ENCLOSURE 1

DRAFT TECHNICAL REPORT

EVALUATION OF AVAILABLE DATA FOR PROBABILISTIC RISK ASSESSMENTS (PRA) OF FIRE EVENTS AT NUCLEAR POWER PLANTS AND RELIABILITY ASSESSMENTS OF FIRE PROTECTION SYSTEMS

By

L.M. Krasner

C.S. Ganti

B.G. Vincent

Prepared for:

Brookhaven National Laboratories

Associated Universities, Inc.

Upton, Long Island, N.Y. 11973

Contract Number BNL122684-S

FMRC J.I. OJOR5.RG

070(A)

December 1983

Approved by:

Cheng Yao,
Asst. Vice President & Manager
Applied Research Department

Factory Mutual Research

1151 Boston-Providence Turnpike
Norwood Massachusetts 02062

TABLE OF CONTENTS

LIST OF TABLES

I
INTRODUCTION

The work presented in this report represents one task (Task 2) of a comprehensive four task program entitled "Reliability and Probabilistic Assessments for Fire Events." The overall program is being conducted by Brookhaven National Laboratories for the Nuclear Regulatory Commission. Factory Mutual Research Corporation is participating in two tasks (Tasks 2 and 3) of the overall effort. This report relates only to Task 2 whose stated objective is to evaluate existing nuclear and nonnuclear fire incident data bases to determine whether sufficient data are available for performing probabilistic and reliability assessment of nuclear power plant fire events and fire protection features. This report details the effort expanded toward accomplishing this objective.

II
THE DATA

Fire loss data for both nuclear and nonnuclear facilities were reviewed during this study.

Nuclear power plant fire loss data were obtained from the Nuclear Regulatory Commission (NRC), American Nuclear Insurers (ANI) and Professional Loss Control, Incoprorated (PLC).

To complement the nuclear loss data various other industrial data bases were evaluated for potential surrogate loss data. It became clear that the options for detailed automated accessible and obtainable data on industrial fire losses of interest were very limited. Those options included our own computerized Factory Mutual loss data base, The National Fire Protection Association (NFPA) loss data base, and the U.S. Fire Administration's National Fire Incident Reporting System (NFIRS). Both the NFPA and NFIRS data bases are coded and computerized in accordance with NFPA Standard 901 Uniform Coding for Fire Protection, 1976, [1] which is the most comprehensive fire coding system in use today. The NFIRS data base is far more inclusive than the NFPA data base. However, the NFIRS data base is currently inactive due to reorganization and funding cuts within the Fire Administration. Although the raw data are still being collected by the Administration, no group presently exists to code and enter the raw data or to assist in defining or performing the manipulation of the automated data base to obtain desired printouts. A strategy is presently being pursued which will fund the NFPA to take over the responsibility for the computer aspects and maintenance of the NFIRS data base. This transition is likely in 1984. For these reasons the NFPA was the only other data base used with the Factory Mutual loss data base as the sources for potential surrogate data.

Although the bulk of the data exists in computerized data bases, all incident report summaries had to be manually reviewed and, in the case of the FM data, the original loss reports surveyed for detailed information. For this reason, the review of fire loss data was confined to those incidents which occurred in operational facilities during the five-year period 1978-1982.

2.1 NUCLEAR POWER PLANT FIRE LOSS EXPERIENCE

Fire loss incidents were gathered from the Nuclear Regulatory Commission (NRC), American Nuclear Insurers (ANI) and Professional Loss Control, Incorporated [2]. During the period 1978-1982, a total of 74 fire incidents were documented as having occurred in operating (post-construction phase) nuclear power plants. The combined operating experience for this period was approximately 390 reactor-years. Previously published reports [2,3] show 62 fire incidents occurring in operational (nonconstruction phase) nuclear power plants from the early 1960's through 1977. The period between the commencement of nuclear power plant operations in the U.S. and the end of 1977 encompasses approximately 294 reactor-years. The total documented fire loss experience (1960-1982) for operating nuclear power plants in this country is approximately 136 incidents in 684 reactor-years*. Eleven additional fire incidents were recorded between 1978 and 1981 using NRC's Preliminary Notification system. However, these incidents could not be documented with NRC Licensee Event Reports or through any other of the sources used in this study.

The nuclear power plant data were examined for the existence of data elements required for making certain probabilistic assessments of fire events. The required data elements included date of fire, fire size as related to the area of damage, type of facility (PWR, BWR, or HTGR), operational status of plant (pre-operational test, operation, shutdown, etc.), area of fire origin, equipment involved, class of fire (or material involved), detection time, suppression time, extinguishment method, and cause(s) of fire. The occurrence rates for these data elements are provided in Table 1. None of the fire incidents reviewed contained an estimate of fire size. Two parameters which might have been used to obtain such an estimate are detection time and property damage. Ramachandran [4] investigated a technique for establishing relationships between detection times, property damage, and area of fire damage for the textile industry. This was the only relevant work discovered during this study. However, it did not prove helpful to the project.

Detection and suppression times were essentially absent from the data set, occurring at rates of 1/74 and 6/74 respectively. The occurrence rate of the parameter, area of fire origin, while well represented in the data set, did not

*There were approximately 684 operating reactor years through 7/83 according to Reference [5].

TABLE 1. OCCURRENCE OF REQUIRED DATA ELEMENTS IN DATA SET OPERATING NUCLEAR POWER PLANT LOSSES (1978-1982)

Parameter	Occurrence Rate (Percentage)	
Date Of Initial Criticality*	74/74	(100%)
Date of Fire	74/74	(100%)
Fire Size	0/74	(0%)
Type Of Facility	62/74	(84%)
Operational Status	74/74	(100%)
Area Of Fire Origin	69/74	(93%)
Equipment Involved	69/74	(93%)
Class Of Fire/Material Involved	74/74	(100%)
Detection Time	1/74	(1%)
Detection Method	55/74	(74%)
Suppression Time (from Detection)	6/74	(8%)
Extinguishment Method	37/74	(50%)
Extinguishing Agent	30/74	(40%)
Cause Of Fire		
Primary	72/74	(97%)
Secondary	23/74	(31%)
Property Damage ($)	4/74	(5%)

*Obtained from Reference 5

provide sufficient detail to define the exact location of the fire.

A summary of the salient characteristics of the nuclear power plant fire loss data is presented as Table 2.

2.2 NONNUCLEAR FIRE LOSS EXPERIENCE (PROPOSED SURROGATE DATA)

Loss incidents proposed for use in constructing a surrogate data base were also reviewed during the data collection phase. Fire loss data from utility, chemical and paper/pulp industries were selected on the basis that these occupancies utilize equipment and systems similar to those found in nuclear power plants. A total of 279 incidents from NFPA (143) and FM (136) were selected for the surrogate data base. A random sample of 46 incidents from NFPA and 40 incidents from FM were used to characterize the respective data sets.

The following rationale is used for random sampling of loss reports: with the available time and resources it is impossible to review all loss summaries and obtain the occurrence of data. Our objective is to evaluate the nonnuclear data bases for the availability of data on the parameters necessary to develop PRA's. A random sample of the loss summaries is adequate to give estimates of the occurrence rates of these data on the corresponding popilations. From these sample estimates the occurrence of these data in the population data bases (FM and NFPA) can be estimated by extrapolation. A fundamental assumption of this approach is that the occurrence rates of these parameters and the corresponding parameter values in the sample are valid estimates of the true population values.

The occurrence of required data elements are shown in Table 3.

The dates upon which the nuclear plants commenced operations are available. These dates are missing from both the NFPA and FM data sets. Such dates are necessary for developing occurrence rate models. More importantly, total operating experience (population data) are not available for NFPA and FM data sets as is the case with nuclear facilities.

Also missing from both data sets are estimates of fire size. Although data points for detection time and properth damage exist in both NFPA and FM data sets, no attempt was made to use Ramachandran's method [4] to determine fire damage areas or fire size. Other key parameters such as detection and suppression times

TABLE 2. OPERATING NUCLEAR POWER PLANT FIRE LOSS SUMMARY (1978 - 1982)

I FACILITY TYPE

PWR	42
BWR	18
HTGR	2
Not Specified	12
Total	74

II PLANT STATUS

Normal Operation (1-100% power)	55
Shutdown	15
Preoperation	4

III CLASS OF FIRE

Class A	7
Class B	29
Class C	38

IV INITIATING COMPONENT/EQUIPMENT

Breaker/Bus	12	Component Cooling Water Pump	1
Diesel Generator	8	Circuit Switcher	1
Transformer	8	Condensate Booster Pump	1
Turbocharger	5	Electrical Outlet	1
Reactor Coolant Pump	3	Electronic Display Panel	1
Cable	3	Radwaste Gas Decay Tank	1
Welding Equipment	3	Fire Pump	1
Battery	3	Hydraulic Oil Line	1
Hydrogen Gas Container	2	Hydrogen Analyzer Cabinet	1
Safety Injection Pump	2	Reactor Protection System	1
Exciter Controls	2	Valve Operator Motor	1
Feedwater Pump	2	Strainer Motor	1
Control Panel	2	Turbine	1
Auxiliary Boiler	1	Not Specified	5

V AREA OF FIRE ORIGIN

Diesel Generator Bldg	14	Cooling Tower	2
Yard	13	Weather Instrumentation Bldg	1
Reactor Bldg	10	Administration Bldg	1
Auxiliary Bldg	7	Control Bldg	1
Switchgear Room	6	Fire Pumphouse	1
Turbine Bldg	5	Security Bldg	1
Battery Room	4	Service Water Pump Room	1
Motor Control Center	2	Not Specified	5

VI CAUSE OF FIRE

Electrical Failure	37	Human Error	4
Component Failure	16	Improper Procedure	2
Welding/Cutting	6	Installation Error	1
Overheated Material	6	Not Specified	2

VII DETECTION METHOD

Plant Personnel	28	Contractors On Site	7
Automatic Detectors	9	Security Personnel	3
Main Control Board	8	Not Specified	19

VIII EXTINGUISHMENT METHOD

Plant Personnel	15	Contractors On Site	4
Self-Extinguishment	9	Security Personnel	1
Fixed Fire Protection System	4	Not Specified	37
Fire Department	4		

IX SUPPRESSION AGENT*

Gas (CO_2, Halon)	11	Dry Chemical	4
Water	11	Not Specified	44
None (Self-extinguishing)	8		

*Multiple methods employed in some incidents

TABLE 3. OCCURRENCE OF REQUIRED DATA ELEMENTS IN NFPA AND FACTORY MUTUAL DATA SETS (1978-1982)

Parameter	Number of Incidents* (Percent of Total Set) NFPA		FM	
Start-up Date	-	(0%)	-	(0%)
Date of Fire	143	(100%)	136	(100%)
Fire Size	-	(0%)	-	(0%)
Type of Facility	143	(100%)	136	(100%)
Operational Status of Plant	-	(0%)	136	(100%)
Area of Fire Origin	114	(80%)	129	(95%)
Equipment Involved	119	(83%)	122	(90%)
Class of Fire/Material Involved	109	(76%)	116	(85%)
Detection Time	84	(59%)	65	(48%)
Detection Method	114	(80%)	112	(82%)
Suppression Time (from Detection)	-		57	(42%)
Extinguishment Method	77	(54%)	98	(72%)
Extinguishing Agent	74	(52%)	57	(42%)
Cause of Fire				
Primary	112	(78%)	98	(72%)
Secondary	61	(43%)	41	(30%)
Property Damage ($)	119	(83%)	116	(85%)

*Extrapolated from samples. Total populations 143 for NFPA, 136 for FM.

**Beginning of operations

appear with higher frequencies in these data than for the nuclear power plant data. However, suppression times are e tirely absent from the NFPA data. Further, the quality of the responses for detection and suppression times also vary from incident to incident. The term "immediate" was used frequently in the incident reports to denote prompt fire detection or suppression operations.

Summaries of salient characteristics of the NFPA and FM data sets are provided in Tables 4 and 5. Incident counts are extrapolated from the samples.

2.3 GENERALIZED DATA CLASSIFICATIONS

The analysis of the data to determine the surrogateness of the nonnuclear NFPA and FM data to the nuclear power plant data requires the reclassification of several parameters so that comparisons can be made.

From a fire protection engineering viewpoint, the following four parameters in the required set (Table 1) of parameters may be used to make judgments regarding the equivalency of the nuclear and nonnuclear data: 1) area of fire origin; 2) equipment involved; 3) cause of fire; and 4) class of fire or material involved. In short, if the occupancies selected for comparison to nuclear power plants in this study, i.e., utility companies, paper/pulp industries and chemical manufacturing, are to be used in making probabilistic assessments of fire events, there should be some equivalency among these four parameters.

Subcategories of three of the four parameters of interest, i.e., area of fire origin, equipment involved and cause of fire, were generalized to assist in making comparisons. It must be realized that the parameters, area of fire origin and cause of fire, are usually subjective judgments. The categories for the parameters, therefore, cannot be considered mutually exclusive. The categories are bound to overlap in the nuclear as well as nonnuclear data. The paramter, class of fire/material involved was categorized according to the Fire Classes A,B,C, or D.

The generalized classifications of the selected data parameters are presented in Tables 6-9. Incident counts for NFPA and FM data have been extrapolated from sample percentages.

TABLE 4. CHARACTERISTICS OF NFPA DATA SET (1978-1982)

I FACILITY TYPE

Utilities	65 (46%)
Paper/Pulp	34 (24%)
Chemical	32 (22%)
Nuclear Power Plant	6 (4%)
Other	6 (4%)
	143

II CLASS OF FIRE

Class A	34 (24%)
Class B	65 (46%)
Class C	6 (4%)
Class D	3 (2%)
Not Specified	35 (24%)

III INITIATING COMPONENT/EQUIPMENT

Manufacturing/Process Equipment	44 (30%)	Generator/Motor	6 (4%)
Switchgear/Transformer	22 (15%)	Cable/Wiring	3 (2%)
Heating Equipment	9 (6%)	Conveyor	3 (2%)
Pump/Compressor	9 (6%)	Other	3 (2%)
Cutting Torch	6 (4%)	None Involved	6 (4%)
Furnace/Oven	6 (4%)	Not Specified	25 (17%)

IV AREA OF ORIGIN

Process/Manufacturing Area*	31 (22%)	Duct	3 (2%)
Machinery Room/Area	28 (20%)	Office/Administration	3 (2%)
Switchgear/Transformer Area	28 (20%)	Roof	3 (2%)
Heating Equipment Area	12 (9%)	Service Equipment Area	3 (2%)
Conveyor	3 (2%)	Not Specified	28 (20%)

V CAUSE OF FIRE

Component Failure	31 (22%)	Human Error	3 (2%)
Electrical Failure	25 (17%)	Incendiary	3 (2%)
Improper Procedure	21 (15%)	Lightning	3 (2%)
Spontaneous Heating	19 (13%)	Not Specified	34 (22%)
Welding/Cutting	6 (4%)		

VI DETECTION METHOD

Manual	109 (76%)
Automatic	6 (4%)
Not Specified	28 (20%)

VII EXTINGUISHMENT METHOD**

Manual	47 (33%)	Self-Extinguishing	13 (9%)
Fixed Fire Protection System	31 (22%)	Not Specified	66 (46%)

VIII SUPPRESSION AGENT**

Water	47 (33%)	None (Self-Extinguishing	13 (9%)
CO_2	16 (11%)	Not Specified	69 (48%)
Dry Chemical	16 (11%)		

*Area peculiar to a given occupancy - no equivalent area in nuclear power plant

**A given incident may involve more than one extinguishing method or suppression agent.

TABLE 5. CHARACTERISTICS OF FM DATA SET (1978-1982)

I FACILITY TYPE

Utilities	34 (25%)
Paper/Pulp	75 (55%)
Chemical	24 (18%)
Other	3 (2%)
Total	136

II CLASS OF FIRE

Class A	3 (2%)
Class B	20 (15%)
Class C	92 (68%)
Not Specified	21 (15%)

III INITIATING COMPONENT/EQUIPMENT

Breaker/Bus	24 (18%)	Compressor	3 (2%)
Circuit Switcher/Switchgear	16 (12%)	Fire Pump	3 (2%)
Cable	14 (10%)	Gas Piping	3 (2%)
Control Panel	14 (10%)	Hydroelectric Generator	3 (2%)
Transformer	11 (8%)	Scrubber	3 (2%)
Welding Equipment	11 (8%)	Turbine	3 (2%)
Control Equipment	7 (5%)	Not Specified	14 (10%)
Electric Motor	7 (5%)		

IV AREA OF FIRE ORIGIN

Production Area*	24 (18%)	Cable Runs/Trav	7 (5%)
Motor Control Center	17 (12%)	Laboratory	7 (5%)
Transformer/Switchgear (outside) Area	14 (10%)	Elevator	3 (2%)
		Pumphouse	3 (2%)
Boiler Room	11 (8%)	Underground Vault	3 (2%)
Power Substation	11 (8%)	Yard Area	3 (2%)
Switchgear (inside) Area	11 (8%)	Not Specified	7 (5%)
Turbine Bldg/Powerhouse	11 (8%)		
Administration/Office Area	7 (5%)		

V CAUSE OF FIRE

Electrical Failure	58 (42%)	Lightning	3 (2%)
Component Failure	20 (15%)	Overheated Material	3 (2%)
Welding/Cutting	14 (10%)	Not Specified	37 (28%)

VI DETECTION METHOD

Manual	95 (70%)	Not Specified	24 (18%)
Automatic	16 (12%)		

VII EXTINGUISHMENT METHOD**

Manual	82 (60%)	Self-Extinguishing	11 (8%)
Fixed Fire Protection System	11 (8%)	Not Specified	38 (28%)

VIII SUPPRESSION AGENT**

Water	34 (25%)	None (Self-Extinguishing)	11 (8%)
Carbon Dioxide	16 (12%)	Not Specified	
Dry Chemical	14 (10%)		

*Area peculiar to a given occupancy (utility, paper/pulp, chemical) - no equivalent area in nuclear power plant

**A given incident may involve more than one extinguishing method or suppression agent.

TABLE 6. CLASS OF FIRE

Type of Fire	No. of Incidents (Percent of Data Set) Nuclear	NFPA	FM
Class A	7 (9%)	34 (24%)	3 (2%)
B	29 (39%)	65 (46%)	20 (15%)
C	38 (51%)	6 (4%)	92 (68%)
D	-	3 (2%)	-
Not Specified		35 (24%)	21 (15%)

TABLE 7. AREA OF FIRE ORIGIN

Location	No. of Incidents (Percent of Data Set)* Nuclear	NFPA	FM
Boiler/Heating Equipment Area	-	12 (9%)	11 (8%)
Control Room**	5 (7%)	-	17 (12%)
Machinery Area (Generators, Motors)	14 (19%)	28 (20%)	-
Machinery Area (Pumps, Compressors)	9 (12%)		3 (2%)
Office/Storage Area	1 (1%)	3 (2%)	7 (5%)
Process, Manufacturing Area***	10 (14%)	31 (22%)	24 (18%)
Transformer/Switchgear Area (outside)	8 (11%)	28 (20%)	25 (18%)
Transformer/Switchgear Room	7 (9%)	-	11 (8%)
Turbine Room	5 (7%)	-	11 (8%)
Other	10 (14%)	12 (9%)	19 (14%)
Not Specified	5 (7%)	28 (20%)	7 (5%)

* NFPA and FM counts extrapolated from sample proportions

** Includes motor control centers

*** Locations specific to a given occupancy includes paper production equipment for paper/pulp, chemical process equipment for chemical industries, reactor for nuclear plants etc.

TABLE 8. EQUIPMENT INVOLVED

	No. of Incidents (Percent of Data Set)*		
	Nuclear	NFPA	FM
Boiler/Heating Equipment	1 (1%)	16 (11%)	-
Cable/Fixed Wiring	4 (5%)	3 (2%)	14 (10%)
Cutting/Welding Equipment	3 (4%)	6 (4%)	10 (8%)
Electric Motor	-	-	7 (5%)
Electronic Control Equipment	7 (9%)	-	20 (15%)
Generator/Motor (Diesel)	12 (16%)	3 (2%)	-
Manufacturing/Process Equipment**	-	44 (30%)	3 (2%)
Pump, Compressor	10 (14%)	9 (6%)	7 (5%)
Switchgear, Overcurrent Protection	11 (15%)	9 (6%)	41 (30%)
Transformer (w/Associated Overcurrent Protection)	8 (11%)	12 (9%)	10 (8%)
Other	13 (18%)	16 (11%)	10 (7%)
Not Specified	5 (7%)	25 (17%)	14 (10%)

* NFPA and FM counts extrapolated from sample proportions

** Equipment specific to a given occupancy. Includes production equipment for paper/pulp and chemical industries, specialized equipment for utilities (e.g., hydroelectric generators) and the reactor for nuclear power plants.

TABLE 9. CAUSE (PRIMARY) OF FIRE

	No. of Incidents*		
Cause	Nuclear	NFPA	FM
Component Failure	16 (22%)	31 (33%)	58 (42%)
Electrical Failure	37 (50%)	25 (17%)	20 (15%)
Human Error/Improper Procedure	7 (9%)	25 (17%)	-
Spontaneous Heating	-	19 (13%)	-
Welding/Cutting	6 (8%)	6 (4%)	14 (10%)
Other	6 (8%)	6 (4%)	7 (5%)
Not Specified	2 (3%)	34 (22%)	37 (28%)

* NFPA and FM counts extrapolated from sample proportions

III

SURROGATENESS OF NONNUCLEAR DATA (FROM A STATISTICAL PERSPECTIVE)

Two nonnuclear loss data sources, Factory Mutual System and the National Fire Protection Association (NFPA), were chosen as potential candidates to contribute to a surrogate fire loss data base. More specifically, the fire loss experience of three occupancy classes, utilities, paper/pulp, and chemical manufacturing, were selected on the basis that such facilities would closely resemble the physical and fire protection engineering features of nuclear power plants.

Computerized fire loss summaries for the selected FM and NFPA occupancies were reviewed and sets of potential surrogate loss incidents selected. The characteristics of these potential surrogate loss data sets were determined using a random sampling procedure. The primary objective of this random sampling scheme was to determine the occurrence rate of certain desirable data elements considered to be of importance in conducting certain Probabilistic Risk Assessments (PRA's) of fire events and fire protection features for nuclear facilities. The random samples consisted of 40 fire loss incidents from the FM data set (total population of 136) and 46 fire losses from the NFPA data set (total 143). The parameter occurrence rates and their corresponding values in the samples are assumed to be valid estimates of the true values in the respective populations.

3.1 COMPARISON OF LOSS EXPERIENCE (NUCLEAR VERSUS NONNUCLEAR)

The NFPA and FM samples are used to estimate several variables of interest and to characterize the nonnuclear population. As stated in Section 2.3, the parameters which are porposed for use in making judgments regarding the surrogateness of the data are 1) area of fire origin, 2) equipment involved, 3) cause of fire, and 4) class of fire.

To make statistical comparisons, two-way, chi-square contingency analyses have been performed. Such an approach to determine the surrogateness of data has been used previously to model oil spill risks [6]. These chi-square contingency analyses should determine whether the relative frequencies of fires for the parameter of interest (e.g., cause of failure) is independent of the data source from which the incident is taken, i.e., the nuclear or nonnuclear data base. It should be noted that the analysis requires a minimum of five expected elements [7] for any given cell (A cell consists of the count of occurrences of data for the experience versus the category of the parameter of interest.) to give reasonable confidence in the conclusions.

Tables A-1 through A-8 in the Appendix present the results of chi-square contingency analyses for comparing nuclear versus nonnuclear (FM and NFPA) fire incident experience. These tables include class of fire, cause of fire, area of fire origin, and type of equipment involved. As can be readily observed, in general the relative frequency of fires for any of the parameters considered is not independent of the experience, i.e., nuclear or nonnuclear. The only exception is that, for type of equipment involved (Table A-7), the relative frequency of fires from the nuclear data base is consistent with the relative frequency of fires from the NFPA data base. However, in view of the small (less than 5) expected frequencies for cables/fixed wiring, the results of the test are not exact (see Reference 7). Thus, overall the relative frequencies of fires are different among nuclear and nonnuclear loss data bases.

One other variable which would have been useful in making these comparisons is the occurrence rate of fires in nuclear and nonnuclear facilities. However, the parameters needed to determine occurrence rates were absent from the nonnuclear loss data. To obtain the rates of occurrence of fires for nuclear versus nonuclear data, for any parameter of interest, the operating experience (e.g., number of plant years, or reactor years) or other suitable exposure parameter is required. Such comparison of rates of occurrence would indeed establish the surrogateness of data and/or its use to determine the fire frequency distributions (as is required in a typical PRA). A fundamental assumption of this argument is that, from an engineering/physical viewpoint the similarities are already established. As an example, suppose that it was determined from fire protection and/or operating experience that the fire frequencies from nuclear and nonnuclear turbine rooms are similar. Then, if a measure of operating experience is available for both data sources, a statistical comparison of the rates of occurrence can be performed. Furthermore, if on the basis of this statistical comparison it was determined that the rates are dictated by similar chance mechanisms, the data (or rates of frequencies) can be combined to produce a combined rate of frequencies. Chapter 5 of the PRA Procedures Guide provides discussion on combining data from different sources (see 5.3.2.1.3, chapter 5, Data Base Development, equation 5.10 on page 5-37). In the PRA guide this was discussed in the light of combining sources of generic prior data for failure rates of components from different sources. It is believed that such techniques are also applicable for combining fire frequency rates from different sources of data (NFPA, FM etc.).

IV

FIRE PROTECTION SYSTEM RELIABILITY

4.1 SPRINKLER SYSTEM RELIABILITY

Sprinklers are probably the most widely used form of automatic fire extinguishment. Their value in controlling and extinguishing fire has long been realized [8].

Reliability: The definition of reliability of a device or system is the probability of its performing in the manner designed for a specified period under relevant environmental considerations [9]. Hence, it would seem that this reliability can be expressed quantitatively and defined numerically as the chance of the system operating when called upon to do so [9]. The primary sources of reliability data for sprinkler systems are operational history, test results, and design information. However, the factors that influence the reliability of sprinkler systems are: the design of the system as it relates to specific rules or standards of installation, the reliability of individual system components, the maintenance and management of the systems, and the human factors. As will be shown in the following subsections, extensive data on the performance or effectiveness of the sprinkler systems as a whole exist, but very little data are available on individual component failures. The failure of individual sprinklers after a fire may not be easy to detect or determine. In general, the effect of failure of a single sprinkler head on the overall system network is marginal. Nevertheless, in borderline cases where the hazard is severe, a single sprinkler head failure could cause the whole system to fail to control the fire [9]. Thus, the reliability of the individual components which comprise the entire system is very important. To the best of our knowledge, no extensive data on the failure rates of single sprinkler heads exist; however, Reference 9 presents a tabulation of test results from the U.K. Fire Research Station (FRS). From this source the following failure rate of sprinklers may be cited: Complete failures (failure of sprinkler to release water) are assessed at 0.92×10^{-2} (less than 1% chance of failure). This failure rate is based on 1967 tests resulting in 18 complete blockages of sprinkler heads.

Availability: While most data involve the performance or effectiveness of the systems after a fire has taken place, no data are readily available on the percent of time a sprinkler system is available so that it will perform its intended function in the event of a fire. Such data are primarily in (narrative-form) reports from field engineers after their inspection of the properties (e.g., FM loss prevention reports). Normally, the reports contain information on the status of automatic sprinkler systems and any major departure from the recommended practices or their maintenance and management.

4.1.1 Performance Or Effectiveness

In contrast to the reliability of individual components, performance or effectiveness is defined for the overall success of the sprinkler system in controlling/extinguishing a fire and this is primarily based on one of several subjective measures (Section 4.1.2). Sprinkler performance statistics are compiled by: the National Fire Protection Association in the United States; the Australian FPA for Australia and New Zealand; the Fire Offices' Committee (FOC) for the United Kingdom and by the Committee European des Assurance (CEA) for several European countries. In addition, at the local/regional level, for example, the New York Board of Fire Underwriters have also published such sprinkler performance statistics in high-rise buildings [10]. Industrial fire insurance companies such as IRI (Industrial Risk Insurers), beginning in 1982 as a part of their loss analyses, started publishing the Sprinkler Performance Statistics [11,12]. Similar statistics on the effectiveness of automatic sprinklers in industrial settings were also reported by the Factory Mutual System of industrial fire insurance companies [13].

While all the above mentioned sources publish sprinkler effectiveness statistics, the definitions of sprinkler effectiveness vary among the sources. The reason for the discrepancy over the definition of the satisfactory performance of an automatic sprinkler system is due largely to the subjectivity involved in the definition. Terms such as "control" and "less than 20% of building and contents damaged" are used to define sprinkler effectiveness. The NFPA definition of "control" in its Fire Journal article [14] is that sprinklers prevent excessive fire spread in accordance with the nature of the occupancy. For example, in certain occupancies, fewer than five sprinklers are deemed adequate for establishing control whereas in other occupancies more than 100 may be needed.

4.1.2 Measures of Sprinkler Performance

The single most commonly used measure of effectiveness is a graph showing the number of sprinkler heads that opened versus the cumulative percentages of fire. Figure 1 reproduced from Reference 8 presents four such graphs utilizing different sets of data. Sprinklers are, in general, considered to be more effective if fewer heads open in a larger percentage of fires. An alternative method of assessing automatic sprinkler performance is a breakdown of successes and failures. However, in such a method, as pointed out in Reference 8, the criterion chosen to determine success or failure is quite arbitrary. In addition, quite often, the term "control" (with the drawbacks pointed out in the above paragraph) is used as a criterion of success. Table 10 presents overall success rates from different sets of data. It is a modified version of Table 2 from Reference 8 with results from several additional data sources included. As can be seen, while the overall success rates are at least 95%, there is a wide variation in these rates. This variance is also evident from Figure 1.

4.1.3 Differences In Sprinkler Performance

Real differences in sprinkler performance do exist; Such differences are the result of sprinkler system design, installation and maintenance. However, other differences are due to variations in reporting and presentation procedures. References 8 and 14 analyze these differences extensively. The following discussion (drawing heavily from these references) briefly summarizes some of the major causes of reporting differences in sprinkler performance statistics.

1) Differences in sampling procedures of these data sources could exist due to bias in sampling. For example, certain data sources could include fires where the sprinkler system failed to operate because the valve was shut.

2) A bias in reporting procedure is noted as one of the most common arguments for the variations in sprinkler performance. It is a common practice to report major fires in which many heads have opened while ignoring to report small fires in which one or two heads opened. Consequently, the data tend to be biased toward the larger fires and reflect sprinklers in a less favorable perspective than is the reality. This situation is particularly aggravating in insurance company statistics because insureds do not report small fires controlled or extinguished by a few heads. This is due to the fact that often the

TABLE 10. OVERALL SUCCESS RATES OF AUTOMATIC SPRINKLERS

Sample	Source	Criterion of Success	Percent Successful
1. Australia & New Zealand 1886-1977	Ref. [15]	Less than 20% of building and contents damaged	99.6
2. NFPA 1925-1969	Ref. [14]	Control	96.2
3. New York High- & Low-Rise Buildings	Ref. [10]	Control	95.8
4. United Kingdom Fire Brigade 1966-1973	Ref. [16]	Control	95.4-96.2 (corrected for unreported fires)
5. Factory Mutual System 1971-1978	Ref. [13]	Control	better than 98.0 (wet systems)
6. Industrial Risk Insurers 1981-1982	Ref. [11,12]	Control	96.0-98.0
7. U.S. Dept. of Energy 1951-1980	Ref. [17]	Control	98.0

monetary loss in those situations would be less than the relevant deductible and the insureds cannot claim any compensation from the insurer (the insurance company). Such a reporting bias prompted NFPA to completely halt the publishing of sprinkler performance statistics after 1970 [8].

3) A comparison of sprinkler performance, based on European statistics revealed [8] that there are no measurable differences between the performance of sprinklers built according to standards and those that are not. In the case of the data sources in the U.S., e.g., NFPA, the sprinkler systems and water supply are presumed to be designed adequately for the occupancy (building use). If, by reason of poor design or human failure, a sprinkler system does not establish control, its performance must be labeled unsatisfactory [14].

4) It is obvious that different occupancies present different degrees of fire risk and therefore need different magnitudes of fire protection. Thus, it would be logical as indicated in Reference 14, that sprinkler performance varies with the type of occupancy. Fires in high-rise occupancies as an example, open a greater number of sprinkler heads. In Reference 14 it was concluded that textile mills and similar occupancies had better than 98% success rate. Further, the average number of sprinklers opened was also shown to vary greatly with the occupancy. It is possible that some variations among different sources of data can be due to the different "spread" of occupancies among the sources.

5) In References 8 and 14, it was shown that wet-pipe systems have, in general, far better sprinkler performance that dry-pipe sprinkler systems. This difference is due primarily to the design of the dry-pipe system which involves initial delay in the opening of sprinkler heads (as air in the pipe network must be expelled). Further, dry sprinklers are particularly used in unheated storage areas which have large, quickly developing fires that open a large number of sprinkler heads. It is also stated [8] that wet-pipe systems dominate in the Australian sprinkler systems reflecting their better overall performance.

6) Differences in types of construction are also expected to affect the variance in sprinkler performance statistics. For example, high-rise buildings, with their fire-resistive construction and compartmentation, tend to have fewer number of heads opening in a fire (Figure 1). However, by an analysis of

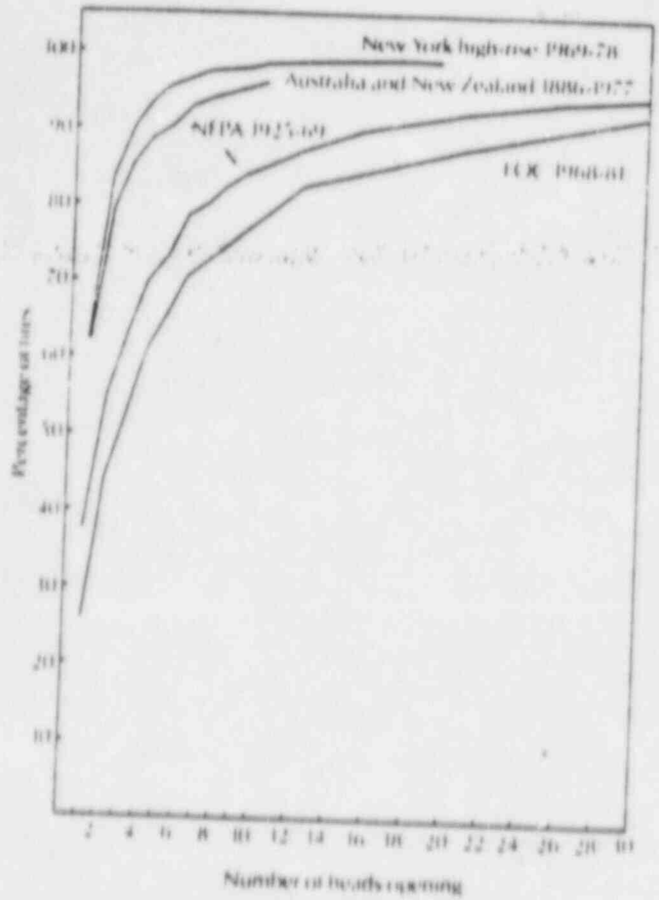

FIGURE 1 AUTOMATIC SPRINKLER PERFORMANCE FROM DIFFERENT SETS OF DATA (from ref: 8)

New York high-rise and low-rise fires it was shown that this difference is not significant. Thus, it is concluded that differences in "mix" of types of construction in different sets of data could exert some influence on variations in sprinkler performance. Additionally, in Reference 13 it was shown that fire-resistive construction had not significantly decreased the monetary damage (loss) in fire.

4.1.4 Unsatisfactory Sprinkler Performance

The NFPA statistics based on reports submitted during 1897-1969 [14] were analyzed with respect to unsatisfactory sprinkler performance in Reference 18. Table 11 excerpted from Reference 18 presents the unsatisfactory performance by failure categories. The satisfactory sprinkler performance was placed at 96.15%; However, these results should be interpreted with regard to the wide spread data period (1897-1969) during which design (and/or maintenance) standards might have changed.

4.1.5 Sprinklers And Life Safety

The 1970 NFPA sprinkler performance tables [14] indicate that Life-saving aspect of sprinkler performance is excellent. This is in spite of the fact that sprinklers were originally developed to reduce fire damage to property and the large majority of the systems currently in service were installed for that purpose. Reference 14 further asserts that there was no major loss-of-life fire in a sprinklered hotel, nursing home, school, public assembly building, factory, or other building. However, several casualties due to explosions occurred in a few sprinklered industrial buildings. Further, the neglect of the possibility or leakage of flammable gas or vapor into areas where people were working was judged as the cause for these explosions (a cause totally unrelated to the sprinkler presence and/or its satisfactory performance).

4.2 RELIABILITY ASSESSMENT OF AUTOMATIC FIRE DETECTORS

Automatic fire detectors are basically installed for the early detection of the products of combustion from a fire [19]. Heat, smoke, flame or any combination of these products comprise the combustion products. The value of an Automatic Fire Detection System (AFDS) is in its ability to quickly detect

TABLE 11. SUMMARY OF CAUSES OF UNSATISFACTORY SPRINKLER PERFORMANCE (NFPA)

Cause of Failures	Number of Fires	Percent of Total
System frozen	44	0.05
Slow operation	56	0.07
Faulty building construction	187	0.23
Obstruction to distribution	256	0.31
Hazard of occupancy	240	0.30
Inadequate maintenance	262	0.32
Antiquated system	65	0.08
Defective dry-pipe valve (equipment)	53	0.07
Water shut-off (premature shut-off)	243	0.30
Inadequate water supply (mains broken)	13	0.02
Explosion	184	0.23
External exposure fire	52	0.06
Miscellaneous and unknown	60	0.07

Source: Data from Reference 18

fire so that evacuation of personnel and extinction of fire can be achieved effectively. Thus, AFDS value is measured with respect to the risk involved and its reliability in performing its expected function. AFDS are installed primarily 1) to protect safety of lives or 2) to safeguard property. Reference 19 tabulates an assessment by chemical plant safety officers from the United Kingdom regarding the performance of AFDS. Table 12 from [19] is reproduced here. In Reference 19, extensive analysis of false alarms from AFDS is also presented as it is believed that false alarms result in serious reduction of AFDS credibility. For different sites, such as plants, laboratories, offices, etc. Reference 19 also computed the AFDS event rates. An observation in Reference 19 is that the location (siting) and choice of detector type are of particular concern and contribute more to the variability in performance at some sites than does the reliability of individual detectors. By analyzing various maintenance and testing operations on the performance of AFDS at United Kingdom health facilities it was concluded [19] that regular maintenance was rather rare. This was attributed to lack of instruction regarding cleaning and maintenance from AFDS from manufacturers.

Several comments are in order on the reliability assessments/computations noted in the above paragraphs:

1) The models are based on the global data from different sites with different types of detectors, different procedures for maintenance and are based on different time periods, detector populations, etc. (see note at end of Table 2).

2) It was shown in [19] that detector types influence the variability in performance (in terms of failure to operate). Also, flame detectors (ultraviolet and infrared) give a high false alarm rate and remarkably high failure-to-operate event rate - for every real alarm there is a failure to operate (see Table 13). The high failure rate of UV and IR detectors could possibly be due to their high-sensitivity and installation in high risk areas.

3) No significant correlation was found [19] between total number of detector heads and total number of faults on testing per year. Thus, primarily system design deficiency is indicated rather than individual detector performance.

4) For properties greater than 2000 m^2 area direct line AFDS appeared to be of economic value. Electrical engineering and chemical industries were

TABLE 12. RELIABILITY ASSESSMENT OF AUTOMATIC FIRE DETECTOR SYSTEMS (AFDS) (Chemical Plant Data for Risk Categories)

Risk Category	E/TD/A* Real Alarm	False Alarm	Failure to Operate	Ratio Real Alarm: False Alarm
Plant in buildings incl. plant office	4.7	3.4	0.15	1: 0.72
Open plants	60	273	27	1: 4.55
Storage in buildings	0.68	9	0.1	1:13.24
Combined plant and storage in buildings	0.27	2.2	0	1: 8.15
Switchrooms and elec. substations	0.05	208	0	1:4,160
Separate instr./control rooms incl. plant computers	18	27	0	1: 1.5
Outside storage	0	36	0	-
Office blocks	0.93	4.1	0	1: 4.41
Labs. and semi-technical plant	1.2	4.8	0.73	1: 4.0
G.P. computer suites	33	55	11	1: 1.67
Workshops, garages and battery charging	0	9.4	0	-
Boiler plant/power stations	0	0	0	-
Training centers, hostels club buildings	2.9	5.7	0	1: 1.97
Total	2.1	7.2	0.16	1: 3.43

*Events/Thousand Detectors/Annum

Source: Reference 19

TABLE 13. [illegible] CHEMICAL PLANT DATA FOR DETECTOR TYPES

Detector Type	E/TD/A*			Ratio
	Real Alarm	False Alarm	Failure to Operate	Real Alarm: False Alarm
Heat	1.5	5.3	0.3	1:3.53
Smoke	5.9	40	0.5	1:6.78
Smoke & Heat	16	38	0	1:2.38
UV & IR (ultra-violet and infrared)	108	622	108	1:5.76

*Events/Thousand Detectors/Annum

Source: Reference 19

found [19] to have the highest degree of AFDS. Although false alarms were determined to be major problems, no significant consequential loss in production could be established. High false alarms are noted to occur during working hours and where there are large numbers of people present (e.g., offices, see Table 2).

5) In high risk areas, where a false alarm or failure of AFDS to operate could result in major catastrophe, or a shutdown, the desired level of reliability of AFDS should be achieved with regard to the various factors exerting influence in AFDS performance. Thus, an adequate consideration of these factors at the early stages of system design installation are recommended [19].

6) A particular recommendation in [19] is that in nuclear plant AFDS it is suggested that uncertainties in AFDS performance could best be resolved through in-house testing of detectors under the environmental conditions anticipated to occur normally in each area. Reference 20 describes results of testing smoke detectors at various United Kingdom health care facilities and presents the 99% threshold concentration level of response of smoke detectors of various types. Table 14 is a reproduction of Table 5 from Reference 20. A specially designed smoke detector tester (called MK1) which generates a controlled quantity of aerosol of dioctylphthalate (DOP) which supposedly simulates the smoke produced by burning material was used to test the smoke detectors (see Reference 20 for details). It is evident that the type of detector had a significant influence on the response. Such a conclusion was also arrived at in Reference 21 after the conduct of a series of tests.

4.3 EFFECTIVENESS OF SPECIAL FIRE PROTECTION SYSTEMS

Insurance company data over the past decade have shown less than 50% effectiveness for special protection systems [22]. However, it is recognized that, as with sprinklers, many successes are not reported for the same reasons as discussed for sprinkler effectiveness. Past studies of the National Association of Fire Equipment Distributors (NAFED) have resulted in claims of a "high rate" of effectiveness [23], but the statistics were based on system actuation and did not include accurate data on incidents where systems failed to operate. In 1980 it was determined that accurate data on the value or effectiveness of special fire protection systems simply did not exist. Hence, in

TABLE 14. RELIABILITY ASSESSMENT OF SMOKE DETECTORS: TEST RESULTS PERFORMED AT UNITED KINGDOM HEALTH CARE FACILITIES

Hospital	Make of Detector	Sample Size	Normal Distribution Parameters: Mean* (mg/m^3)	Normal Distribution Parameters: Standard* Deviation	Threshold limit for 99% of detectors to respond
18 Oxford Road	Type A	5	73.3	19.6	117.9
Leytonstone House-I	Type F	71	97.0	27.3	160.5
16 Orford Road	Type A	3	69.6	4.6	80.3
London Whitechapel	Type G	16	122.5	32.7	198.5
	Type H	15	144.1	58.0	248.9
	Type A	2	73.6	28.4	139.6
Bounds Green	Type I	15	97.0	12.0	124.7
Clatterbridge-I	Type F	47	77.9	12.0	105.7
New Cross	Type J	6	72.0	17.4	112.4
	Type A	15	58.3	40.0	150.5
North Middlesex	Type A	25	79.2	9.0	99.9
Clatterbridge-II	Type B	31	76.0	13.0	106.0
Claybury	Type C	133	69.6	16.6	108.2
Wanstead	Type D	33	100.4	35.5	182.9
South Ockendon	Type A	6	69.6	20.5	117.3
Warley D Block	Type C	28	60.1	24.5	117.2
Harold Wood	Type E	12	133.9	34.6	214.5
Greentrees	Type A	5	146.0	10.7	170.8
Thrope Coombe	Type A	54	114.2	33.7	192.5
Royal Wolverhampton	Type L	4	158.9	30.8	230.2
	Type I	28	191.8	16.9	231.2
Leytonstone House-II	Type F	120	78.5	14.9	113.1
Thurrock	Type I	21	147.8	29.4	216.2
Rochford	Type K	78	111.7	11.2	137.7
Warley	Type C	227	126.7	40.6	221.2

*Concentration of DOP (aerosol)

Source: Reference 20

1980 a fire protection industry study was initiated to evaluate the reliability of carbon dioxide, dry chemical, and Halon special protection fire suppression systems. The study was conducted by the National Fire Protection Association Industrial Fire Protection section and jointly funded by Factory Mutual, Industrial Risk Insurers, Kemper, Fire Equipment Manufacturers Association, National Association of Fire Equipment Distributors, and the National Fire Protection Association. The study solicited anonymously-submitted case histories of fire incidents involving these systems. A special incident report form was designed by the program sponsors which included all pertinent data relative to the fire incidents necessary for the determination of system effectiveness. Over 2000 of these incident report forms were requested and distributed to parties interested in participating in the study. Only 60 of these incident report forms were ever returned of which 38 were actually fire incidents; 22 were accidental discharge or discharge not called for. Of the 38 fire incidents, 23 involved CO_2 systems; 7 involved dry chemical systems; and 8 involved Halon systems.

The net result of this comprehensive study was that there were still inadequate data upon which to accurately determine the value or effectiveness of special protection systems. An in-depth literature search conducted on the computerized Lockheed interactive data base failed to turn up any additional data on the subject.

V

SUMMARY

The data reviewed thus far have yielded: 1) 74 fire incidents occurring in operating nuclear power plants for the period 1978-1982. This number, together with 62 previously (1960-1977) documented operating nuclear power plant fires, results in a total of 136 fire incidents over an approximate six reactor-years; and 2) a total of 279 fire incidents for the period 1978-1982 occurring in nonnuclear facilities (utilities, paper/pulp and chemical plants) judged to be equivalent from a fire protection engineering viewpoint. Because all loss incidents had to be manually reviewed, the losses investigated during this study were confined to the period 1978-1982. All nuclear fire loss incidents (74) were reviewed and random samples consisting of approximately 30.8 percent (40 FM incidents, 46 NFPA incidents) of the 279 nonnuclear incidents (136 FM incidents, 143 NFPA incidents) were also reviewed.

The inclusion of the nonnuclear fire incident data would probably improve the quality of the data base and perhaps allow for ultimate refinement of PRA's. However, in general from a statistical perspective it could not be established whether the nonnuclear data are indeed surrogates for the nuclear data. The only exception to this statement is their relative frequency of fires by equipment involved was consistent between nuclear and nonnuclear (NFPA) data. Data on a key parameter, operating experience at nonnuclear facilities, could not be obtained.

Thus, statistically, it could not be conclusively proven that the available data for the selected nonnuclear occupancies were compatible to the nuclear power plant data. This problem may be circumvented in either one of two ways. The first is to allow the initial assumption of equivalence from a fire protection engineering assessment to take precedence over the limited statistical comparison technique, i.e., the chi-square contingency analysis, or one can review a broader range of occupancies, selecting only the parameters of interest from the set of all industrial fire losses.

The second approach assumes that, for example, a Class B fire in a nuclear power plant pump room is equivalent, in terms of fire protection, to a Class B pump room fire in a refinery, which, in turn, is the same as a Class B pump room fire in a liquefied natural gas processing facility. This approach can be taken even further by using four of the five fire event characteristics* listed as required data elements in Table 1. It is likely that if sufficient data were available on nuclear and nonnuclear fire events to subcategorize by Area of Fire Origin, Equipment Involved, Class of Fire, and Cause of Fire, there would be a similarity in physical characteristics of the fire events.

In terms of the adequacy or effects of the present (available) nuclear and nonnuclear data bases on the refinements of the PRA's, the following observations can be made:

1) fire frequency: data exist on the nuclear/nonnuclear facilities; however, the rates of accurrence at nonnuclear facilities cannot be determined as there are no available data on operating experience;

2) fire size (magnitude): no such data exist in the nonnuclear/nuclear facilities; however, if property damage ($) can be taken as an appropriate substitute measure for fire size, then significant data exist on this parameter at nonnuclear facilities; no such data was available on property damage at nuclear facilities;

3) transient material fire: data on class of fire indicating the material involved exist at both nuclear and nonnuclear data bases; however, whether the material involved is transient cannot be established;

4) area of fire origin: data on this parameter exist (at better than 80% of the time) for both nuclear and nonnuclear facilities;

5) equipment involved: the availability of data on this parameter is also very good in both nuclear and nonnuclear data bases;

6) detection time: data are virtually nonexistent at nuclear facilities; however, for nonnuclear facilities reasonable estimated times are available. Therefore, if it can be assumed that detection times at nuclear and nonnuclear facilities are similar, distribution of absolute detection times can be derived for the available; nonetheless, distribution of detection time conditional on fire magnitude (size) cannot be derived in view of the nonexistence of data on fire size;

---

*Fire Size, Area of Fire Origin, Equipment Involved, Class of Fire and Cause of Fire

7) suppression time (from detection): negligible data exist at nuclear facilities; among the nonnuclear data bases, NFPA data base has no data on this parameter, while FM data base has adequate (sample size). With this availability, the distribution of absolute suppression times can be developed but the distribution of suppression times conditional on fire size cannot be derived as there are no data on fire size;

8) Frequency of fires with secondary independent initiating events cannot be derived for either nuclear or nonnuclear loss experience from the available data.

9) Data on component responses to different magnitudes of fires cannot be obtained from the present nuclear or nonnuclear data bases.

10) Refinements of prior distribution of frequency of fires: refining estimates of fire frequencies at nuclear facilities are possible only if it can be established that rates of occurrence at nonnuclear facilities are compatible with the nuclear loss experience. Statistical techniques for combining rates of occurrence are available in the current PRA state-of-the-art (Chapter 5, PRA Procedures Guide).

A thorough review of the available data sources, literature, etc., indicates that, among all forms of fire protection systems, automatic sprinkler systems have the highest performance record (better than 95%) in terms of their effective control of fires. They are also the oldest form of automatic fire protection. However, several factors influence their performance. Adequate design and maintenance of these systems will increase their reliability and performance. Automatic Fire Detection Systems (AFDS) are not as widespread as the automatic sprinkler systems. Therefore, data on reliability of AFDS are not as extensive as the sprinkler systems. However, the location (siting) and type of detector (heat, smoke, etc.) for the occupancy (building use) account for the variability in performance. Adequate testing of these AFDS by simulating environmental conditions anticipated during normal operations in the area of facility is highly recommended. It is also suggested that, in high risk areas where failure of AFDS to operate results in significant damage, proper consideration must be given to the factors affecting their variability in the early stages of system design installation. Special fire protection systems are yet another form of automatic fire protection systems. Carbon-dioxide, dry chemical, and Halon are the chief extinguishing agents in these systems. Virtually no accurate data exist on the effectiveness of these special protection systems. Estimates range from a "high-degree" of effectiveness to less than 50%.

REFERENCES

1. National Fire Protection Association, Uniform Coding For Fire Protection, NFPA No. 901, 1976
2. Dungan, K.W. and Lorenz, M.S., "Nuclear Power Plant Fire Loss Data," Professional Loss Control, Inc., Report to Electric Power Research Institute (EPRI), EPRI Report No. NP-3179, July 1983
3. Sideris, A.G. and Garlington, D.C., "Nuclear Plant Fire Incident Data Analysis," American Nuclear Insurers, June 1978
4. Ramachandran, G., "Economic Value of Automatic Fire Derectors," Building Research Establishment Information Paper, IP 27/80, November 1980
5. "World List of Nuclear Power Plants," Nuclear News, August 1983, pp 83-102
6. "Deepwater Ports Approach/Exit Hazard and Risk Assessment," Report No. CG-D-6-79, Final Report, February 1979, U.S. Coast Guard, Department of Transportation, Office of Research and Development, Washington, D.C. 20590, pp 93-96.
7. "Probability and Statistics for Engineers and Scientists," 2nd Edition, Ronald E. Walpole and Raymond H. Myers, 515, McMillan Publishing Co., Inc., New York, 1978, pp 268-272
8. "How Successful Are Sprinklers"? Frank Smith in SFPE Bulletin, April 1983, (originally published in Fir Prevention, November 1982).
9. "The Reliability of Sprinkler Systems," P. Nash and R. Young, FIRE SURVEYOR, Vol. 5 No. 2, pp 21-27, April 1976
10. "Sprinkler Experience in High-Rise Buildings (1969-1979)," W.R. Powers, SFPE Technology Report 791-1, SFPE (1979)
11. "Analyzing IRI's 1981 Losses," THE SENTINEL, Fourth Quarter 1982
12. "Analyzing IRI's 1982 Losses," THE SENTINEL, Third Quarter 1983
13. "The Automatic Sprinkler in Controversial Settings: Are Sprinklers The Best Fire Protection System For Computer Rooms and Anechoic Chambers? Are They Needed In Concrete Buildings," Factory Mutual Record, November-December 1980
14. "Automatic Sprinkler Performance Tables - 1970 Edition," FIRE JOURNAL, July 1970

15. "Automatic Sprinkler Performance in Australia and New Zealand-1886-1968," H.W. Marryatt, Australian Fire Protection Association (1971)

16. Memorandum 9/78 Fire Research Home Office Scientific Advisory Branch, 1978 (United Kingdom)

17. "Automatic Sprinkler System Performance and Reliability in United States Department of Energy Facilities; 1952-1980," DOE/EP-0052, June 1982, U.S. DOE Office of the Assistant Secretary for Environmental Protection, Safety, and Emergency Preparedness

18. "An Assessment of the Performance of Automatic Sprinkler Systems," J. Kenneth Richardson, Technical Note, FIRE TECHNOLOGY, November 1983

19. "Reliability Appraisal of Fire Detection Systems," by S.T. Peacock, Dr. A.R.R. Kamath and Dr. A. Zibeller, paper presented at AIChE Prevention Symposium, 1982

20. "Reliability Assessment of Smoke Detectors," by A.R.R. Kamath, A.Z. Keller in RELIABILITY ENGINEERING, Vol. 2 (1981) pp 281-288

21. "Fire Tests in Ventilated Rooms: Detection of Cable Tray and Exposure Fires," EPRI Report No. NP-2751 prepared by Factory Mutual Research Corporation (J.S. Newman, Principal Investigator) Interim Report, February 1983

22. "The Reliability of Fire Protection Systems," M.J. Miller, Factory Mutual Research Corporation, November 1973

23. several related articles Firewatch, Vol 15, No. 2, June 1978

BIBLIOGRAPHY

Baldwin, R., and North, M.A., "The Number of Sprinklers Opening and Fire Growth," FIRE TECHNOLOGY, November 1973

"Sprinkler Trade-Offs: Are They Justified," James P. Barris Dario . L Conte-Russian, Fire Journal, May 1980

"Sprinkler Trade-offs And The Australasian Experience," Harry W. Marryatt, FIRE JOURNAL, January 1981

"The Handbook of Property Conservation," Second Edition, Factory Mutual Engineering Corporation, Factory Mutual System, Norwood, MA 02062, 1978

"Interpretation of Statistics on the Performance of Sprinkler Systems," D.J. Rasbash, CONTROL, Vol. 2, No. 2, pp 63-73, May 1975

"The Australian Experience With Automatic Sprinklers," H.W. Marryatt, AFPA FIRE JOURNAL, September 1974

"Why Sprinkler Trade-Offs Work," Edward J. Reilly, SPRINKLER OF NEWS, September 1980

APPENDIX

RESULTS OF CHI-SQUARE CONTINGENCY ANALYSIS FOR COMPARISON
NUCLEAR VERSUS NONNUCLEAR (FM AND NFPA)
FIRE INCIDENT EXPERIENCE BY

- CLASS OF FIRE
- CAUSE OF FIRE
- AREA OF FIRE ORIGIN
- EQUIPMENT INVOLVED

TABLE A-1. COMPARISON OF NUCLEAR VERSUS NONNUCLEAR EXPERIENCE FOR CLASS OF FIRE EXPERIENCE

Class of Fire	Nuclear	Nonnuclear (NFPA) (Est. number in the population)*	Total
A	7 (17)	34 (24)	41
B	29 (39)	65 (55)	94
C	38 (18)	6 (26)	44
Total	74	105	179

Notes and Computations

1) No Class D fires in the nuclear data base; However there was 1 Class D fire in the NFPA sample and the corresponding estimated number of Class D fires in the population are 3 fires, thus for the contingency analysis 108 - 3 = 105 fires are used (108 are the total estimated from Table 6)

2) The numbers in parentheses are the expected frequencies computed as (for any cell) $e = \frac{RC}{T}$ where R = row total, C = column total and T = grand total; ex: Class A nuclear fires 41 x 74 ÷ 179 = 17 (rounded)

and $\chi^2 = \sum_i \frac{(O_i - e_i)^2}{i}$ where O_i = observed frequency e_i = expected frequency (for ith cell) is distributed as χ^2 with (r - 1) x (- 1) degrees of freedom (d.f.),

where r = no. of rows and c = no. of columns

$$\chi^2 = \frac{(7 - 17)^2}{17} + \frac{(34 - 24)^2}{24} + \frac{(29 - 39)^2}{39} + \frac{(65 - 55)^2}{55}$$

$$+ \frac{(38 - 18)^2}{18} + \frac{(6 - 26)^2}{26}$$

= 5.88 + 4.17 + 2.56 + 1.82 + 22.22 + 15.38

= 52.04

χ^2 (cal) = 52.04 with (3-1) x (2-1) = 2 d.f.

At 5% level of significance, the χ^2 (theoretical) value for 2 d.f. is 5.991 (Reference 7, p 515)

and since the computed value exceeds the theoretical value, reject the hypothesis that relative frequencies by class of fires is independent of the experience (nuclear or nonnuclear).

TABLE A-2. COMPARISON OF NUCLEAR VERSUS NONNUCLEAR EXPERIENCE FOR CLASS OF FIRE

Class of Fire	Nuclear	Nonnuclear FM	Total
Class A	7(4)	3(6)	10
Class B	29(19)	20(30)	49
Class C	38(51)	92(79)	130
Total	74	115	189

Note: There were an estimated 21 fires in the FM population (extrapolated from 6 in the sample) for which the class of fires were unspecified.

Calculation:

$$\chi^2 = \frac{(7-4)^2}{4} + \frac{(3-6)^2}{6} + \frac{(29-19)^2}{19} + \frac{(20-30)^2}{30}$$

$$+ \frac{(38-51)^2}{51} + \frac{(92-79)^2}{79} = 2.250 + 1.50 + 5.263 + 3.33$$

$$+ 3.314 + 2.139 = 17.796 \text{ with } (3-1) \times (2-1) = 2\text{df}$$

At 5% level of significance, the χ^2 theoretical value for 2 d.f. is 5.991; since the computed value exceeds the theoretical value, reject the hypothesis that the relative frequencies by class of fires is independent of the experience.

TABLE A-3. COMPARISON OF NUCLEAR VERSUS NONNUCLEAR EXPERIENCE FOR CAUSE OF FIRE

Cause Of Fire	Nuclear	Nonnuclear NFPA (Estimated number in the population)	Total
Component Failure	16 (18)	31 (29)	47
Electrical Failure	37 (24)	25 (38)	62
Human Error Improper Procedure	7 (12)	25 (20)	32
Spontaneous Heating & Welding/Cutting	6 (12)	25 (19)	31
Total	66	106	172

Computation:

$$\chi^2 = \sum_i \frac{(O_i - e_i)^2}{e_i} = \frac{(16-18)^2}{18} + \frac{(31-29)^2}{29} + \frac{(37-24)^2}{24} + \frac{(25-38)^2}{38}$$

$$+ \frac{(7-12)^2}{12} + \frac{(25-20)^2}{20} + \frac{(6-12)^2}{12} + \frac{(25-19)^2}{19}$$

$= .222 + .138 + 7.042 + 4.447 + 2.083 + 1.250 + 3.00 + 1.895 = 20.077$

with $(4-1) \times (2-1) = 3$ d.f. χ^2 (theoretical) at .05 level = 7.815

(Reference 7, p 515)

Therefore, since the computed value exceeds the theoretical value, reject the hypothesis that the relative frequency of fires by cause of fire is independent of the experience (nuclear or nonnuclear).

TABLE A-4. COMPARISON OF NUCLEAR VERSUS NONNUCLEAR EXPERIENCE FOR CAUSE OF FIRE

Cause of Fire	Nuclear	Nonnuclear FM	Total
Component Failure	16 (31)	58 (43)	74
Electrical Failure	37 (24)	20 (33)	57
Human Error/Improper Procedure	7 (3)	0 (4)	7
Spontaneous Heating, Welding/Cutting	6 (8)	14 (12)	20
Total	66	92	158

Calculation

$$\chi^2 = \frac{(16-31)^2}{31} + \frac{(58-43)^2}{43} + \frac{(37-24)^2}{24} + \frac{(20-33)^2}{33} + \frac{(0-4)^2}{4} + \frac{(7-3)^2}{3}$$

$$+ \frac{(6-8)^2}{8} + \frac{(14-12)^2}{12}$$

$$= 7.258 + 5.232 + 7.042 + 5.121 + 40 + .924 + 0.333 + 5.333$$

$$= 35.243 \qquad \text{with } (4-1) \times (2-1) = 3 \text{ d.f.}$$

χ^2 theoretical at .05 level = 7.815; therefore, since the computed value far exceeds the theoretical, reject the hypothesis that the relative frequency of fires by cause of fire is independent of the experience (nuclear or nonnuclear)

TABLE A-5. COMPARISON OF NUCLEAR VERSUS NONNUCLEAR EXPERIENCE FOR AREA OF FIRE ORIGIN

Location	Nuclear	Nonnuclear FM (Est. No. in population)	Row Totals (R)
Control Rooms	5 (9)	17 (13)	22
Machinery Areas	23 (11)	3 (15)	26
Transformer/Switchgear Areas	15 (22)	36 (30)	51
Turbine Rooms	5 (6)	10 (8)	15
Column Totals (C)	48	66	114

Notes: Machinery Areas include both categories in Table 7 (generators, motors, pumps and compressors). Transformer/switchgear areas are both outside and inside. Boiler/Heating equipment, Process/Manufacturing and Office/Storage areas, as well as the categories Other and Not Specified not included in this analysis.

We have (r-1) x (c-1) = (4-1) x (2-1) = 3 d.f.

The test statistic is

$$\chi^2 = \frac{(5-9)^2}{9} + \frac{(17-13)^2}{13} + \frac{(23-11)^2}{11} + \frac{(3-15)^2}{15} + \frac{(15-22)^2}{22} + \frac{(36-30)^2}{30} + \frac{(5-6)^2}{6} + \frac{(10-9)^2}{p}$$

$$= 1.78 + 1.23 + 13.09 + 9.6 + 2.23 + 1.23 + 1.7 + .11$$

$$= 29.44$$

The theoretical χ^2 with 3 d.f. ($\alpha = 0.05$ level of significance) = 7.815

Therefore reject assumption of independence of experience relative frequency of fires for area of fire origin,

TABLE A-6. COMPARISON OF NUCLEAR VERSUS NONNUCLEAR EXPERIENCE FOR AREA OF FIRE ORIGIN

Location	Nuclear	Nonnuclear NFPA	Row Totals (R)
Control Room	5 (2)	0 (3)	5
Machinery Areas	23 (24)	28 (27)	51
Transformer/Switchgear Areas	15 (20)	28 (23)	43
Turbine Rooms	5 (2)	0 (3)	5
	48	56	104

$$\chi^2 = \frac{(5-2)^2}{2} + \frac{(0-3)^2}{3} + \frac{(23-24)^2}{24} + \frac{(28-27)^2}{27} + \frac{(15-20)^2}{20} + \frac{(28-23)^2}{23} + \frac{(5-2)^2}{2} + \frac{(0-3)^2}{3}$$

$$= 4.5 + 3.0 + .04 + .04 + 1.25 + 1.09 + 4.5 + 3.0$$

$$= 17.42 \text{ with } (4-1) \times (2-1) = 3 \text{ d.f.}$$

The χ^2 theoretical value at 0.05 level of significance is 7.81; therefore, since the computed value is far greater than the theoretical value, reject the hypothesis that the relative frequency of fires by area of fire origin is independent of the experience nuclear or nonnuclear (NFPA)

ENCLOSURE 2

BROOKHAVEN NATIONAL LABORATORY

MEMORANDUM

DATE: February 3, 1984

TO: J. Boccio

FROM: P. Samanta P. Samanta

SUBJECT: Review of FMRC Draft Technical Report "Evaluation of Available Data for Probabilistic Assessments (PRA) of Fire Events at Nuclear Power Plants and Reliability Assessments of Fire Protection Systems"

The Factory Mutual Research Corporation (FMRC) has reviewed fire-loss incidents for nuclear and non-nuclear facilities during the period 1978-1982. The primary purpose of this study was to determine the existence of various data elements necessary to estimate the parameters required to conduct Probabilistic Risk Assessment (PRA) of fire events in nuclear power plants. It is known from present PRA's that many data elements are absent in the nuclear data base; thus, the further objective was to establish if non-nuclear data bases are compatible with nuclear data bases and if so, whether more usable data are available in the non-nuclear data base for enhancing the limited nuclear data base. This is expected to serve two purposes, 1) in cases where the data base is virtually non-existent it will provide a realistic data base, and 2) in cases where the data base is limited, the use of compatible non-nuclear data will reduce the uncertainties in those parameters.

In the present report, FMRC has completed what can be termed the first phase of the overall objective. By evaluating the fire-loss data over a limited period (1978-1982), it has established the occurrence rate of data elements in nuclear and non-nuclear data bases. As mentioned in the report, this study provided few encouraging observations.

1. The data on detection time, virtually non-existence in nuclear data base (1/74), is available in the non-nuclear data base (149/279). This provides an adequate data base for determining the distribution on detection times.

2. The data on suppression time (from detection) is also very limited in nuclear data base (6/74); however, the non-nuclear data base, in this case, also provides a good data base (57/279).

Thus, in the two critical areas of nuclear power plant probabilistic risk assessments, the non-nuclear data base appears very encouraging. However, there are areas of disappointment in non-nuclear data base.

1. The non-nuclear data base is incapable of producing the operating experience without much effort. This causes difficulty in comparing the compatability of nuclear and non-nuclear data and also prohibits its use in directly evaluating the fire frequency.