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Fire Events - Update of U.S. Operating Experience, 1986 – 1999

Commercial Power Reactors

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ABSTRACT

This report documents an update of fire events from nuclear power plant operating experience from 1986 through 1999 and provides estimates of fire event frequencies for selected plant areas.

This report updates the Office for Analysis and Evaluation of Operational Data (AEOD) report AEOD/S97-03, "Special Study, Fire Events - Feedback of U.S. Operating Experience," June 1997, by adding the following to the database: Licensee Event Reports (LERs) (1996-1999); fire event-related component failures from the Equipment Performance and Information Exchange (EPIX) system, including Nuclear Plant Reliability Data System (NPRDS) fire event archival data for 1995-1996 and EPIX fire event data for 1997–1999; previously excluded short duration fire events from the Electric Power Research Institute (EPRI) database (1968–1988) for 1986–1988 survey data; and new survey reported fire event data from the National Electrical Insurance Limited (NEIL) database for 1993–1999. Using LERs and NPRDS/EPIX, the smoke event data were updated for the 1986–1999 period.

This report provides: (1) a proprietary updated fire events database (1986–1999); (2) fire event and data source histograms for power operation, shutdown, and total (1986–1999); (3) fire frequencies by plant location for power operation, shutdown, and total (1993–1999); and (4) an updated smoke events database (1986–1999).

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EXECUTIVE SUMMARY

This report documents an analysis of fire events covering operating experience from 1986 through 1999 and characterizes the frequency and nature of the fire events.

This report updates the Office for Analysis and Evaluation of Operational Data (AEOD) report AEOD/S97-03, "Special Study, Fire Events – Feedback of U.S. Operating Experience," June 1997 (Ref.1), by adding: short duration fire events, 1986–1995; Licensee Event Reports (LERs) (1996–1999); fire event-related component failures from the Equipment Performance and Information Exchange (EPIX), including Nuclear Plant Reliability Data System fire event archival data for 1995–1996 and EPIX fire event data for 1997–1999; additional short duration fire events from the Electric Power Research Institute (EPRI) database for 1986–1988, and survey reported fire event data from the National Electrical Insurers Limited (NEIL) proprietary database for 1993–1999. An updated proprietary fire events database was developed from these sources as a basis for fire frequency analyses in this report. Using LERs and NPRDS/EPIX smoke event data from 1995–1999, an update of the smoke events listing was made for the 1986–1999 period.

This report identified the following summary of results:

- Despite the inclusion of small, short-duration fires excluded in the original report, the power operation fire frequencies for all locations were generally lower than the corresponding frequencies estimated in the initial report (1986–1994). The fire frequencies for power operation, shutdown, and total by plant location are summarized in Tables ES-1, ES-2, and ES-3, respectively.

- The number of fire events and associated fire frequencies by plant location were generally higher for shutdown than for power operation.

- For shutdown operation, no fires were reported for the cable spreading room or the battery room for the updated period, 1986–1999. For power operation, no fires were reported for the same locations for 1989–1999.

- The updated smoke events data (1995–1999) indicated that there were no smoke events where the extent of smoke was heavy. Only one smoke event involved an evacuation. It was due to carbon dioxide mixed with light smoke in the circulating water fire pumphouse.

- For power operation, small fires of short duration (less than 20 minutes) dominated. The majority of those small fires have a duration of less than 5 minutes (45%).

- For power operation fires, portable fire extinguishers were the major means of suppression (35%), with most of the remaining suppression means consisting of self extinguished (18%) and power source removed (15%).

- Excluded from the scope of this study are:

  - A risk significance evaluation of the fire event data or the updated ignition fire frequencies. In fire risk assessments, the severity of the fire events are first evaluated, and the fire ignition frequencies are adjusted appropriately.

  - Fire severity, risk implications, and duration of power operation fire events were not updated from the initial study (Ref.1).

Table ES–1. Power Operation Fire Frequencies by Plant Location

Plant Location	Fire Frequency		
	5% Lower Bound	Mean	95% Upper Bound
Containment	1.2e-05	3.0e-03	1.1e-02
Reactor Building	1.1e-04	2.8e-02	1.1e-01
Aux. Building	1.0e-04	2.7e-02	1.0e-01
Turbine Building	1.6e-04	4.1e-02	1.6e-01
Control Room	2.8e-05	7.2e-03	2.8e-02
Cable Spreading Room	3.3e-06	8.4e-04	3.2e-03
Switchgear Room	2.0e-05	5.1e-03	1.9e-02
EDG Building	5.3e-05	1.4e-02	5.2e-02
SWS Pumphouse	2.8e-05	7.2e-03	2.8e-02
Switch Yard	7.0e-05	1.8e-02	6.8e-02
Battery Room	3.3e-06	8.4e-04	3.2e-03

Table ES–2. Shutdown Fire Frequencies by Plant Location

Plant Location	Fire Frequency		
	5% Lower Bound	Mean	95% Upper Bound
Containment	8.93-04	2.3e-01	8.7e-01
Reactor Building	1.3e-03	3.3e-01	1.3e+00
Aux. Building	1.1e-03	2.8e-01	1.1e+00
Turbine Building	1.4e-03	3.6e-01	1.4e+00
Control Room	8.9e-05	2.8e-02	8.7e-02
Cable Spreading Room	1.3e-05	3.2e-03	1.2e-02
Switchgear Room	2.0e-04	5.2e-02	2.0e-01
EDG Building	2.4e-04	6.2e-02	2.4e-01
SWS Pumphouse	5.1e-05	1.3e-02	5.0e-02
Switch Yard	2.0e-04	5.2e-02	2.0e-01
Battery Room	1.3e-05	3.2e-03	1.2e-02

Table ES–3. Total Fire Frequencies by Plant Location

Plant Location	Fire Frequency		
	5% Lower Bound	Mean	95% Upper Bound
Containment	1.9e-04	4.9e-02	1.9e-01
Reactor Building	3.7e-04	9.3e-02	3.6e-01
Aux. Building	3.0e-04	7.6e-02	2.9e-01
Turbine Building	4.2e-04	1.1e-01	4.1e-01
Control Room	3.8e-05	9.7e-03	3.7e-02
Cable Spreading Room	2.6e-06	6.6e-04	2.6e-03
Switchgear Room	5.6e-05	1.4e-02	5.4e-02
EDG Building	9.0e-05	2.3e-02	8.8e-02
SWS Pumphouse	3.0e-05	7.7e-03	2.9e-02
Switch Yard	9.5e-05	2.4e-02	9.3e-02
Battery Room	2.6e-06	6.6e-04	2.6e-03

ACKNOWLEDGMENTS

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ACRONYMS

AEOD	Office for Analysis and Evaluation of Operational Data
BWR	boiling water reactor
EDG	emergency diesel generator system
EPIX	Equipment Performance and Information Exchange
EPRI	Electric Power Research Institute
LER	Licensee Event Report
LOOP	loss of offsite power
NEIL	Nuclear Electric Insurance Limited
NPRDS	Nuclear Plant Reliability Data System
NRR	Office of Nuclear Reactor Regulation
PWR	pressurized water reactor
RES	Office of Nuclear Regulatory Research
USNRC	U. S. Nuclear Regulatory Commission

Fire Events - Update of U.S. Operating Experience, 1986 – 1999

1 INTRODUCTION

1.1 Purpose

This report provides an update of fire events to assist the NRC staff in performing fire analyses. Fire frequencies are estimated for all fires, regardless of duration, in plant locations that contain safety-related systems and/or components. In addition, the update provides more detailed information on smoke events, causes of fires, methods of fire detection, and means of fire suppression.

1.2 Background

An earlier study, AEOD/S97-03, "Special Study - Fire Events - Feedback of U.S. Operating Experience," June 1997 (Ref. 1), provided fire events, smoke events, and fire frequencies for plant location areas for two time periods, 1965–1985 and 1986–1994. The fire events included in this earlier study were generally limited to fires with durations of 5 minutes or longer. Exceptions to this duration limit were when safety-related systems or components were affected, when an explosion occurred, or when loss of power occurred. The data for the first period, 1965–1985, were considered archival and are not included in this update. This period was prior to the implementation of 10 CFR 50 Appendix R plant modifications and procedures.

1.3 Scope

The fire events update in this report provides the following products:

- A proprietary updated fire events database (1986–1999);
- An updated listing of smoke events by plant location (1986–1999);
- The distribution of fire events by information source and year (1986–1999) for total number of events, number of events during power operation, and the number of events for shutdown; and
- Fire frequencies by plant location area for total, power operation, and shutdown operation (1993–1999). The fire frequencies estimated are "ignition" fire frequencies that use all fire events that occurred in plant location areas, regardless of duration.
- Excluded from the scope of this study are:
  - Risk significance evaluation of the fire event data or the updated ignition fire frequencies. In fire risk assessments, the severity of the fire events are first evaluated, and the fire ignition frequencies are adjusted appropriately.
  - Fire severity, risk implications, and duration of power operation fire events were not updated from the initial study (Ref.1).

1.4 Report Structure

The report is structured as follows:

- Section 2 contains an overview of the data sources, a description of the resultant fire events database and smoke database, and a description of the statistical methods used to estimate the fire event frequencies,
- Section 3 presents the fire frequencies and general insights,
- Appendix A describes the details of the statistical analyses,
- Appendix B contains the updated fire events database, and
- Appendix C contains the updated smoke events database.

Appendices B and C are in Volume 2 of this report.

2 DATA SOURCES AND ANALYSIS METHODS

2.1 Data Sources[1]

The proprietary updated fire events database, contained in Appendix B, includes fire events occurring in nuclear power reactors obtained from four different sources. They are (1) Licensee Event Reports (LERs), (2) fires associated with component failures reported in the industry's Equipment Performance and Information Exchange (EPIX) database and Nuclear Plant Reliability Data System (NPRDS), (3) plant-specific survey database information from the Electric Power Research Institute (EPRI), and (4) information from a continuing survey conducted by Nuclear Electric Insurance Limited (NEIL). The information from the last three sources is proprietary. The smoke event data are from LER and EPIX/NPRDS sources only.

The information from the LERs, NPRDS, and EPIX cover all operating nuclear power plants from 1986 through 1999. However, the EPRI and NEIL fire survey data cover two different periods. The fire survey data from EPRI cover only three years, 1986–1988. (EPRI fire survey data include the years 1965 through 1988, but this report covers only 1986–1999.) The second period covers 1993 through 1999. These data are from NEIL. In addition, not all plants participated in either survey. No survey data exist for 1989 through 1992.

Dates, descriptions, and fire attributes contained in the event description were compared with each source, and any duplicates were removed. The priority for characterizing event sources are LERs, EPIX/NPRDS, and then the survey data. That is, if an event was contained in the LER list and others, it was entered into the database as an LER event. Secondly, if an event was in the EPIX/NPRDS list and the survey data, it was entered into the database as an NPRDS/EPIX event. Finally, any remaining events in the survey list were added to the database.

[1] References 2 through 5 identify correspondence between the NRC and INPO, NEIL, and EPRI. The EPIX database is available to EPIX Users and the proprietary EPRI and NEIL databases are available to NRC staff through RES/OERAB.

2.2 Updated Fire Events Database

The initial fire events database (Appendix B, Table B-1) from the initial AEOD fire events study (Ref. 1) was updated to include new data from the 1995–1999 period. This updated database was used as a source for the fire frequency estimates provided in this report. The initial fire events database was updated to include:

- EPRI survey short-duration fire events from the 1986–1988 period, which were excluded from the initial database,
- The means of fire suppression (e. g., portable fire extinguishers, self-extinguished, power source removed, manual hose, etc.) where such information was directly available or determined from review of the fire event, and
- The means of fire detection (e.g., fire alarm, plant personnel, fire watch, etc.), where information was available.

A list of characteristics coded in the database (acronyms and abbreviations) is presented in Appendix B, Table B-2. Appendix B, Table B-3 provides definitions of fire event terms.

2.3 Fire Frequency Estimation Method

The fire frequencies include the 1993–1999 fire events from LERS, NPRDS, EPIX and the NEIL survey data. Frequency estimates for each plant location include the number of fires divided by the hours of operation for power operation, shutdown operation, and total (power + shutdown) operation.

The plant locations for which fire frequencies were estimated are the following: containment, auxiliary building (for PWR), reactor building (for BWR), turbine building, control room, cable spreading room, switchgear room, switch yard, emergency diesel generator building, battery room, and service water pumphouse. Fires that affected locations that do not contain safe shutdown or risk significant structures, systems, or components (SSC) are included in the database, but were excluded from the fire frequency estimation.

The NEIL survey data only included fire events from 68 plants. Therefore it was necessary to extrapolate the data for fire frequencies for the plants that did not report to NEIL. This was done by checking the statistical and engineering characteristics the fire events for LERs and NPRDS/EPIX of the 68 plants reporting to NEIL and the 41 plants not reporting survey data. The statistical hypotheses–that the two distributions are the same–were not rejected, for either power operation or shutdown operation. The engineering characteristics were similar. Appendix A presents the detailed steps and results of the statistical analyses.

2.4 Updated Smoke Event Database

Information was provided for the updated smoke events listing that did not involve a fire or explosion (i.e., smoke only). The smoke data are an update of the smoke event data provided in the initial report (1986–1994, Ref. 1) for the extended 1986–1999 period. Where evacuation occurred due to smoke, this was indicated in both the initial smoke events table (Ref.1) and in the updated smoke events table. The nonproprietary data sources for both the initial table and its update are based on LER events and NPRDS/EPIX component failure histories involving smoke.

Appendix C, Table C-1 provides an updated listing of smoke only events for the 1986-1999 period and Appendix C, Table C-2 provides a listing of terms and acronyms used in the smoke events database. Appendix C, Table C-3 provides definitions of smoke event terms.

3 RESULTS

3.1 Fire Event Occurrences by Year

Figures 1, 2, and 3 provide histograms for fire events by data reporting source at plant locations for 1986–1999 for power operation, shutdown, and total, respectively. Fire events for other plant locations, such as the fuel handling building, offgas treatment building, or offsite, were excluded. For the 1986–1988 period, only EPRI survey fire events exist and are included. For the 1989–1992 period, there were no plant surveys. For the1993–1999 period, NEIL survey fire events exist and are included.

3.2 Estimated Fire Frequencies by Plant Location

The initial report (Ref. 1), covering 1986–1994, provided fire frequencies for plant locations that excluded many, less risk-significant fire events of short duration that did not involve safety-related equipment failure or loss of plant power. The updated fire frequencies included these short-duration fire events, mostly from EPRI survey information (1986-1988) fire events and NEIL survey data (1993–1999). The NEIL survey data included many short-duration fire events that occurred at shutdown operation (0% power).

Table 1 and Figure 4 show the power operation fire frequencies by plant location for the 1993–1999 period. Table 2 and Figure 5 show the shutdown fire frequencies by plant location for the 1993–1999 period. Table 3 contains the total (combined power operation and shutdown) fire frequencies by plant location for the 1993–1999 period.

The event counts for each plant location are found in Appendix A. Appendix A also contains the methods and results for extrapolating the number of fires to account for the 41 plants that did not report data to the NEIL survey.

3.3 General Insights

The following are general insights for the fire events and fire frequencies:

- Despite the inclusion of small, short-duration fires excluded in the original report, the power operation fire frequencies were lower than the corresponding frequencies estimated in the previous initial report (1986–1994), except for two cases. For battery room, the estimates are about equal; for the control room, the updated estimate is greater than that of the initial study.

- The number of fire events and associated fire frequencies by plant location were generally higher for shutdown than for power operation.

- No fires were reported for the cable spreading room or the battery room for the updated period, 1986–1999, for shutdown operation. No fires were reported for the same locations for power operation for 1989-1999.

- The updated smoke events data (1995–1999) indicated that there were no smoke events where the extent of smoke was heavy. Only one smoke event involved an evacuation. It was due to carbon dioxide mixed with light smoke in the circulating water fire pumphouse.

For power operation fire events, The following observations are made:

- Electrical failure was the predominant cause (54%), with overheated material next in significance (33%), accounting for 87% of the total fires for power operation.

- Small fires of short duration (less than 20 minutes) predominated. The majority of those small fires have a duration of less than 5 minutes (45%).

- Portable fire extinguishers were the major means of suppression (35%), with the most of the remaining suppression means consisting of self extinguished (18%) and power source removed (15%).

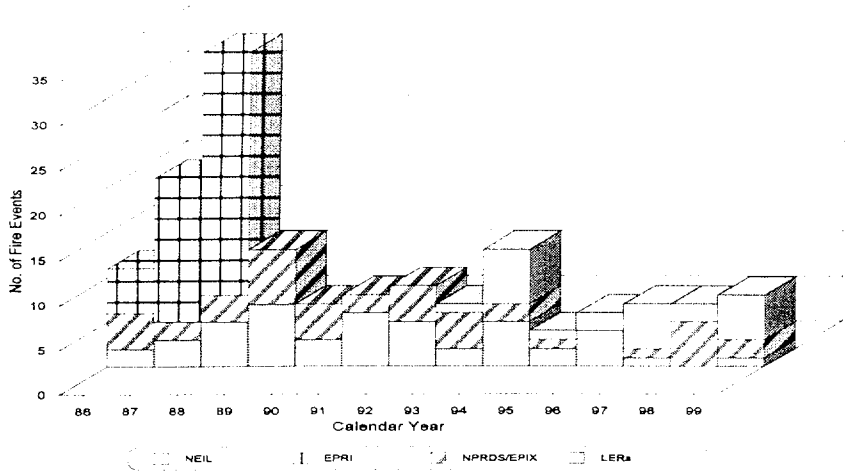

Figure 1. Histogram of power operation fire events by source

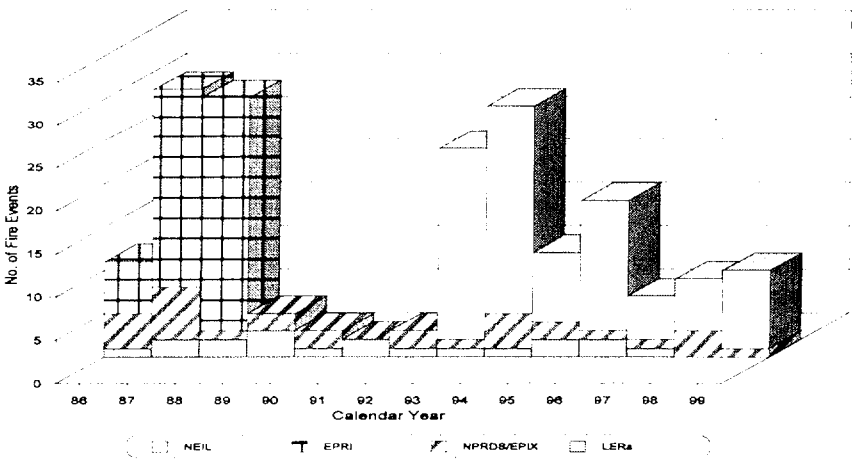

Figure 2. Histogram of shutdown fire events by data source

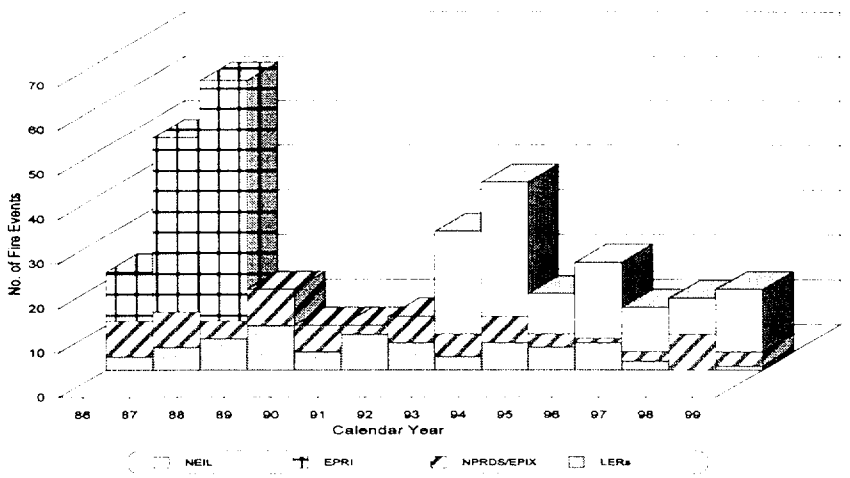

Figure 3. Histogram for total fire events by source

Table 1. Power operation fire frequencies by plant location

Plant Location	Fire Frequency		
	5% Lower Bound	Mean	95% Upper Bound
Containment	1.2e-05	3.0e-03	1.1e-02
Reactor Building	1.1e-04	2.8e-02	1.1e-01
Aux. Building	1.0e-04	2.7e-02	1.0e-01
Turbine Building	1.6e-04	4.1e-02	1.6e-01
Control Room	2.8e-05	7.2e-03	2.8e-02
Cable Spreading Room	3.3e-06	8.4e-04	3.2e-03
Switchgear Room	2.0e-05	5.1e-03	1.9e-02
EDG Building	5.3e-05	1.4e-02	5.2e-02
SWS Pumphouse	2.8e-05	7.2e-03	2.8e-02
Switch Yard	7.0e-05	1.8e-02	6.8e-02
Battery Room	3.3e-06	8.4e-04	3.2e-03

Table 2. Shutdown fire frequencies by plant location

Plant Location	Fire Frequency		
	5% Lower Bound	Mean	95% Upper Bound
Containment	8.93-04	2.3e-01	8.7e-01
Reactor Building	1.3e-03	3.3e-01	1.3e+00
Aux. Building	1.1e-03	2.8e-01	1.1e+00
Turbine Building	1.4e-03	3.6e-01	1.4e+00
Control Room	8.9e-05	2.8e-02	8.7e-02
Cable Spreading Room	1.3e-05	3.2e-03	1.2e-02
Switchgear Room	2.0e-04	5.2e-02	2.0e-01
EDG Building	2.4e-04	6.2e-02	2.4e-01
SWS Pumphouse	5.1e-05	1.3e-02	5.0e-02
Switch Yard	2.0e-04	5.2e-02	2.0e-01
Battery Room	1.3e-05	3.2e-03	1.2e-02

Table 3. Total fire frequencies by plant location

Plant Location	Fire Frequency		
	5% Lower Bound	Mean	95% Upper Bound
Containment	1.9e-04	4.9e-02	1.9e-01
Reactor Building	3.7e-04	9.3e-02	3.6e-01
Aux. Building	3.0e-04	7.6e-02	2.9e-01
Turbine Building	4.2e-04	1.1e-01	4.1e-01
Control Room	3.8e-05	9.7e-03	3.7e-02
Cable Spreading Room	2.6e-06	6.6e-04	2.6e-03
Switchgear Room	5.6e-05	1.4e-02	5.4e-02
EDG Building	9.0e-05	2.3e-02	8.8e-02
SWS Pumphouse	3.0e-05	7.7e-03	2.9e-02
Switch Yard	9.5e-05	2.4e-02	9.3e-02
Battery Room	2.6e-06	6.6e-04	2.6e-03

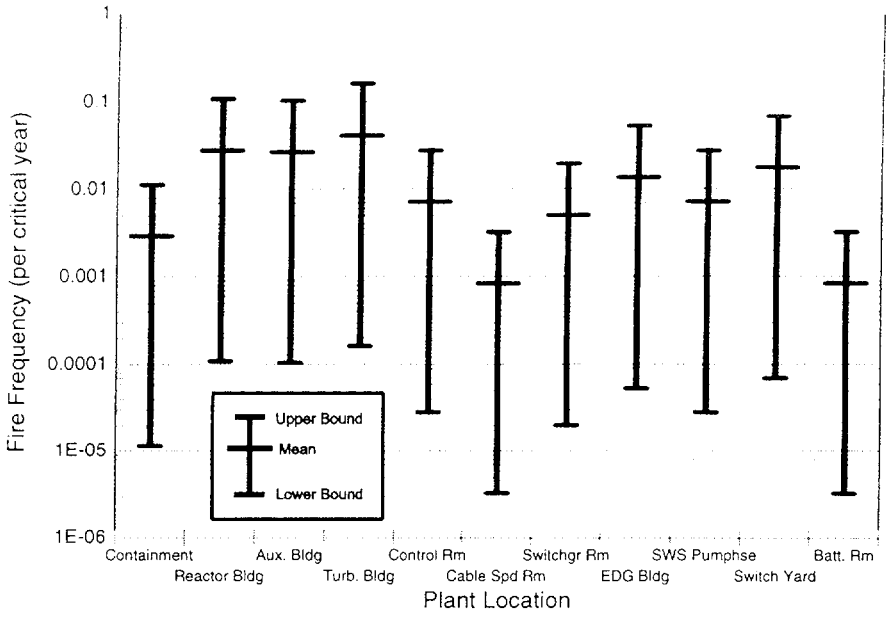

Figure 4. Mean fire frequencies with uncertainty bounds for power operation by plant location

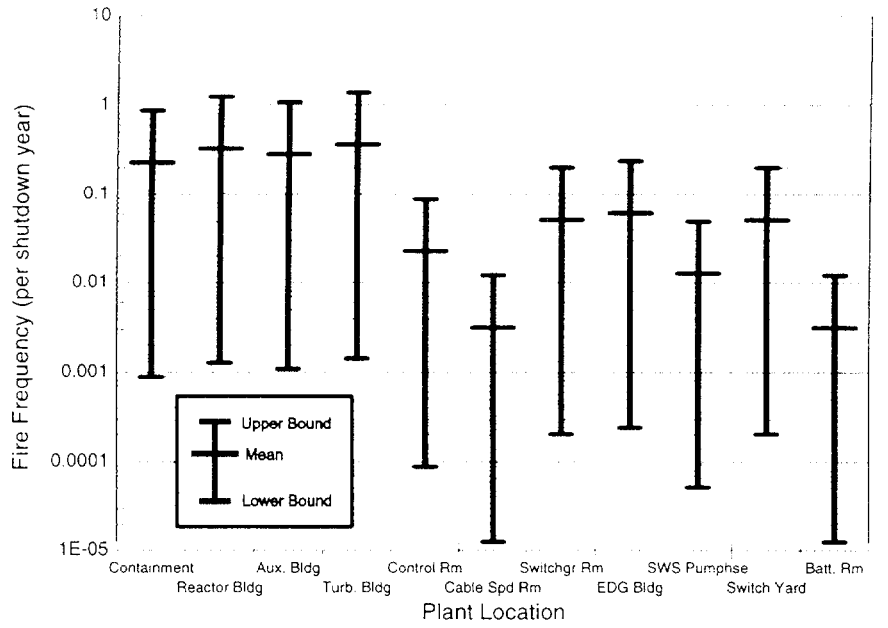

Figure 5. Mean fire frequencies with uncertainty bounds for shutdown by plant location

4 REFERENCES

1. U.S. Nuclear Regulatory Commission, "Special Study - Fire Events - Feedback of U.S. Operating Experience," AEOD/S97-03, June 1997.

2. Letter from NRC (L. Joseph Callan) to Institute of Nuclear Power Operations (Mr. Kenneth A. Strahm), dated September 26, 1997 on Memorandum of Agreement of use of EPIX Database, including NPRDS archived data.

3. INPO 98-001, Rev. 3, dated September 2001 (Limited Distribution), "Equipment Performance and Information Exchange System (EPIX) Reporting Requirements."

4. Letter from NRC (Thomas L. King) to NEIL (Mr. Wayne Sohlman), dated September 26, 2000 on the use of proprietary document entitled "Electric Generation Fire Incident Database."

5. Letter from NRC (Thomas L. King) to EPRI (Mr. John D. Bateman), dated August 11, 2000 on use of proprietary document "Fire Events Database for U.S. Nuclear Power Plants" version FEDB-88.

APPENDIX A

Fire Frequency Estimation Statistical Methods and Results

A-1 DATA SOURCES

A-1.1 Description of Data Sources

The proprietary updated fire events database, contained in Appendix B, includes fire events occurring in nuclear power reactors obtained from four different sources. They are (1) LERs, (2) fires associated with component failures reported the industry's Equipment Performance and Information Exchange (EPIX) database and NPRDS, (3) plant-specific survey database information from the Electric Power Research Institute (EPRI), and (4) information from a survey conducted by Nuclear Electric Insurance Limited (NEIL). The information from the last three sources is proprietary. The smoke event data are from LER and EPIX/NPRDS sources only.

The information from the LERs, NPRDS, and EPIX cover all operating nuclear power plants from 1986 through 1999. However, the EPRI and NEIL fire survey data cover two different periods. The fire survey data from EPRI cover only three years, 1986–1988. (EPRI fire survey data include the years 1965 through 1988, but this report only covers 1986–1999.) The second period covers 1993 through 1999. These data are from NEIL. In addition, not all plants participated in either survey. No survey data exist for 1989 through 1992.

Dates, descriptions, and fire attributes contained in the event description were compared with each source, and any duplicates were removed. The priority for characterizing event sources are LERs, EPIX/NPRDS, and then the survey data. That is, if an event was contained in the LER list and others, it was entered into the database as an LER event. Secondly, if an event was in the NPRDS/EPIX list and the survey data, it was entered into the database as an NPRDS/EPIX event. Finally, any remaining events in the survey list were added to the database.

Since the period from 1989 to 1992 did not contain any fire event survey data from either EPRI or NEIL, the fire frequency estimates were based on the most recent continuous period 1993-1999, for which data re available from LERs, EPIX and fire surveys (NEIL).

Fire frequencies were estimated for the plant locations containing equipment needed to bring the plant to a safe shutdown (remove decay heat). Fires that affected other locations, such as the fuel handling building and standby gas treatment building, were excluded from the fire frequency analyses.

A-1.2 Extrapolation of "Missing" NEIL Survey Data

In statistical analyses it is desirable to use all relevant information, if possible. In this study, 68 plants have fire event data from the three available sources (LERs, NPRDS/EPIX, and NEIL), while 41 plants only have data from LERs and NPRDS/EPIX. To limit the estimation to only the 68 plants would eliminate valuable, relevant information. Therefore, it was desirable to use the data for the 41 plants that did not participate in the NEIL survey.

The rationale for making an extrapolation are the following:

- The statistical characteristics of the LER and NPRDS/EPIX data for the 68 plants reporting to NEIL were similar to the LER and NPRDS/EPIX data for the 41 plants that did not participate in the NEIL survey.

- There is no evidence that the engineering characteristics of fires in the LER and NPRDS/EPIX data for the 41 plants that did not report to NEIL differ from the characteristics of fires in the LER and NPRDS/EPIX data for the 68 plants that reported to NEIL.

The procedure described below for extrapolating the number of fire events does not require distributional assumptions about the events (e.g., the events follow a Poisson distribution). In fact, for this case, the data do not follow a Poisson distribution.

The first step was to assess the similarity of the 68 plants that participated in the NEIL survey and the 41 plants that did not. This was done by comparing the distributions of the LER and NPRDS/EPIX data for the two groups for power operation and shutdown operation, shown in Table A-1 and A-2, respectively. The first column in each table is the number of fire events observed at a plant. The second and fifth columns in each table show the number of plants that had the indicated number of fire events for power operation and shutdown operation, respectively. For example, the number of plants with 0 fires for power operations is 48. The third and sixth columns contain the number of plants with the indicated number of fire events that did not participate in the NEIL survey. Using these numbers, a Chi-square goodness-of-fit test was used to test the hypothesis that the distributions are the same. For power operation, the value of the test statistic is 3.435 with 2 degrees of freedom. The p-value for this case equals 0.180. For shutdown, the value of the test statistic equals 4.783 with 2 degrees of freedom, which results in a p-value of 0.091. Based on these goodness of fit tests, we cannot reject the statistical hypotheses that the distributions are the same. Thus, we make the assumption that the distributions of the two groups will be similar for the NEIL data.

The fires reported in the NEIL data are generally small fires with short durations (89%). They generally do not affect plant power, plant safety systems, plant fire safe shutdown equipment, or plant power distribution systems (98%). Because of these reasons, we believe that the plants not reporting to NEIL will have similar fires with the similar characteristics.

The next step was to extrapolate the distribution of the NEIL fire events in the 68 plants to the 41 plants that did not report to NEIL. Table A-2 contains the distribution of events for power operation. Column 1 is the number of fire events at a plant. Column 2 contains the number of plants experiencing the number of fire events in Column 1. Column 3 is the fraction of the 68 plants. It is obtained by dividing the entries in Column 2 by 68. The number of events (Column 4) is obtained by multiplying entries in Column 1 with the corresponding entries in Column 2.

Column 5 contains the distribution for the 41 plants that did not report to NEIL. The entries in this column are obtained by multiplying the entries in Column 3 by 41. Column 6 is the rounded result of Column 5. The last column (7) contains the extrapolated number of events associated with the distribution in Column 6. The results are obtained by multiplying the corresponding entries in Column 6 and Column 1. The sum of the entries in Column 7 is the number of events to be added to the existing fire event totals. The number of events to be added equals 14 for power operation. The Figure A-1 shows a histogram of the distribution.

Table A-1. Distribution of fire events by plant in LERs and NPRDS/EPIX data

No. of Fire Events at a Plant	Power Operations			Shutdown		
	Number of Plants			Number of Plants		
	NEIL Survey Plants	Other Plants	Total	NEIL Survey Plants	Other Plants	Total
0	48	34	82	52	38	90
1	16	7	23	15	3	18
2	4	0	4	1	0	1
Total	68	41	109	68	41	109

Table A-2. Distribution of fire events for NEIL survey data and estimated distribution of fires for non-NEIL survey data for power operation

(1) No. of Fires at a Plant	(2) Number of Plants	(3) Fraction	(4) No. of Events	(5) Expected No. of Plants	(6) Expected No. of Plants (Rounded)	(7) Expected No. of Fire Events
		(Col.2 / 68)	(Col. 1 × Col. 2)	(Col. 3 × 41)		(Col. 1 × Col. 6)
0	52	0.76	0	31.4	31	0
1	11	0.16	11	6.6	7	7
2	4	0.06	8	2.4	2	4
3	1	0.01	3	0.6	1	3
Total	68	1.00	22	41	41	14

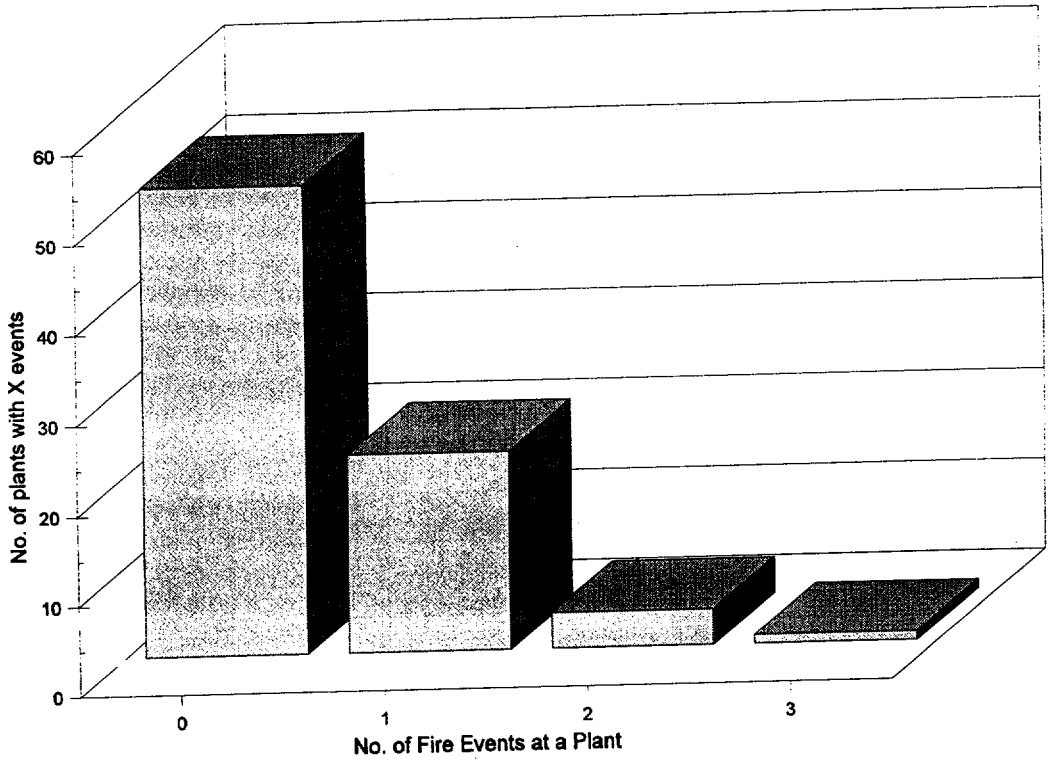

Figure A-1. Histogram of NEIL survey fires for power operation

Table A-3. Distribution of fire events for NEIL survey data and estimated distribution of fires for non-NEIL survey data for shutdown operation

(1) No. of Fires at a Plant	(2) Number of Plants	(3) Fraction	(4) No. of Events	(5) Expected No. of Plants	(6) Expected No. of Plants (Rounded)	(7) Expected No. of Fire Events
		(Col 2 / 68)	(Col. 1 × Col. 2)	(Col. 3 × 41)		(Col. 1 × Col. 6)
0	38	0.56	0	22.91	23	0
1	12	0.18	12	7.24	7	7
2	7	0.10	14	4.22	4	8
3	2	0.03	6	1.21	1	3
4	3	0.04	12	1.81	2	8
5	2	0.03	10	1.21	1	5
6	1	0.01	6	0.60	1	6
7	1	0.01	7	0.60	1	7
8	0	0.00	0	0.00	0	0
9	1	0.01	9	0.60	0	0
10	0	0.00	0	0.00	0	0
11	0	0.00	0	0.00	0	0
12	0	0.00	0	0.00	0	0
13	1	0.01	13	0.60	1	13
14	0	0.00	0	0.00	0	0
Total	68	1.00	89	41	41	57

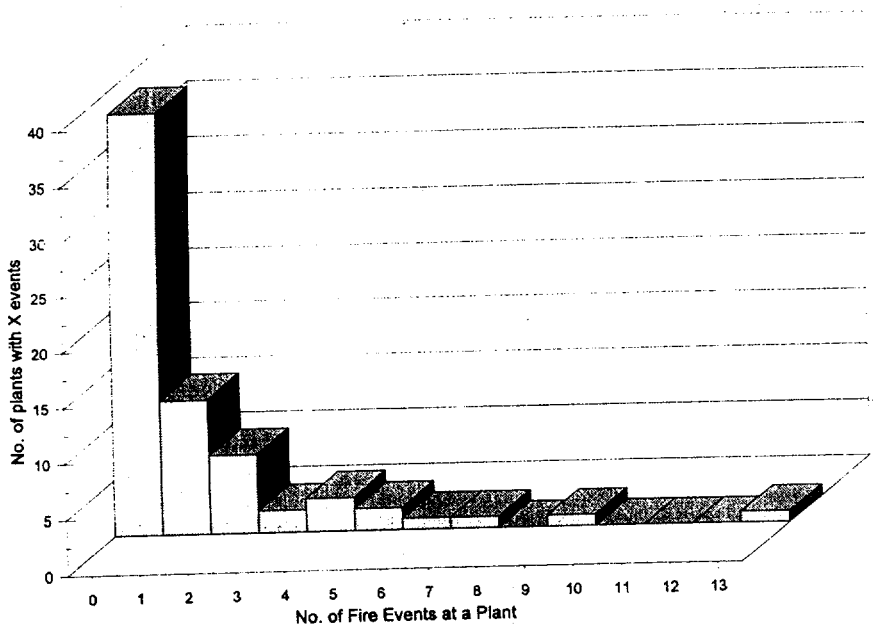

Figure A-2. Histogram of NEIL reported fires during shutdown

A-2 ESTIMATION OF PLANT LOCATION FIRE FREQUENCIES

A-2.1 Overview of Results

The results of the fire frequency estimation are shown in Tables A-4, A-5, and A-6 for power operation, shutdown operation, and total, respectively. The following describes the estimation of the mean frequency and the uncertainty distribution.

Some plant locations involve more than one area in a plant, such as switch gear rooms and battery rooms. In this report, the fire frequencies for such plant locations are based on data from all locations in the plant. The fire frequency for these plant locations should be apportioned when more than one such location exists in a plant. Similarly, the frequencies for the reactor building (BWR) and auxiliary building (PWR) should be apportioned for areas within these plant locations.

A-2.2 Fire Frequency Estimation

The total number of events estimated in Section A-1.2 was distributed over the plant locations based on the percent of fire events in each location. The results are shown in the third column of Tables A-4 and A-5.

The estimate of the fire frequency, denoted by λ, for each plant location is obtained by calculating the maximum likelihood estimate (MLE), denoted by λ_0, for each plant location for power operation, shutdown , and total. This is done by dividing the number of events for each category by the appropriate reactor years. That is, reactor critical years for power operation, reactor shutdown years for shutdown, an reactor calendar years for total. The results are shown in Tables A-4, A-5, and A-.6. The MLE is taken as the mean of the associated uncertainty distribution.

An additional estimation of the plant location fire frequencies was made using only the fire data for the 68 plants that participated in the NEIL survey. These data include information from LERs, NPRDS, EPIX, and NEIL. These fire frequency estimates were similar to those in the tables.

A-2.3 Estimation of Uncertainty Distribution

For each frequency, λ, a constrained noninformative distribution[1] was estimated. For this case, a constrained noninformative prior distribution is a Gamma distribution with shape parameter a = ½ and scale parameter b = $1/(2\lambda_0)$. This distribution was chosen since it maximizes the uncertainty in λ . This distribution was used to estimate the lower 5% bound and the 95% upper bound. These are probability bounds, not confidence intervals. These distributions should be used as industry prior distributions to obtain plant-specific fire frequency distributions.

A-2.4 Comparison with Previous Fire Frequency Estimates

Table A-7 contains the mean fire frequency estimates of the previous fire study and the updated study. The last column indicates where the frequency of the current study is less than, greater than, or about equal to the frequency of the initial study For one case, they are about equal; for the control room, the updated estimate is greater than that of the initial study. For all other cases, the updated estimate is less than the estimate of the initial study. The updated estimate includes fires that were excluded from the initial study (i.e., small fires) and the estimated number of fires for those plants that did not participate in the NEIL survey.

Figure A-4 shows the histogram of all fire events for power operations. Figure A-5 contains the histogram of fire events with durations greater than 5 minutes. Figures A-6 and A-7 show the corresponding histograms for shutdown events.

Table A-4. Fire events and frequencies for power operation by plant location

Plant Location	No. Fire Events	No. of Extrapolated Events	Total	Reactor Critical Years	5% Lower Bound	Mean	95% Upper Bound
Containment	1	0.26	1.26	596.5	1.2e-05	3.0e-03	1.1e-02
Reactor Building	4	1.04	5.04	198.5	1.1e-04	2.8e-02	1.1e-01
Aux. Building	8	2.07	10.07	398.0	1.0e-04	2.7e-02	1.0e-01
Turbine Building	19	4.93	23.93	596.5	1.6e-04	4.1e-02	1.6e-01
Control Room	3	0.78	3.78	596.5	2.8e-05	7.2e-03	2.8e-02
Cable Spreading Room	0	0.00	0.00	596.5	3.3e-06	8.4e-04	3.2e-03
Switchgear Room	2	0.52	2.52	596.5	2.0e-05	5.1e-03	1.9e-02
EDG Building	6	1.56	7.56	596.5	5.3e-05	1.4e-02	5.2e-02
SWS Pumphouse	3	0.78	3.78	596.5	2.8e-05	7.2e-03	2.8e-02
Switch Yard	8	2.07	10.07	596.5	7.0e-05	1.8e-02	6.8e-02
Battery Room	0	0.00	0.00	596.5	3.3e-06	8.4e-04	3.2e-03
Total	54	14	68.00				

Table A-5. Fire events and frequencies for shutdown by plant location

Plant Location	No. Fire Events	No. of Extrapolated Events	Total	Reactor Shutdown Years	5% Lower Bound	Mean	95% Upper Bound4
Containment	23	12.03	35.03	156.5	8.93-04	2.3e-01	8.7e-01
Reactor Building	12	6.28	18.28	57.5	1.3e-03	3.3e-01	1.3e+00
Aux. Building	18	9.41	27.41	99.0	1.1e-03	2.8e-01	1.1e+00
Turbine Building	37	19.35	56.35	156.5	1.4e-03	3.6e-01	1.4e+00
Control Room	2	1.05	3.05	596.5	8.9e-05	2.8e-02	8.7e-02
Cable Spreading Room	0	0.00	0.00	156.5	1.3e-05	3.2e-03	1.2e-02
Switchgear Room	5	2.61	7.61	156.5	2.0e-04	5.2e-02	2.0e-01
EDG Building	6	3.14	9.14	156.5	2.4e-04	6.2e-02	2.4e-01
SV/S Pumphouse	1	0.52	1.52	156.5	5.1e-05	1.3e-02	5.0e-02
Switch Yard	5	2.61	7.61	156.5	2.0e-04	5.2e-02	2.0e-01
Battery Room	0	0.00	0.00	156.5	1.3e-05	3.2e-03	1.2e-02
Total	109	57	166				

Table A-6. Total fire events and frequencies by plant location

Plant Location	Total	Reactor Calendar Years	5% Lower Bound	Mean	95% Upper Bound
Containment	36.29	753	1.9e-04	4.9e-02	1.9e-01
Reactor Building	23.31	256	3.7e-04	9.3e-02	3.6e-01
Aux. Building	37.49	497	3.0e-04	7.6e-02	2.9e-01
Turbine Building	80.27	753	4.2e-04	1.1e-01	4.1e-01
Control Room	6.82	753	3.8e-05	9.7e-03	3.7e-02
Cable Spreading Room	0	753	2.6e-06	6.6e-04	2.6e-03
Switchgear Room	10.31	753	5.6e-05	1.4e-02	5.4e-02
EDG Building	16.69	753	9.0e-05	2.3e-02	8.8e-02
SWS Pumphouse	5.30	753	3.0e-05	7.7e-03	2.9e-02
Switch Yard	17.69	753	9.5e-05	2.4e-02	9.3e-02
Battery Room	0	753	2.6e-06	6.6e-04	2.6e-03
Total	234				

Table A–7. Power operation fire frequency comparison by plant location

	Mean Fire Frequency		
Plant Location	Ref. 1	Current	Change
Containment	9.4e-03	3.0e-03	↘
Reactor Building	5.4e-02	2.8e-02	↘
Aux. Building	4.6e-02	2.7e-02	↘
Turbine Building	6.9e-02	4.1e-02	↘
Control Room	2.6e-03	7.2e-03	↗
Cable Spreading Room	4.3e-03	8.4e-04	↘
Switchgear Room	1.3e-02	5.1e-03	↘
EDG Building	2.8e-02	1.4e-02	↘
SWS Pumphouse	1.1e-02	7.2e-03	↘
Switch Yard	3.0e-02	1.8e-02	↘
Battery Room	8.5e-04	8.4e-04	→

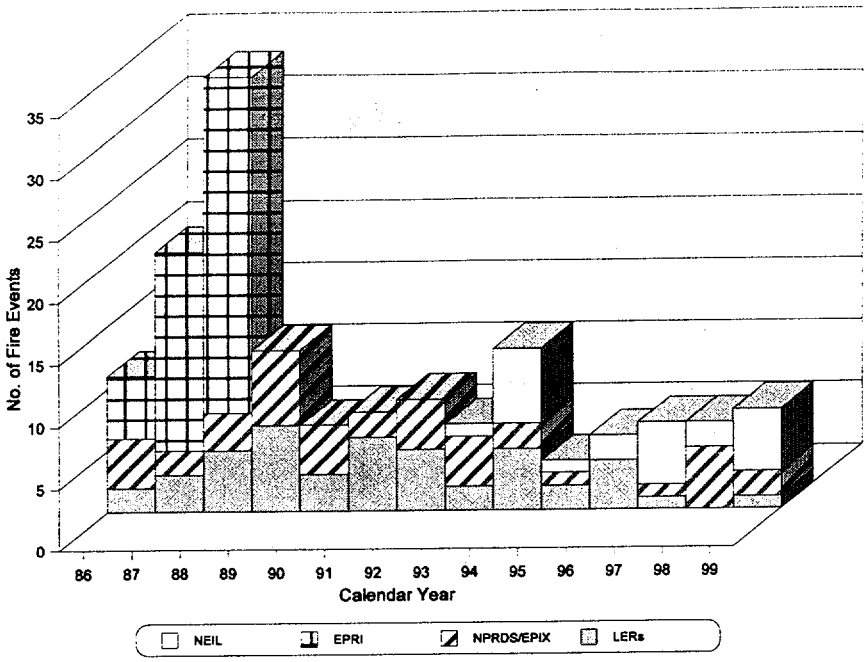

Figure A-3. Histogram of all power operation fires by year

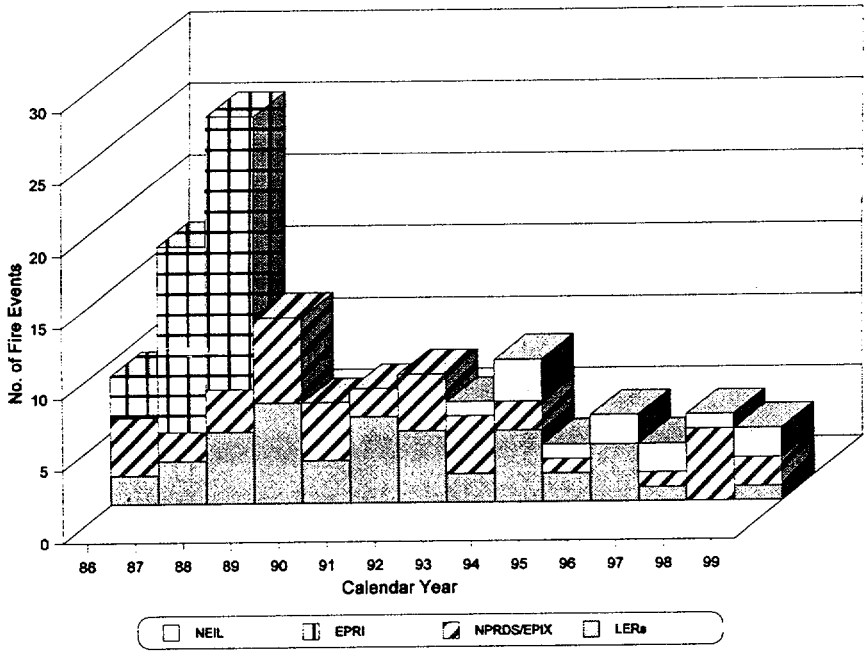

Figure A-4. Histogram of power operation fires with durations > 5 minutes by year

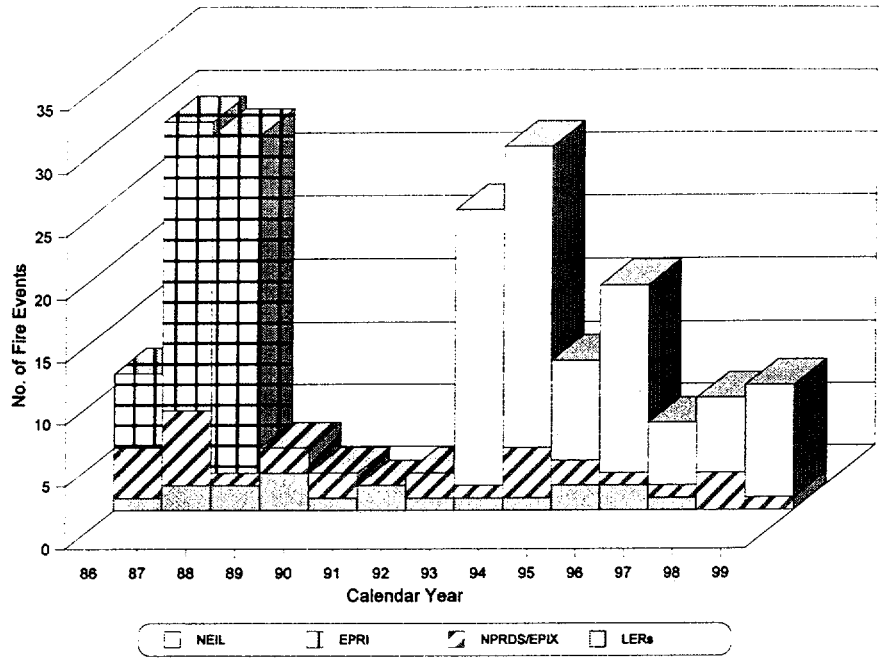

Figure A-5. Histogram of all shutdown fires by year

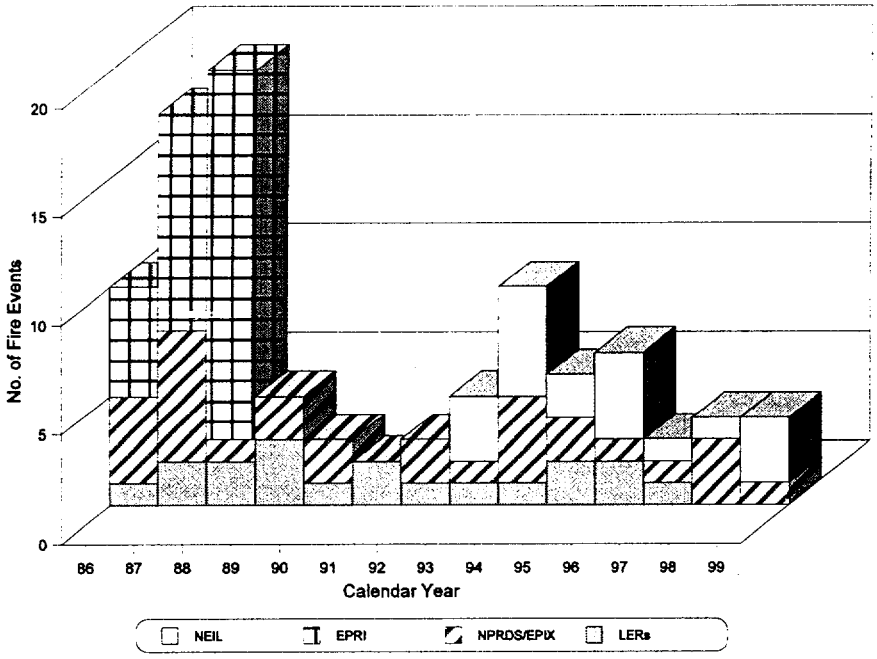

Figure A-6. Histogram of shutdown fires with durations > 5 minutes by year

A-3 REFERENCES

1. Atwood, C. L. "Constrained Noninformative Priors in Risk Assessment," *Reliability Engineering and System Safety*, Vol. 53, Issue 1, pp. 37-46. 1994.