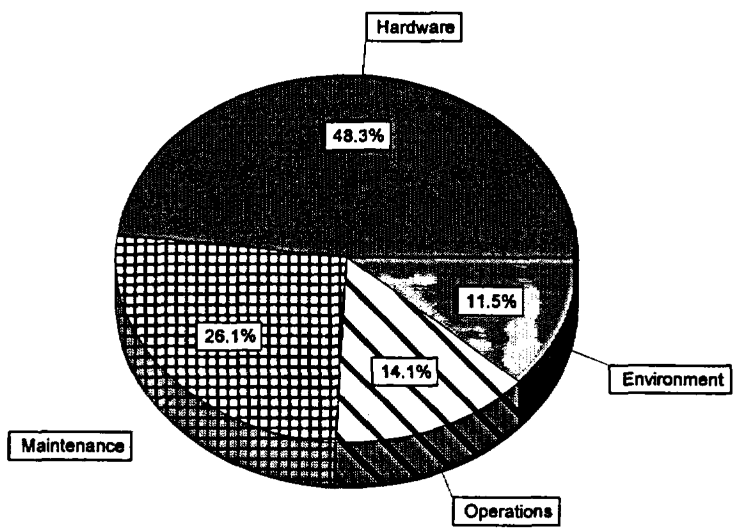



b. Distribution of causes of only the complete CCF events.

**Figure 4.** Distribution of CCF events by cause.




a. Distribution of shared cause factors for both complete and partial CCF events.




b. Distribution of shared cause factors for only the complete CCF events.

**Figure 5.** Distribution of CCF events by shared cause factor.

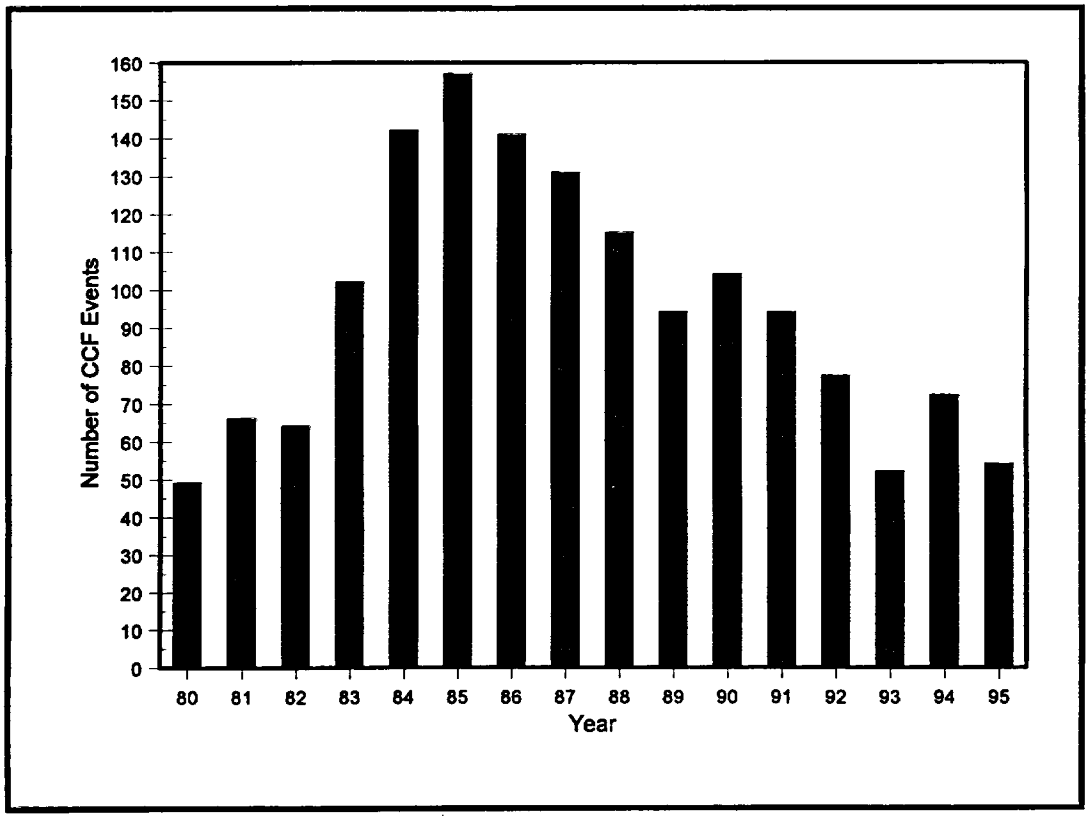



**Figure 6**. Distribution of all CCF events in database by year.

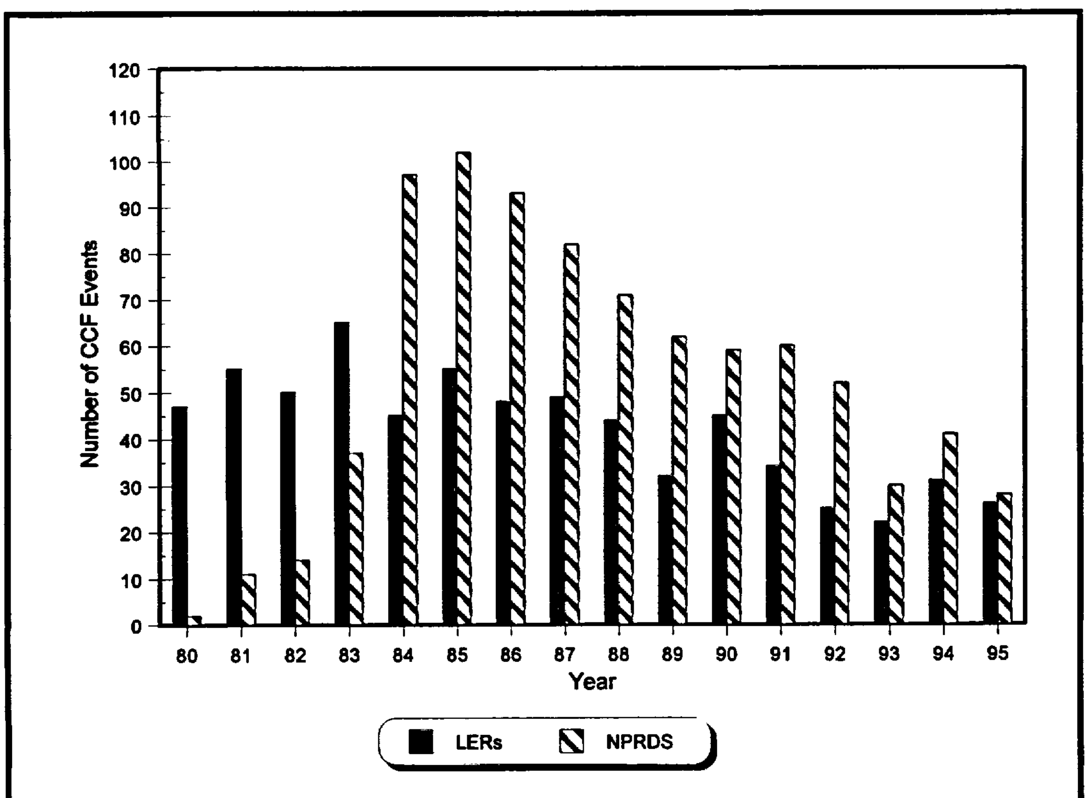



**Figure 7**. Distribution of CCF events by year and source.

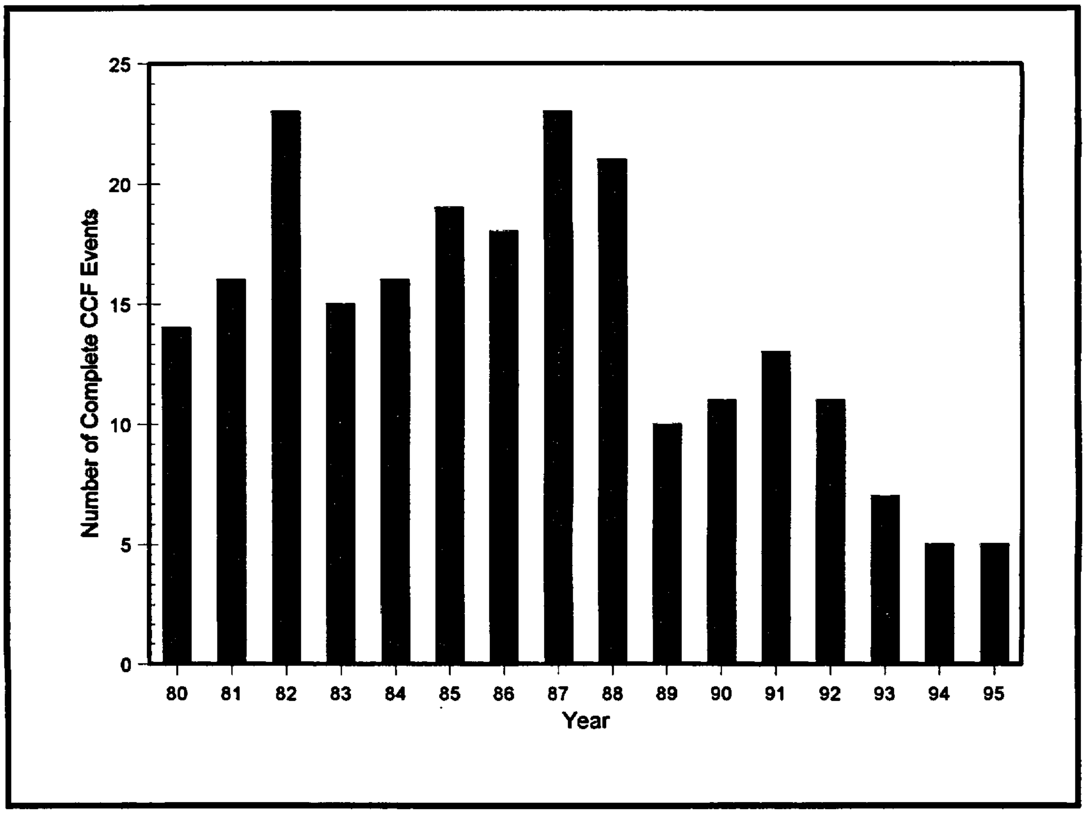


**Figure 8.** Distribution of complete CCF events by year.

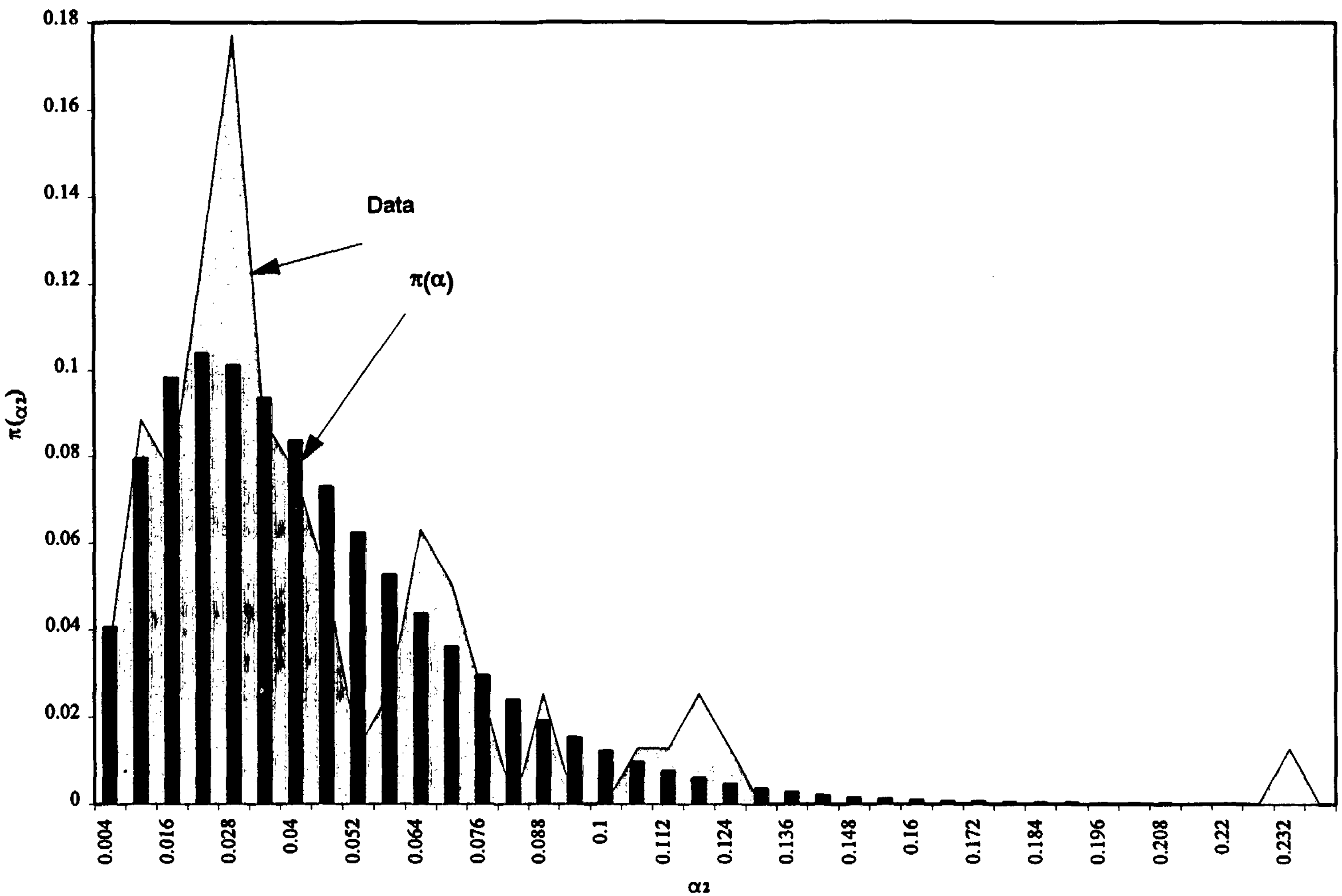



**Figure 9.** Component-to-component variability of alpha factors.

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# GLOSSARY

*Application*—A particular set of CCF events selected from the common cause failure database for use in a specific study.

*Average Impact Vector*—An average over the impact vectors for different hypotheses regarding the number of components failed in an event.

*Basic Event*—An event in a reliability logic model that represents the state in which a component or group of components is unavailable and does not require further development in terms of contributing causes.

*Common Cause Event*—A dependent failure in which two or more component fault states exist simultaneously, or within a short time interval, and are a direct result of a shared cause.

*Common Cause Basic Event*—In system modeling, a basic event that represents the unavailability of a specific set of components because of shared causes that are not explicitly represented in the system logic model as other basic events.

*Common Cause Component Group*—A group of (usually similar [in mission, manufacturer, maintenance, environment, etc.]) components that are considered to have a high potential for failure due to the same cause or causes.

*Common Cause Failure Model*—The basis for quantifying the frequency of common cause events. Examples include the beta factor, alpha factor, and basic parameter, and the binomial failure rate models.

*Complete Common Cause Failure*—A common cause failure in which all redundant components are failed simultaneously as a direct result of a shared cause; i.e., the component degradation value equals 1.0 for all components, and both the timing factor and the shared cause factor are equal to 1.0.

*Component*—An element of plant hardware designed to provide a particular function.

*Component Boundary*—The component boundary encompasses the set of piece parts that are considered to form the component.

*Component Degradation Value* (*p*)—The assessed probability ($0.0 \le p \le 1.0$) that a functionally or physically degraded component would fail to complete the mission.

*Component State*—Component state defines the component status in regard to its intended function. Two general categories of component states are defined, *available* and *unavailable*.

- *Available*—The component is available if it is capable of performing its function according to a specified success criterion. (N.B., available is not the same as availability.)

- *Unavailable*—The component is unavailable if the component is unable to perform its intended function according to a stated success criterion. Two subsets of unavailable states are *failure* and *functionally unavailable*.

  - *Failure*—The component is not capable of performing its specified operation according to a success criterion.

  - *Functionally unavailable*—The component is capable of operation, but the function normally provided by the component is unavailable due to lack of proper input, lack of support function from a source outside the component (i.e., motive power, actuation signal), maintenance, testing, the improper interference of a person, etc.

• *Potentially unavailable*—The component is capable of performing its function according to a success criterion, but an incipient or degraded condition exists. (N.B., potentially unavailable is not synonymous with hypothetical.)

- *Degraded*—The component is in such a state that it exhibits reduced performance but insufficient degradation to declare the component unavailable according to the specified success criterion.

- *Incipient*—The component is in a condition that, if left unremedied, could ultimately lead to a degraded or unavailable state.

*Shared Cause Factor/Mechanism*—A set of causes and factors characterizing why and how a failure is systematically induced in several components.

*Date*—The date of the failure event, or date the failure was discovered.

*Defense*—Any operational, maintenance, and design measures taken to diminish the frequency and/or consequences of common cause failures.

*Dependent Basic Events*—Two or more basic events, A and B, are statistically dependent if, and only if,

$$P[A \cap B] = P[B|A]P[A] = P[A|B]P[B] \neq P[A]P[B],$$

where P[X] denotes the probability of event X.

*Event*—An event is the occurrence of a component state or a group of component states.

*Exposed Population*—The set of components within the plant that are potentially affected by the common cause failure event under consideration.

*Failure Mechanism*—The history describing the events and influences leading to a given failure.

*Failure Mode*—A description of component failure in terms of the component function that was actually or potentially unavailable.

*Failure Mode Applicability*—The analyst's probability that the specified component failure mode for a given event is appropriate to the particular application.

*Impact Vector*—An assessment of the impact an event would have on a common cause component group. The impact is usually measured as the number of failed components out of a set of similar components in the common cause component group.

*Independent Basic Events*—Two basic events, A and B, are statistically independent if, and only if,

$$P[A \cap B] = P[A]P[B],$$

where P[X] denotes the probability of event X.

*Mapping*—The impact vector of an event must be "mapped up" or "mapped down" when the exposed population of the target plant is higher or lower than that of the original plant that experienced the common cause failure. The end result of mapping an impact vector is an adjusted impact vector applicable to the target plant.

*Mapping Up Factor*—A factor used to adjust the impact vector of an event when the exposed population of the target plan is higher than that of the original plant that experienced the common cause failure.

*Potential Common Cause Failure*—Any common cause event in which at least one component degradation value is less than 1.0.

*Proximate Cause*—A characterization of the condition that is readily identified as leading to failure of the component. It might alternatively be characterized as a symptom.

*Reliability Logic Model*—A logical representation of the combinations of component states that could lead to system failure. A fault tree is an example of a system logic model.

*Root Cause*—The most basic reason for a component failure which, if corrected, could prevent recurrence. The identified root cause may vary depending on the particular defensive strategy adopted against the failure mechanism.

*Shared-Cause Factor (c)*—A number that reflects the analyst's uncertainty ($0.0 \le c \le 1.0$) about the existence of coupling among the failures of two or more components, i.e., whether a shared cause of failure can be clearly identified.

*Shock*—A shock is an event that occurs at a random point in time and acts on the system; i.e., all the components in the system simultaneously. There are two kinds of shocks distinguished by the potential impact of the shock event, i.e., *lethal* and *nonlethal*.

*System*—The entity that encompasses an interacting collection of components to provide a particular function or functions.

*Timing Factor (q)* —The probability ($0.0 \le q \le 1.0$) that two or more component failures (or degraded states) separated in time represent a common cause failure. This can be viewed as an indication of the strength-of-coupling in synchronizing failure times.

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10. SUPPLEMENTARY NOTES


11. ABSTRACT (200 words or less)
This volume of the Common Cause Failure Database and Analysis System report presents an overview of common cause failure methods for use in the U.S. commercial nuclear power industry. It summarizes how data (on common cause failure events) are gathered, evaluated, and coded. It then describes the process for estimating probabilistic risk assessment (PRA) common cause failure parameters. It also references other volumes of this report for specific details.

Equipment failures that contribute to common cause failure events are identified through searches of Licensee Event Reports (LERs) and Nuclear Plant Reliability Data System (NPRDS) failure reports. Once common cause failure events are identified by reviewing reports of equipment failures, INEEL staff enter the event information into a personal computer data analysis system (CCF system) using the method presented in this and companion volumes. The events stored in the CCF system are used for common cause failure PRA parameter estimations using common cause failure quantification methods.


| 12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)<br><br>Common cause failure | 13. AVAILABILITY STATEMENT<br>Unlimited<br>14. SECURITY CLASSIFICATION<br>(This page)<br>Unclassified<br>(This report)<br>Unclassified<br>15. NUMBER OF PAGES<br><br>16. PRICE |
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