4. DATA SOURCES

Two types of data sources can be utilized to produce the various parameter estimates that are needed in a probabilistic risk assessment (PRA). This chapter identifies and discusses these two data sources. Section 4.1 identifies and discusses plant-specific data sources. Section 4.2 does the same for generic data sources.

4.1 Plant-Specific Data Sources

The incorporation of plant-specific data in the parameter estimates used in a PRA produces risk estimates that reflect the actual plant experience.

The scope of a plant-specific data analysis is determined by the events that are included in the PRA models. In general, plant-specific data is generally reviewed for the following types of events:

1. The accident initiating events analyzed in the PRA.
2. The components included in system models (generally fault trees). For components the definition includes the component boundary and failure mode. For unavailabilities due to maintenance or testing it is necessary to know whether the unavailabilities are to be specified at the component, segment, train, or system level
3. Some recovery events included in the PRA models. Although most recovery events are analyzed using human reliability analysis, the probabilities of some events can be based upon a review of operating experience.

Identifying the scope of the plant-specific data analysis is important because the definitions of the component boundaries and the component failure mode definitions have to be consistent with those used in the systems analysis. The collected raw failure data must be consistent with the failure modes identified for that model.

Once the data needs are identified, the sources of raw data at the plant are identified. In most cases, the information needed may have to come from multiple sources. For example, identification of maintenance events and their duration may come from a control room log, but other sources such as maintenance work requests may be required to determine other information such as whether a component had experienced a catastrophic or degraded failure.

There are many sources of raw data at a nuclear power plant. Different plants have different means of recording information on initiating events and component failure and maintenance events. Since no one source exists at a nuclear power plant that contains all the necessary data, different sources must be reviewed. The ease in which the plant-specific data can be interpreted and the subsequent quality of the resulting parameter estimates are a function of how well the plant personnel recorded the necessary information.

Basic requirements associated with raw data sources and some typical sources of raw data available at nuclear power plants are identified in the following sections.

4.1.1 Requirements on Data Sources

There are a variety of data sources that exist at a plant and can be used in a data analysis. However, there are some basic requirements that these raw data sources should meet in order to be useful. Some typical requirements, some of which were suggested in EPRI TR-100381 (EPRI 1992), are delineated below.

4.1.1.1 Initiating Events

For reports on initiating events it is essential to include the status of those systems that would be impacted as a result of the event. This is typically not a problem since the Licensee Event Report (LER) that is required to be filed with the Nuclear Regulatory Commission (NRC) following a plant trip, usually contains this type of information. It is also common for utilities to generate additional detailed trip reports that delineate the cause and effects of the event. Such reports need to specify critical information needed for data analysis such as the power level at the time of the plant trip and the sequence of events including the timing of individual events.

4.1.1.2 Component Failures

For each event at a plant resulting in the unavailability of a component, it is necessary that the raw data sources identify the particular component or set of components associated with the event. In order to determine if a specific event contributes to a particular component failure mode or an unavailability due to the component being in maintenance (either preventive or corrective), it is necessary to be able to distinguish between different degrees of degradation or failure. The event reports should therefore specify whether maintenance was required and if the maintenance was corrective or preventive. If the component maintenance is preventive there is generally no failure that initiates the maintenance.

If an event involves corrective maintenance, information is required to allow determination of the severity of the failure (see Section 3.3 for definitions of event severity). The ability to distinguish between severity levels of failures is particularly important since the difference between the frequencies of catastrophic and degraded modes of failures can be significant. In addition, information is required to determine the component in which the failure actually occurred and the mode of failure (i.e., how the component failure revealed itself). Finally, it should be possible to determine the time the component is unavailable during each maintenance event.

The data analysis may use plant data on component unavailability that is being collected for other than PRA purposes. The requirements for recording the data for these other purposes may use definitions of severity and failure modes that are different from the PRA definitions. The definitions used for the data collection programs should be determined and an appropriate translation to the PRA basic events made.

4.1.1.3 Recovery Events

The information needed to estimate the probabilities associated with recovering specific components or systems from a failed state is similar to that needed for component failures. Specific information pertaining to the type of failure experienced by the component or system (e.g., fail to operate, fail to start, fail to run), the number of repair occurrences, and the time required to perform the repair is needed to produce component repair probabilities.

4.1.2 Data Sources

Data sources that can provide information for determining the number of initiating events include:

- internal plant failure records (e.g., scram reports or unusual event reports)
- operator logs
- LERs
- monthly operating reports/Gray Book

Some data sources that typically provide information on the occurrence of component failures include:

- LERs
- internal plant failure records (e.g., failure reports, trouble reports, or unusual event reports)
- maintenance records (e.g., maintenance work orders, work request records)
- plant logs (e.g., control room log, component history logs)
- data bases (e.g., Equipment Performance and Information Exchange System/Nuclear Plant Reliability Data System)

The evaluation of component failure rates also requires the number of demands and operating time for the components. Sources of data for these parameters include:

- monthly operating reports/Gray Book
- component history logs
- plant population lists
- test procedures
- plant operating procedures
- component demand or operating time counters

Repair information can be obtained from sources such as:

- plant logs

- maintenance work orders

The type of information available in these sources and their limitations are discussed in the following sections.

4.1.2.1 Regulatory Reports

All plants are required to submit Licensee Event Reports (LERs) to the NRC for all events meeting the 10 CFR 50.73 reporting criteria presented in NUREG-1022 (NRC 2000a). LERs deal with significant events related to the plant, including plant shutdowns required by the technical specifications, multiple train failures, engineered safety feature actuations, and conditions outside the design basis or not covered by plant procedures. An LER includes an abstract that describes the major occurrences during the event; the components, systems, or human failures that contributed to the event; the failure mode, mechanism, and effect of each failed component; and an estimate of the elapsed time from the discovery of the failure until the safety system train was returned to service. A computerized search of LER information is possible using the Sequence Coding and Search System (SCSS).

LERs generally provide a good description of the causes of a reactor trip and subsequent events. However, their value for obtaining component failure data is very limited. The reporting criteria are limited to safety-related trains or system failures and therefore, LERs are not generally submitted for all failures. Furthermore, LERs may not be submitted for every safety-related component failure since individual component failures do not have to be reported if redundant equipment in the same system was operable and available to perform the safety function. The reporting criteria for LERs are also subject to interpretation by the persons generating the reports and thus can lead to inconsistencies in the LER data base. Furthermore, there are other perceived deficiencies in the LERs (Whitehead 1993) that limit the usefulness of the LER system for use in obtaining estimates of component failure rates. The NRC staff prepared NUREG-1022, Revision 1 (Allison 1998), to address general issues in reporting that have not been consistently applied and covers some of the issues identified above.

The original LER rule published in 1983 has recently been amended and the reporting guidance in NUREG-1022, Revision 2 (NUREG 2000a) has been revised to eliminate the burden of reporting events of little or no safety significance, to better align the rules with the NRC's current needs and to clarify the reporting guidance where needed. However, the rule still only requires the reporting of failures leading to the unavailability of safety-related system trains and thus LERs will not provide failure data for all risk significant components.

In summary, LERs are a good source for identifying and grouping initiating events. However, they have very limited value for obtaining component failure data.

A plant's Technical Specifications requires that a monthly operating report be provided by the plant licensee to the NRC. The scope of the information requested of the licensees was originally identified in Draft Regulatory Guide 1.16 (NRC 1975) and includes operating statistics and shutdown experience information. The information requested to be included in the monthly operating report contents was revised by Generic Letter 97-02 (NRC 1997) and eliminated some reporting requirements. Information that still must be reported includes identification of all plant shutdowns, whether they were forced or scheduled shutdowns, their duration, the reason for the shutdown, the method of shutting down the reactor, and corrective actions that were taken. In addition, the monthly operating reports include the number of hours the reactor was critical, the number of hours the generator was on line, and the net electrical output of the plant.

The NRC initially compiled the information from the monthly operating reports on a monthly basis and published it in a hard copy form as NUREG-0020, "Licensed Operating Reactors - Status Summary Report" (NRC, 1995). This document is referred to as the "Gray Book." NUREG-0020 was discontinued after the December 1995 report. However, the data requested in Generic Letter 97-02 is being collected and computerized as part of the NRC Performance Indicator Project.

In summary, the monthly operating reports provide information on the number of scrams, the time spent at full power, and the time spent in shutdown. This information can be used in identifying and grouping initiating events and in calculating the exposure time in which they occurred. It is important to note that this same information is generally available from the control room logs and other sources. Thus, in general, the monthly operating reports can be used to supplement or verify other data sources.

4.1.2.2 Internal Plant Failure Reports

Different plants have different means of recording initiating events and component failures. For each automatic and manual scram, most plants generate an internal scram report. Scram reports generally cover the same information provided in LERs and monthly operating reports. Thus, they can be used as the primary or supplementary source for evaluating plant scrams.

Most plants have a means of recording component failures, records that are for the licensee's own use rather than for a regulatory use. Reports are generally created when significant component failures or degraded states occur during plant operation or are identified during plant surveillance tests. These reports may be called Unusual Occurrence Reports, Action Reports, Failure Reports, Discrepancy Reports, or Trouble Reports. Some of the events documented in these reports may lead to an LER. However, these reports may not identify all component failures and generally are not exhaustive. Thus, these reports are useful for supplemental information but are not a good source of component reliability data.

4.1.2.3 Plant Logs

At each plant, a control room log is typically completed for each shift and contains a record of all important events at a plant. Control room logs identify power level and plant mode changes, essential equipment status changes, major system and equipment tests, and entry and exit of Technical Specification Limiting Conditions of Operation (LCOs). When properly maintained, a control room log is a good source of information on major equipment and unit availability. However, the amount of information entered can vary from shift to shift. Furthermore, the entries tend to be brief.

The control room logs are difficult to use as a source of maintenance data since the tag-out and tag-in for a maintenance event may span days or even months and may not be dutifully recorded. The control room logs are also limited in value as a source of component failure data since not all failures may be recorded by the operators. Component maintenance and failure information is generally found more easily in maintenance work orders. All plant trips are likely to be recorded on control room logs, but likely will not include a description of the cause of the trip or the subsequent transient behavior. LERs or plant scram reports must be reviewed to obtain this additional information.

In summary, control room logs are good supplementary sources of information but there are usually more convenient and complete sources of information available. However, the control room logs are probably the best source of data for indicating when redundant system trains are switched from operating to standby status.

There may be other logs at a plant that contain essential data. One example is a component history log. These logs typically contain data on every failure and maintenance and test action for a given component. As such, component history logs are good sources for identifying not only the number of component failures, but also the number of demands a component experiences.

4.1.2.4 Maintenance Records

At all plants, some form of written authorization form is required to initiate corrective or preventative maintenance work, or design changes. These authorization forms are known under different names at various plants including work request/completion records, maintenance work orders, clearance requests, work requests, or tag-out orders. Maintenance records are a primary source of component failure data since they usually identify the component being maintained, whether the component has failed or is degraded, the corrective action taken, and the duration of the maintenance action. The time of the failure is also available but maintenance records generally contain limited information on the impact, cause, and method of discovery of the component failure.

4.1.2.5 Component Exposure Data Sources

Calculation of plant-specific failure rates requires determination of the number of failures and the corresponding number of demands or operating time. As indicated in the previous subsections, some of the data sources used to establish the number of failures also contain information on the number of demands and operating time. However, these sources do not contain all component demands or the operating time for all components. Additional documents that must be reviewed for information about component demands and operating hours include test procedures.

In addition to demands presented by automatic initiations and maintenance activities (obtained from sources such as control room logs and maintenance records), periodic testing is an important source of demands especially for safety-related equipment. To establish the number of demands due to testing, testing procedures pertinent to a component must be reviewed. In addition to the actual test demands, additional test demands may be imposed by technical specifications following failure of a component. A typical example where this is imposed is when a diesel generator is unavailable for operation. Test logs or similar records can be examined to obtain an estimate of the number of tests carried out during the time period of interest.

It should also be noted that at some plants, some major components may be monitored to count the number of actuations experienced by the breakers (breaker cycle counters). In addition, the operating hours for large motor-driven components at some plants may be automatically registered on running time meters at the electrical switchgear. Such counters and logs can be used to supplement the demand and operating time information obtained from other sources.

4.1.3 Plant-Specific Data Bases

The Institute of Nuclear Power Operations (INPO) has maintained several databases of component failure data provided by each nuclear power plant since 1984. The first, Nuclear Plant Reliability Data System (NPRDS), was a proprietary computer based collection of engineering, operational, and failure data on systems and components in U.S. nuclear power plants through 1996. The second, the Equipment Performance and Information Exchange (EPIX) System replaced NPRDS and includes data reported since 1987. Both data bases are discussed in the following sections.

4.1.3.1 Nuclear Plant Reliability Data System

In the early 1970s, industry committees of the American National Standards Institute (ANSI) and the Edison Electric Institute (EEI) recognized the need for failure data on nuclear plant components. As a result, a data collection system was developed whose objective was to make available reliability statistics (e.g., failure rates, mean-time-between-failures, mean-time-to-restore) for safety related systems and components.

This system, the Nuclear Plant Reliability Data System (NPRDS) (Tushjian 1982), was developed by Southwest Research Institute (SwRI). Plants began reporting data on a voluntary basis in 1974, and continued reporting to SwRI until 1982. In January 1982, the INPO assumed management responsibility for the system until reporting was terminated at the end of 1996.

Originally the scope of the NPRDS covered the systems and components classified by ANSI standards as Safety Class 1, 2, or 1E, with a few exceptions such as reactor vessel internals and spent fuel storage. However, later the scope was expanded to cover any system important to safety and any system for which a loss of function can initiate significant plant transients (Simard 1983). By the end of 1984, 86 nuclear power plant units were supplying detailed design data and failure reports on some 4,000 - 5,000 plant components from 30 systems (Simard 1985).

Data reported to NPRDS consisted of two kinds–engineering reports and failure reports. The engineering reports provided detailed design and operating characteristics for each reportable component. The failure reports provided information on each reportable component whenever the component was unable to perform its intended function. The same operational data contained in the NUREG-0200 was also included in the system. The NPRDS failure reports provided to INPO were generally generated by plant licensees utilizing maintenance records such as maintenance work orders. These reports utilized a standard set of component boundaries and failure mode definitions.

Limitations in the Data Available from the NPRDS

Several issues regarding the quality and utility of the NPRDS data have been observed, including:

(1) Input to NPRDS was discontinued on December 31, 1996.
(2) The number of component demands is provided by estimation.
(3) The exposure time is estimated.
(4) The amount of time needed to repair components out for corrective maintenance is not provided.
(5) Maintenance rates are not provided.
(6) The voluntary nature of the reporting system introduces uncertainty into measuring the frequency at which a particular type of problem occurs.
(7) The final results of a problem investigation or the ultimate corrective action taken are not always included.
(8) Report entries tend to be brief and often do not provide enough information to identify the exact failure mechanism.

4.1.3.2 Equipment Performance and Information Exchange System (EPIX)

The need for high-quality, plant-specific reliability and availability information to support risk-informed applications was one impetus for a proposed reliability data rule by the NRC to require utilities to provide such information. Instead of a regulatory rule, the nuclear industry committed to voluntarily report reliability information for risk-significant systems and equipment to the Equipment Performance and Information Exchange (EPIX) System. EPIX is a web-based database of component engineering and failure data developed by INPO to replace NPRDS. The utilities began reporting to EPIX on January 1, 1997.

EPIX enables sharing of engineering and failure information on selected components within the scope of the NRC's Maintenance Rule (10CFR 50.65) and on equipment failures that cause power reductions. It also provides failure rate and reliability information for a limited number of risk-significant plant components. This includes components in the systems included in the scope of the Safety System Performance Indicator (SSPI) program. EPIX consists of:

- a site-specific database controlled by each INPO member site with web-based data entry and retrieval,
- an industry database on the INPO web site where selected parts of the site-specific database are shared among plants, and
- a retrieval tool that provides access to the vast historical equipment performance information available in the NPRDS.

Events reported to EPIX include both complete failures of components and degraded component operation. The number of demands and operating hours (i.e., reliability data) and the unavailability are required to be collected for key components in the SSPI safety systems for each plant. In addition, contributors to EPIX are also to include one time estimates of the number of demands and run hours for other risk-significant components not included in SSPI systems.

4.1.3.3 Reliability and Availability Data System (RADS)

The NRC has developed the Reliability and Availability Data System (RADS) to provide the reliability and availability data needed by the NRC to perform generic and plant-specific assessments and to support PRA and risk-informed regulatory applications. The NRC is incorporating data from EPIX and INPO's Safety system Performance Indicator system along with information from other data sources (e.g., LERs and monthly operating reports,) into RADS. Data is available for the major components in the most risk-important systems in both BWRs and PWRs.

The reliability parameters that can be estimated using RADS are:

- probability of failure on demand,
- failure rate during operation (used to calculate failure to continue operation probability)

- maintenance out-of-service unavailability (planned and unplanned), and
- time trends in reliability parameters.

The statistical methods available in RADS include classical statistical methods (maximum likelihood estimates and confidence intervals), Bayesian methods, tests for homogeneity of the data for deciding whether to pool the data or not, Empirical Bayes methods, and methods for trending the reliability parameters over time.

4.2 Generic Data Sources

Several generic data sources currently available and used throughout the nuclear power PRA industry are identified in this section. Several of these data bases are discussed with regard to their attributes, strengths, and weaknesses. Data bases for both initiating events and component failure rates are included. Some data sources represent compilations of raw data which has been collected directly from various facilities and processed and statistically analyzed. Other data sources utilize the results of the statistical analyzes of other data bases to derive estimates for component probabilities.

Section 4.2.1 contains discussions and summaries of generic data bases sponsored by the NRC for use in both government and industry PRAs. Section 4.2.2 contains discussions and summaries of generic data bases sponsored by the Department of Energy (DOE) for use in PRAs. Section 4.2.3 contains discussions and summaries of generic data bases developed by nuclear power industry related organizations. Section 4.2.4 contains a summary of a foreign data base, the Swedish T-book. Section 4.2.5 contains a discussion of several non-nuclear data bases which could be useful for some data issues in nuclear power PRA.

4.2.1 NRC-Sponsored Generic Data Bases

The discussion of NRC-sponsored generic data bases is presented in two sections. The first discusses current data bases. These data sources are deemed appropriate for current and future use. The second section briefly summarizes some historical data bases that have been used or referenced in past analyses. **While useful at the time, these data bases are no longer considered appropriate sources of information.**

4.2.1.1 Current Data Bases

Current NRC-sponsored data bases are discussed in the following subsections. Major attributes for each data base are identified, and limitations associated with each data base are provided.

As a reminder, these data bases are considered to be appropriate sources of information for use in PRAs or other risk assessments. However, it is the user's responsibility to ensure that any information from these data bases used in their analysis is appropriate for their analysis.

4.2.1.1.1 Severe Accident Risks Study Generic Data Base (NUREG-1150)

The generic data base developed for the NRC's Severe Accident Risks study (NUREG-1150) (NRC 1990) is documented in NUREG/CR-4550 as supporting documentation (Drouin et al. 1987). This data base was developed from a broad base of information, including:

- WASH 1400 (NRC 1975),
- the IREP data base (Carlson et al. 1983),
- Zion (ComEd 1981), Limerick (PECO 1982), Big Rock Point (CPC 1981), and the Reactor Safety Study Methodology Application Program (RSSMAP) PRAs (Hatch et al. 1981),
- NRC LER summaries (Hubble and Miller 1980, Appendices O through Y), and
- the NRC's Station Blackout Accident Analysis (Kolaczkowski and Payne 1983).

Component failure probabilities, failure rates, and initiating event frequencies typically modeled in the NUREG-1150 plant analyses are included in the data base. A mean value and an error factor on a log normal distribution are provided for each entry into the data base.

Limitations in the Data Available from NUREG-1150

The basis of the NUREG-1150 data base is from a broad group of prior PRA analyses and generic data bases. Thus, it does not directly represent the results of the analysis of actual operational data. Furthermore, the data upon which those previous analyses are based suffer from limitations similar to those for older NRC data sources and the NPRDS data base (Sections 4.2.1.2 and 4.2.3.1).

4.2.1.1.2 Evaluation of Loss of Offsite Power Events at Nuclear Power Plants: 1980 - 1996

The report, *Evaluation of Loss of Offsite Power Events at Nuclear Power Plants: 1980 - 1996*, NUREG/CR-5496 (Atwood et al, 1998), presents an analysis of loss of offsite power (LOSP) initiating event frequency and recovery times for power and shutdown operations at commercial nuclear power plants. The evaluation is based on Licensee Event Reports (LERs) for events that occurred during 1980 through 1996. The primary objective of the study was to provide mean and uncertainty information for LOSP initiating event frequencies and recovery times. A secondary objective was to re-examine engineering insights from NUREG-1032 (a LOSP study covering the years 1968 through 1985) using the more recent data.

The major findings of the report are:

- Not all LOSP events that occur at power result in a plant trip.
- Plant-centered events clearly dominate the LOSP frequency during both power and non-power operational modes.
- Plant-centered LOSP frequency is significantly higher during shutdown modes than during power operation.
- No statistically significant variation among units was found for plant-centered sustained initiating events.
- During shutdown, statistically significant variation among plants was found for plant-centered sustained initiating events.
- Equipment faults were the main contributor (58%) to plant-centered LOSP initiating events that occurred during power operations. Human error accounted for a smaller contribution (23%).
- During shutdown conditions, human error was the dominant contributor (58%).
- A clear downward trend can be seen for the plant-centered initiating event frequency.
- Grid related LOSP frequency is small.
- For severe weather, statistically significant site-to-site variability exists for sustained shutdown LOSP frequencies.
- Severe weather events had significantly longer sustained recovery times.
- For sustained recovery times, no pattern was found correlating unit design class with longer recovery times.
- Longer recovery times were observed for sustained plant-centered LOSP events that did not result in a plant trip or that occurred during shutdown.

Nominal frequencies and upper and lower bounds are given in the report.

Limitations in the Data Available from NUREG/CR-5496

The generic data base developed in this NRC sponsored data study is based on raw data from LERs. LERs constitute data only involving reportable events at nuclear power plants, and the degree of detail provided in the LERs varies. Some information needed in the data analysis had to be estimated (e.g., allocation of 1980 time into critical and shutdown time), and the analysis ended with events that occurred in 1996. Thus, the data base does not contain events that occurred after 1996, and may not be representative of actual current operational experience.

4.2.1.1.3 Rates of Initiating Events at U.S. Nuclear Power Plants: 1987 - 1995

The report, *Rates of Initiating Events at U.S. Nuclear Power Plants: 1987 - 1995*, NUREG/CR-5750 (Poloski 1999a), presents an analysis of initiating event frequencies at domestic nuclear power plants. The evaluation is based primarily on the operational experience from 1987 through 1995 as reported in LERs. The objectives of the study were to :

- provide revised frequencies for initiation events in domestic nuclear plants,
- compare these estimates to estimates used in PRAs and Individual Plant Evaluations (IPEs), and
- determine trends and patterns of plant performance.

Major findings of the report are:

- Combined initiating event frequencies for all initiators from 1987 - 1995 are lower than the frequencies used in NUREG-1150 (NRC 1990) and industry IPEs by a factor of five and four, respectively.
- General transients constitute 77% of all initiating events, while events that pose a more severe challenge to mitigation systems constitute 23%.
- Over the time period of the study, either a decreasing or constant time trend was observed for all categories of events.
- LOCA frequencies are lower than those used in NUREG-1150 and industry IPEs.

Nominal frequencies and upper and lower bounds are given in the report.

Limitations in the Data Available from NUREG/CR-5750

The generic data base developed in this NRC sponsored data study is primarily based on raw LER data from 1987 through 1995. For some events (e.g., LOCAs) information from additional operating experience, both domestic and foreign, was used with other sources of information (e.g., engineering analyses) to estimate the initiating event frequencies. Since the analysis ended with events that occurred in 1995 and made use of other sources of information, the data base and may not be representative of actual current operational experience.

4.2.1.1.4 System Reliability Studies

A series of system reliability studies, documented in the multi-volume NUREG/CR-5500 report[1], presents an analysis of system unreliability for various systems.[2] The following volumes comprise the systems that will be studied:

- Volume 1: auxiliary/emergency feedwater system (Polaski et al. 1998)
- Volume 2: Westinghouse reactor protection system (Eide et al. 1999a)
- Volume 3: General Electric reactor protection system (Eide et al. 1999b)
- Volume 4: high-pressure coolant injection system (Grant et al. 1999a)
- Volume 5: emergency diesel generator power system (Grant et al. 1999b)
- Volume 6: isolation condenser system (Grant et al. 1999c)
- Volume 7: reactor core isolation cooling system (Poloski et al. 1999b)
- Volume 8: high-pressure core spray system (Poloski et al. 1999c)
- Volume 9: high pressure safety injection system (Poloski et al. 2000)
- Volume 10: CE reactor protection system (Wierman et al. 2002a)
- Volume 11: B&W reactor protection system (Wierman et al. 2002b)

With the exception of the reactor protection system volumes, the analyses of the other systems are based on information obtained from LERs. For the reactor protection system volumes, the analyses are based on information obtained from NPRDS and LERs.

The analyses: (1) estimate the system unreliability based on operating experience, (2) compare the estimates with estimates using data from PRAs and IPEs, (3) determine trends and patterns in the data, and (4) provide insights into the failures and failure mechanisms associated with the system.

Unreliability estimates (means and distributions) are provided for the entire system for each plant. In addition, unreliability estimates for major train

[1] Currently, it is expected that some of these reports will be updated with new information.

[2] Train, subsystem or system data can be combined with basic event failure data to obtain improved estimates of component failure rates. A Bayesian method for doing this is described in Martz and Almond 1997.

segments failure modes (e.g., failure to start–pump, driver, valves, and associated piping) are provided. Common cause failure estimates are also provided.

Limitations in the Data Available from NUREG/CR-5500

The information available from this NRC sponsored data study is based on that available from LERs and NPRDS. LERs constitute data only involving reportable events at nuclear power plants, and the degree of detail provided in the LERs varies. The limitations associated with NPRDS are provided in Section 4.2.3.1. The information used in the studies spans various time frames, with the most up to date information coming from 1997. Thus, the results of the studies may not be representative of actual current operational experience.

4.2.1.1.5 Component Performance Studies

A series of component performance studies, documented in the multi-volume NUREG-1715 report, presents an analysis of component performance for various components. The following volumes comprise the components that have been studied:

- Volume 1: turbine-driven pumps (Houghton and Hamzehee 2000a)
- Volume 2: motor-driven pumps (Houghton and Hamzehee 2000b)
- Volume 3: air-operated valves (Houghton 2001a)
- Volume 4: motor-operated valves (Houghton 2001b)

The analyses are based on information obtained from NPRDS and LERs. The data included in the studies cover the period 1987 through 1995

The analyses: (1) estimate the system-dependent unreliability of selected components, (2) compare the estimates with estimates from PRAs and IPEs, (3) determine trends and patterns in the data, and (4) provide insights into component performance, including component failure mechanisms.

System-dependent unreliability estimates (means and distributions) for various failure mechanisms are provided for each component. Trends in component failure rates were also evaluated in these studies.

Limitations in the Data Available from NUREG-1715

The information available from this NRC sponsored data study is based on that available from LERs and NPRDS. LERs constitute data only involving reportable events at nuclear power plants, and the degree of detail provided in the LERs varies. The limitations associated with NPRDS are provided in Section 4.2.3.1. The information used in the studies spans various time frames, with the most up to date information coming from 1998. Thus, the results of the studies may not be representative of actual current operational experience.

4.2.1.2 Historical Data Bases

In the past, NRC sponsored several programs to develop data bases on nuclear power plant component reliability and initiating event frequencies. These programs included:

- In-Plant Reliability Data Base for Nuclear Power Plant Components (IPRDS) (Drago 1982) - established at Oak Ridge National Laboratory to establish methods for data collection and analysis.
- Nuclear Reliability Evaluation Program (NREP)- generic data base developed to support the Probabilistic Safety Analysis Procedures Guide, NUREG/CR-2815 (Papazoglou 1984).
- Interim Evaluation Program Generic Data Base (IREP) - developed to support the performance of five PRAs in the 1980s and documented in the IREP procedures guide (Carlson et al. 1983).
- Nuclear Computerized Library for Assessing Reactor Reliability (NUCLARR) - developed as a repository of human error and hardware failure information that could be used to support a variety of analytical techniques for assessing risk. NUCLARR was documented in five volumes as NUREG/CR-4639 (Gertman et al. 1990).

Major attributes for each program and the resulting data bases are documented in the cited references.

4.2.2 DOE-Sponsored Generic Data Bases

Several data bases have been developed to support DOE-sponsored projects. Two of these data bases are discussed in the following sections.

4.2.2.1 Component External Leakage and Rupture Frequency Estimates

Estimates of external leakage and rupture frequencies for components such as piping, valves, pumps, and flanges are necessary for detailed risk analysis of internal flooding. These estimates have been developed and documented in EGG-SSRE-9639 (Eide et al. 1991). The estimates are based on an analysis of data gathered from a comprehensive search of LERs contained in Nuclear Power Experience (NPE) (Hagler-Bailly 1972).

The NPE data base was searched for data covering the period September 1960 through June 1990. The external leakage and rupture events collected from the data were converted to component leakage and rupture frequencies in a three-step process:

- The ratios of external rupture events to external leakage and rupture events were examined for various components by size and system to decide how to group the data.
- The final probabilities of an external rupture, given an external leakage or rupture event, were determined.
- Lastly, the external leakage and rupture frequencies were obtained by estimating component populations and exposure times.

Limitations in the Data Available from EGG-SSRE-9639

The generic data base developed in this DOE sponsored data study is based on raw LER data from 1960 through 1990. LERs constitute data only involving reportable events at nuclear power plants, and the degree of detail provided in the LERs varies. Since the analysis ended with events that occurred in 1990, the data base and may not be representative of actual current operational experience.

4.2.2.2 Generic Component Failure Data Base for Light Water and Liquid Sodium Reactor PRAs

A generic component failure data base was developed by INEL for light water and liquid sodium reactor PRAs. This data base is documented in EGG-SSRE-8875 (Eide et al. 1990). The intent of this project was to base the component failure rates on available plant data as much as possible rather than on estimates or data from other types of facilities. The NUCLARR data base (see Section 4.2.1.1.4) and the Centralized Reliability Data Organization (CREDO) (Manning et al. 1986) were used as the primary sources of component failure data. If specific components and failure modes were not covered in those two sources, then other standard sources such as IEEE STD-500 (IEEE 1983) (for electrical components) and WASH-1400 (NRC 1975) were used. The data base is organized into four categories according to the working fluid of the component:

- mechanical components (water or steam),
- mechanical components (liquid sodium),
- mechanical components (air or gas), and
- electrical components.

Limitations in the Data Available from EGG-SSRE-8875

The generic data base developed in this DOE sponsored data study is based on information from multiple sources. Since the analysis ended with events that occurred in 1990, the data base and may not be representative of actual current operational experience.

4.2.3 Industry Data Bases

Several data bases developed within the nuclear power industry for both risk assessment and for plant operations are summarized here. Data bases discussed in this section were developed by EPRI and the consulting firms of EQE, International and Science Applications International Corporation.

Although the NPRDS and EPIX data bases (described in Section 4.1.3) contain plant-specific data, they can be used to generate generic failure rates for components. Methods for aggregating individual plant data to estimate failure rates are described in Section 8.2 of this handbook. Aggregation of data from EPIX can be performed using the RADS software developed under the NRC auspice.

4.2.3.1 EQE, International

The EQE, International generic data base (formerly known as the Pickard, Lowe, and Garrick or PLG data base) for light water reactors is set up to support PRA and reliability analysis for which both point estimates and uncertainty distributions are developed[3]. The data base contains information on:

- Component failure rates,
- Common cause failures,
- Component maintenance frequencies and mean durations,
- Initiating events,
- Fire and flood events at nuclear sites,
- Shutdown events involving loss of RHR cooling and loss of inventory.

The fire, flood and shutdown events are a compendium of experience event summaries from all U.S. nuclear sites. The common cause data are presented as event description and have been classified according to the methodology of NUREG/CR-4780 (Mosleh et al. 1989). The fire, flood, shutdown and common cause events have, in addition to the description, information in various fields making them convenient for sorting and for use in plant-specific screening analysis.

All other data are in the form of distributions and are compatible with the PLG risk assessment software, RISKMAN® . These distributions are generated using the data analysis module of RISKMAN® which can be used as a stand-alone software. The distributions developed are available to the other modules of RISKMAN® used for fault-tree quantification and core damage sequence quantification (PLG 1998).

The actuarial data are from over 20 nuclear sites in the U.S. and in Europe. Other sources of generic information also used are:

- EPRI reports on components, shutdown accident events, initiating events, loss of offsite power.
- Special NUREG reports on components such as pumps, valves, diesel/generators.
- Compiled data bases such as Nuclear Power Experience, NUCLARR, IEEE-500 (IEEE 1983), NPRDS, etc.
- Insurance company databases for loss events.

The database includes statistics for components that cover population, demands, operating times, failures, maintenance outages and durations at specific plants. It also includes event-by-event analyses for initiating events, common cause failures, and fires and floods over the whole U.S. plant population. In addition to this factual information, parameter estimates from published sources of generic reliability data are also provided.

The actuarial data and the other generic data are combined using a two-stage Bayesian updating technique. The generic distributions maintain what is referred to as “plant-to-plant variability. Since the data are developed specifically to be used for Monte Carlo sampling, they are defined with a minimum of 20 discrete bins with special attention given to the tails of the distributions.

The database is available in a format compatible with RISKMAN® and also as ASCII files.

Limitations in the Data Available from EQE, International

The EQE data base is proprietary, so the adequacy and comprehensiveness of the underlying data have not been evaluated for this document. As noted above, several of the sources of generic information incorporated into the data base are discussed previously in this chapter (e.g., NUCLARR, NPRDS), thus it is possible that some of the data from the EQE data base may have limitations similar to other data bases discussed in this chapter. However, it should be noted that the proprietary nature of the EQE data base precludes any definitive judgement as to how data bases such as NUCLARR and NPRDS were utilized in

[3] The information on the EQE/PLG data base is based on personal correspondence from Shabha Rao, PLG, Newport Beach, California, to Timothy Wheeler, Sandia National Laboratories, September 16, 1999 and to Donnie Whitehead, Sandia National Laboratories, April 4, 2001.

the development of the EQE database.

4.2.3.4 Science Applications International Corporation

Science Applications International Corporation (SAIC) has developed a generic, proprietary data base for application to PRAs on commercial nuclear power plants.[4]

The scope of the data base for components and their failure modes was established by a review and tabulation of all basic events and component failures in SAIC conduced PRAs. Components were grouped into generic categories rather than specifically by system or application. Thus, all basic events for motor-driven pumps were categorized into a single "motor-driven-pump" category rather than delineated size or by system. Some component failure modes were merged to reflect the available data (e.g., air-operated valves fail-to-open and fail-to-close were combined into a single failure mode–fail-to-operate. Component boundary definitions are given for all components in the SAIC generic data base.

The data base was developed by collecting all sources of available parameter estimates relevant to the component failures defined by the scoping process. Each data source was evaluated against a set of acceptance criteria, including availability (no proprietary sources were included), compatibility of data to being fit to a log-normal distribution, and Bayesian updating. Any source which used Bayesian parameter estimation methods to develop estimates for component failure modes were rejected. Such data sources were considered to be too plant-specific for inclusion into a generic data base.

Each individual data source selected against the acceptance criterial was fitted to a log-normal distribution. Then, all data sources for each particular component failure were aggregated through a weighted sum approach (each source was weighted equally). Each aggregated distribution was fitted to a log-normal distribution.

Limitations in the Data Available from the SAIC Data Base

The SAIC data base is proprietary, so the adequacy and comprehensiveness of the underlying data has not been evaluated for this document.

4.2.3.3 Advanced Light Water Reactor Data Base

EPRI's Advanced Light Water Reactor (ALWR) Utility Requirements Document (EPRI 1989) contains a reliability data base for use in ALWR PRAs. Several data sources were reviewed and representative failure rates and event probabilities were compiled from these data sources. A best estimate value was selected for each component type and failure mode based on judgment regarding the applicability of the data source to the expected ALWR design. The primary sources used in the data survey were the Oconee PRA (Duke 1984), the Seabrook Probabilistic Safety Study (PLG 1983), parameter estimates from licensee-event reports documented in NUREG/CR-1363 (Battle 1983) for valves, NUREG/CR-1205 (Trojovsky 1982) for pumps, and NUREG/CR-1362 for diesel generators (Poloski and Sullivan 1980).

Limitations in the Data Available from the ALWR Data Base

The ALWR data base lists only best estimates for each initiating event, failure rate, and event probability. The survey is well documented in that all estimates collected for each parameter estimate are shown. However, only a cursory statement of rationale for deriving the best estimate value is given. No uncertainty bounds or probability density functions are given.

4.2.4 Foreign Source

Two sources of data from Nordic nuclear power plants are available. The I-book documents initiating event frequency data and the T-book documents component failure data.

[4] The information on the SAIC data base is based on a personal correspondence from Alan Kolaczkowski, Vice President, SAIC, to Donnie Whitehead, Sandia National Laboratories, April 18, 2001.

4.2.4.1 Sweden's T-Book for Nordic Nuclear Power Plants

Since the early 1980's a Reliability Data Handbook, the T-Book (ATV 1992) has been developed and used for nuclear power plant of Swedish design. The T-Book provides failure data for the calculation of component reliability for use in regulatory safety analyses of nordic nuclear power plants. The 3rd edition is based on operation statistics from 12 Swedish and two Finnish nuclear power plants, including approximately 110 reactor years of experience.

The failure characteristics incorporated into the parameter estimations in the T-book are based on Licensee Event Reports delivered to the Swedish Nuclear Power Inspectorate (SKi) and from failure reports in ATV's central data base. Only critical failures, those that actually caused a component's function to stop or fail, are incorporated into the parameter estimations. A multistage empirical Bayesian approach is used to develop the component parameter estimates from the raw data (Pörn 1996).

Limitations in the Data Available from the T-Book

Data for the T-Book collected from LERs delivered to the SKi, thus the parameter estimates derived from the data are based only on data of reportable incidents. It is not understood how representative such data may be of actual operational experience.

4.2.4.2 Sweden's I-Book for Nordic Nuclear Power Plants

The I-Book (Pörn 1994) contains a compilation of initiating events that have occurred in Nordic nuclear power plants. The data reflects 215 reactor years of operating experience prior to 1994. In the first edition of the I-Book, issued in 1993 (Pörn 1993), initiating event groups were identified and frequencies generated. The operating experience from two additional plants in Finland were included in the second edition (Pörn 1994).

The I-Book includes the development of a statistical model for performing a trend analysis. The model is based on nonhomogeneous Poisson (Power Law) processes and includes a complete treatment of parametric uncertainty using Bayesian methods.

Limitations in the Data Available from the I-Book

Data for the I-Book is collected from operating experience at Nordic plants. It is not understood how representative such data may be of operational experience in nuclear power plants in the U.S.

4.2.5 Non-Commercial Nuclear Power Plant Data Bases

There are many non-nuclear data bases that contain failure data that can potentially be used in nuclear power plant PRAs. Several of these data bases are described below. When using data from non-commercial nuclear sources, care must be taken to ensure that the data are for components and conditions representative of those that exist in nuclear power plants.

4.2.5.1 Reliability Analysis Center

The Reliability Analysis Center (RAC) in Rome, New York, maintains two data bases on electronic and non-electronic component reliability. The data bases are:

- Electronic Parts Reliability Data (Denson et al. 1997), and
- Non-Electronic Parts Reliability Data (Denson et al. 1995).

These RAC databases provide empirical field failure rate data on a wide range of electronic components and electrical, mechanical, and electro mechanical parts and assemblies. The failure rate data contained in these documents represent cumulative compilation from the early 1970s up to the publication year for each document. Data are collected from sources such as:

- published reports and papers,
- government-sponsored studies,
- military maintenance data collection systems,
- commercial/industrial maintenance databases,
- direct submittals to the RAC from military or commercial organizations that maintain failure data bases.

Limitations in the Data Available from the RAC Handbooks

The RAC handbooks provide point estimate parameter estimations for failure rates (or demand probabilities). No treatment of uncertainty is provided.

4.2.5.2 Offshore Reliability Data Project

The Offshore Reliability Data (OREDA) project has collected and processed data from offshore oil platforms operated by 10 different companies off the coasts of the U.K., Italy, and Norway. Reliability data collected and processed by OREDA has been published in the Offshore Reliability Data Handbook (Det Norske Veritas 1997). The main objective of OREDA is to collect reliability data for safety important equipment in the offshore oil industry.

Components and systems for which data are collected are:

- Machinery
  - Compressors
  - Gas turbines
  - Pumps
- Electric generators
- Mechanical Equipment
  - Heat exchangers
  - Vessels
- Control and Safety Equipment
  - Control Logic Units
  - Fire and Gas Detectors
  - Process sensors
- Valves
- Subsea Equipment
  - Control Systems
  - Well completions

Data have been collected from 7,629 individual equipment units (e.g., individual pumps, valves, motors) over a total observation period of 22,373 years. The records include 11,154 failures.

Under each category of equipment (e.g., Machinery) information is collected on each type of component (e.g., centrifugal compressors). Data are further sorted by a component's driving mechanism (e.g., electric motor-driven), by failure mode (e.g., fails-to-start, fails-while-running), and by the criticality of each failure (e.g., critical - terminates the operation of the component, degraded - component still operates).

The OREDA-97 handbook presents failure rate and demand failure probability estimates for various combinations of component function, application, capacity, operating fluid, and size.

Limitations in the Data Available from the OREDA Data Base

Certain data quality issues have arisen in the development of OREDA (Sandtorv et al. 1996). The quality and availability of data can vary significantly among the 10 participating companies. Interpretations of equipment definitions and failure mode specifications can vary among the participants as well, affecting the quality of data. The effect of preventive maintenance on equipment reliability is difficult to measure. Since preventive maintenance practices vary among the participating companies it is unclear as to what would be the baseline rate of a generic type of equipment.

4.2.5.3 IEEE-500 Standard

The Institute of Electrical and Electronic Engineers (IEEE), Inc Standard 500-1984 (IEEE 1983) contains failure estimates for various electrical, electronic, sensing, and mechanical components. Delphi procedures (an elicitation process) were used in producing component failure estimates. Multiple sources of information, including nuclear, fossil fuel, and industrial, were considered by the experts as part of the Delphi process.

Limitations in the IEEE-500 Data Base

The major limitations associated with the IEEE-500 data base are 1) the data base contains dated material (i.e., the latest information used to develop the data base comes from the early 1980s), and 2) the process used to support development of the failure estimates was a non controlled process (A survey was sent to various individuals requesting them to provide information on selected issues. No inherent controls were placed on the individuals, and no training on how to estimate failure probabilities was provided to the individuals filling out the survey forms.). In addition, it should be noted that IEEE Standard 500-1984 has been withdrawn and is no longer available from IEEE.