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Evaluation of Available Data for Probabilistic Risk Assessments (PRA) of Fire Events at Nuclear Power Plants

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ABSTRACT

Several crucial parameters are needed in the assessment of fire risk in nuclear power plants. Among those that need to be developed from a data base are: (1) fire frequency, (2) fire detection time, and (3) fire suppression time. Currently, the data base for nuclear power plants is not large enough to develop these parameters, considering fuel location, fuel geometry, combustion properties, enclosure geometry, etc. This study attempts to augment the nuclear data base by investigating the usefulness of other nonnuclear data bases which contain fire incident loss experience of occupancy classes having somewhat similar physical features and fire protection engineering systems normally found in nuclear power plants. This study has found that indeed some useful information can be gleaned from nonnuclear sources; in particular, detection and suppression times. However, other fire-risk data needs such as fire frequency and fire size would require other forms of data searches and data analyses that at this stage can only be conceptualized.

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EXECUTIVE SUMMARY

This document presents a study in which several existing data bases were evaluated with regard to their potential usefulness in 1) the refinement of probabilistic risk assessments of fire events in nuclear power plants and in 2) the assessment of the reliability of fire protection systems. Fire-incident data bases, other than those developed by the nuclear industry, were examined as well to see whether the information supplied therein could be used to augment and enhance fire data normally culled and analyzed from direct nuclear experience.

Making these evaluations required i) identification of those nonnuclear data bases containing sufficient fire-incident information in order to determine its surrogateness to nuclear power plant fire-incident experience, ii) establishment of specific fire data needs and requirements through a review of current state-of-the-art in fire-risk analysis, iii) establishment of important (critical) parameters required for the refinement of fire-risk analysis, iv) determination of occurrence rates of those identified parameters, based upon data needs for the Probabilistic Risk Assessment (PRA) of fire events in nuclear power plants, and v) comparison of nuclear versus nonnuclear experience (and therefore surrogateness) by comparing the occurrence rates of certain, fire-related parameters.

The scope of this effort was structured to not only investigate a means to enhance those data bases normally used in nuclear power plant fire-risk studies but also to provide a more firmer foundation from which the reliability of nuclear power plant fire protection features and systems can be appraised. In this regard, efforts stressed methods, approaches, and data for evaluating the performance of automatic detection and suppression systems.

The nonnuclear data bases investigated included a proprietary data base developed by the Factory Mutual System (FM). Queries into this data base and other nonnuclear data bases (NFPA, etc.) were conducted by FM under subcontract to Brookhaven National Laboratories (BNL). These data bases, chosen as potential candidates to contribute to a surrogate fire-loss data base, contain fire-loss experience of several occupancy classes that (in some respects) are similar to the physical and fire-protection features found in nuclear power plants.

Elements sought from the nonnuclear data base sets were dictated by data needs and requirements inherent in existing, state-of-the-art fire-risk analyses as well as the potential users interested in operational data on fire-safety equipment failures and successes. These elements and users are identified in Section II of this report.

In Section III, fire loss data for both nuclear and nonnuclear facilities are identified for the period 1978-1982 and summaries of the salient characteristics of all data sets queried are tabulated. To determine the surrogateness of the nonnuclear data (NFPA and FM sources) to the nuclear power plant data (LERs, ANI, EPRI), a reclassification of several parameters in the data set was necessary before comparisons could be made.

In Section IV of the report, these comparisons were made using chi-squared, two-way contingency analysis. This technique is designed to test the hypothesis that the loss occurrence (relative frequencies) by parameter of interest (area of fire origin, cause of fire, equipment involved, etc.) is independent of the data source, i.e., independent of the nuclear and nonnuclear data sources.

Overall, the study has established the availability of data of certain key parameters (e.g., detection and suppression times) in the nonnuclear data bases investigated which are highly deficient in the nuclear data bases examined. However, the statistical comparisons for other select fire parameters shown in Appendix and summarized in Section IV, did not result in the compatability between the nuclear industry data bases and the nonnuclear industry data bases.

Specifically, in terms of the adequacy or effects of the data bases examined for potential usefulness in fire-risk analysis, the study has shown the following:

1. Fire Frequency: While data, albeit sparse, exist for nuclear facilities, attempting to extract such information from nonnuclear sources would entail a large expenditure of effort.
2. Physical Fire Size: No such data exist in the nonnuclear and nuclear data bases.
3. Combustible Material: Data on class of fire (i.e., material involved) exist from both data sources.
4. Area of Fire Origin: Data largely available for both nuclear and nonnuclear facilities.

5. Equipment Involved: The availability of data is also very good for both nuclear and nonnuclear installations.

6. Detection Time: Virtually nonexistent data at nuclear facilities; reasonable availability of this type of data for nonnuclear facilities.

7. Suppression Time: Negligible data for nuclear sites. Among the nonnuclear data bases, NFPA has no data while FM data exist in reasonable form.

Accordingly, the study indicates that for detection and suppression times, absolute distributions could be derived if one can first establish the similarity of fire environments in nuclear and nonnuclear facilities. In order to pursue this further, the study recommends that partitioning of nonnuclear data should be done on specific locations of interest and not directly by occupancy class.

Thus, the initial premise of this study that nonnuclear data sources can, overall, provide useful information for fire-risk analysis with minor additional data analysis effort could only be justified on certain aspects of nuclear fire data needs. Indeed, what this study had found is that some useful information can be gleaned from these sources. In particular, detection and suppression times. Other fire-risk data needs, e.g. fire frequency and fire size, would require other forms of data searches and data analyses that at this stage of the study can only be conceptualized. Implementing these concepts would require much additional effort.

I
INTRODUCTION

The occurrence of fires and their effects on nuclear power plant safety are rather complex issues. Methods that are used to evaluate the hazards of fire and its impact on plant operations can be broadly divided into two categories: physical models and probabilistic models. Methodologies that have been developed which incorporate a hybrid of models within each of these two categories have been utilized in so-called full scope Probabilistic Risk Assessments (PRAs) to quantify the risk from fires in nuclear power plants. Basically, these methods must not only account for the many aspects of a fire incident (e.g., fire ignition, propagation, detection and suppression, the characteristics of materials under fire conditions, etc.) but also must account for the behavior of plant safety functions under fire-induced accident conditions.

In quantifying the impact of fire on plant operability and safety, large uncertainties prevail. These uncertainties arise from different sources, viz., (1) intrinsic randomness, (2) uncertainties with respect to mathematical/physical model(s), and (3) uncertainties with respect to the stochastic model(s). The first source refers to the real scatter of the natural phenomena (such as fires); the other two refer to our lack of knowledge when attempting to translate the various phenomological aspects of a fire incident into physical and statistical models. In fire risk analysis (as well as other fields of engineering) the model uncertainties are at least as equally important as the intrinsic randomness. Relevant data are very limited, incomplete or in specific cases not available at all. Consideration of these sources of uncertainty therefore requires, at least partly, probability assignments accompanied by experience and judgment. Thus, although engineering judgment must continue to be an integral part of probabilistic risk assessment procedures, a primary purpose of this study is to investigate the usefulness and applicability of other sources of fire incident data bases, heretofore not considered nor utilized in the appraisal of nuclear power plant fire risk. A primary motive for this study is to enhance existing nuclear data bases thereby reducing (somewhat) our incomplete knowledge concerning the inherent variability of fire within the nuclear industry.

In this report, various data bases were evaluated that are presently available for potential application in probabilistic and reliability assessments of fire events and fire protection features. In those cases where the data base and data base sets have been found inadequate, recommendations are made as to where various data-base elements can be improved.

Through the course of this program, efforts had been placed in examining data bases in the following areas:

1. frequency/magnitude of fires,
2. distribution of detection time,
3. distribution of suppression time,
4. distribution of fire with a secondary, independent initiating event, and
5. component responses to different magnitudes of fire.

In this context, Section II provides a broad overview of data needs and requirements of both risk-assessment analyses and fire-protection system reliability determinations. Elements of a requisite data base set are defined to provide a sharper focus of the needed information that should be gleaned from the data bases queried. In Section III, various nuclear and nonnuclear data bases are examined in a framework structured by the data needs and requirements established in Section II. To assess surrogateness of the nonnuclear data bases to the nuclear power plant data bases, a reclassification scheme is indicated for subsequent comparison. With this reclassification scheme established, evaluation of both data base sets is made in Section III. Here, and in Section IV, indications are made as to where existing, nonnuclear data can provide useful information in nuclear power plant fire risk assessments and fire-protection system reliability appraisals.

From this study and its initial attempts for determining surrogateness of nonnuclear data, Section IV focuses on the problems one faces in using these data bases and their inherent limitations based upon risk-assessment parameter needs. From the experienced accrued during the course of this study recommendations are provided (Section V and Section VI) as to how these existing data can be further analyzed and incorporated with needed deterministic fire growth modeling and probabilistic fire risk assessment. For those more interested in the data analysis manipulations and how the recommendations can be implemented, Appendix A and B are provided.

II
DATA REQUIREMENTS FOR NUCLEAR POWER PLANT FIRE ANALYSIS

Before one can establish a data-requirements set for a nuclear power plant fire-safety analysis, potential data users of such a data set must be first identified. A major objective of this study has not only been to investigate nonnuclear, fire-incident data-base sources in an attempt to improve or augment existing nuclear data bases for PRA studies but also to indicate other potential uses of these added sources of fire-incident information. One of the potential uses is improved fire-system reliability. Data on fire mitigating equipment failures and failure rates can serve as input for generic analysis of the reliability of fire-safety equipment. These data sets can also be used in a confirmatory role. Operational data on fire-safety equipment failures and successes can greatly expand the existing data base and serve to check the level of safety built into the equipment and the plant. Another use is in a redefinition role in a sense to evaluate the validity of and provide input to potential technical specification modifications. Finally, the comparative evaluation of nuclear and nonnuclear data bases can define the weaknesses in the nuclear fire data base and will identify the elements that should be reported in future nuclear fire loss incidents.

In general, fire data requirements must include both fire initiating event data and equipment failure as well as operational data under harsh, fire-induced, environmental conditions. To best see how these data needs and requirements become manifest, the following equation (which is used in one form or another in fire-risk analysis) is presented for illustrative purposes. The equation,

$$\phi_x = \sum_i \lambda_i f^i_{fuel} \, Q(t_G, t_s) \, Q^i_I \, Q^i_{a,x} \, Q^i_{u,x} \quad ,$$

expresses the frequency of a particular plant damage state due to a fire where

$\phi_x \equiv$ frequency of damage state x.

$i \equiv$ denote a critical area.

$\lambda_i \equiv$ frequency of fire in critical area i.

$f^i_{fuel} \equiv$ conditional frequency of fires involving a certain class of pilot fuels in the critical area.

$Q(t_G, t_s)$ ≡ conditional frequency of fire growth given the fire involving the pilot fuel of f^i_{fuel}.

Q^i_I ≡ conditional frequency of the initiating event I, given the fire.

$Q^i_{a,x}$ ≡ conditional frequency of failure or non-restoration of components affected by fire that would lead to plant damage state x if initiating event I occurs and other components unaffected by the fire fail.

$Q^i_{u,x}$ ≡ unavailability of components due to causes other than fire.

From the definitions of each of the above noted factors, four basic steps are required to analyze the risk due to fires in a nuclear power plant, viz.:

1. Identification of important fire-related accident scenarios (usually termed as sequences in PRAs).
2. Assessment of the frequency of fires.
3. Assessment of the fraction of fires that damage critical components.
4. Assessment of the conditional frequency of severe consequences, given damage to critical components.

Four ideas are central to the quantification: i) the occurrence of fires, ii) the physical effects of fires (given that fire-mitigating systems are in effect), iii) the response of the plant under the prevailing and pervasive effects of the fire and its attendant products and iv) the fire-fighting activities. Indeed, the occurrence of fires and their effects on plant safety are such complex issues that PRA practitioners must resort to highly conservative assumptions coupled with engineering judgment in order to perform the analysis. Also, because of the rarity of fire occurrences in nuclear power plants, there is a need for physical and probabilistic models that utilize to the greatest degree possible the available evidence from the plants and, at the same time, provide results that can be used directly in probabilistic risk analysis.

Thus, until physical models are developed that couple ignition, propagation, and fire growth with detection and suppression sub-models in a fashion that represents a more cogent compromise between accuracy in real fire environment simulation and practicality of implementation what drives the fire-incident data needs and requirements is the existing PRA methodology.

Accordingly, in fire risk studies, it becomes necessary to establish the frequency of fires (λ_i) of a certain fuel class, at a certain location, and with a certain severity level as exemplified through the functional expression $Q(t_G,t_s)$. This expression relates in probabilistic terms the time, t_s, required by fire-mitigating activities to inhibit further growth and thereby preventing the fire from reaching higher levels of severity. To date, nuclear power plant fire risk analyses utilize deterministic fire-growth models (for t_G) with statistical data (for t_s) in a highly decoupled manner, i.e., deterministic growth models (or physical models) do not explicitly take into account the concomitant effects of fire suppression activities. Indeed, the large state-of-knowledge uncertainties in modeling fire behavior are judged to dominate the statistical uncertainties.

The remaining parameters in the above functional expression implicitly indicate that the data necessary for fire frequency calculations ideally should include information on the sequence of events in every fire incident. These details should include, among other things, the ignition cause, medium of propagation, pattern of propagation, methods and timing of detection and suppression, components affected, plant and operator action through the course of the event, and the age and status of the plant.

To delineate the above discussion in terms of data needs for nuclear fire risk assessment, one essentially seeks to establish a data base for the frequency of fire, the time of detection which influences the fire growth, and the suppression time. However, the determination of these parameters are complicated by the fact that they are dependent on a large number of associated factors. Even though the influence of each or a combination of these factors are not clearly known, one can identify, based on engineering judgment, the factor expected to be of dominant influence. The frequency of fire is dependent on the fire location and the equipment involved. The establishment of the frequency of fires requires the knowledge of the time period over which the fire incidents are counted, i.e., one requires the startup date of the plant and its outages. The detection time is largely influenced by the detection method and the class of fire, other than the parameters indentified with fire frequency. The suppression time is a function of detection time, extinguishment method (manual or automatic), and extinguishing agent. Of course, the other crucial parameter influencing these three parameters (fire frequency, detection time and suppression time) is the fire size. However, the means of defining the fire size in a fire loss report is not yet specified and it is highly optimistic to develop this parameter from the data base. Deterministic modeling using detection, suppression times and the property damage will remain the vehicle for estimating the fire size.

Based on the above considerations, Table 1 provides the parameters that should, at the minimum, be identified in fire-loss reports for use with current state-of-the-art deterministic and probabilistic models.

III
THE DATA

3.1 APPPROACH

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

It was recognized that nuclear power plant design, as well as fire protection features, requirements and reporting, have changed in recent years. Since the primary objective of this effort was to determine if sufficient data exists to develop key distributions, it was decided to look only at the time period 1978-1982 for nuclear losses. It was assumed that, if key data were not available for that most recent 5-year time frame, then certainly they would not be available for any preceding period. In addition, it was questioned whether the earlier data would be applicable to current technology even if available. It should be recognized that more than half of all documented nuclear fire incidents occurred during this period. Further, at the time this study was initiated, it was also clear that inclusion of post-1982 data would be impractical within time and funding constraints and premature. It should also be recognized that post 1982 data, once sufficient quantity are available, could prove to be significantly different due to the impact of Appendix R.

For purposes of consistency, the same time period was selected for the nonnuclear loss data with the assumption that the presence or absence of key loss data during this period would be representative of earlier years as well. Further, additional years could be included at a later date if necessary for distribution development.

Nuclear power plant fire loss data were obtained from the Nuclear Regulatory Commission (NRC), American Nuclear Insurers (ANI), and Professional Loss Control, Incorporated (PLC) via Electric Power Research Institute (EPRI).

Due to the acknowledged shortage of nuclear loss data, various other industrial data bases were evaluated for potential surrogate loss data. It became clear that the options for detailed automated and obtainable data on industrial fire losses of interest were very limited. These options included the Factory Mutual (FM) 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).

The primary value of an automated data base is the ability to retrieve and sort incidents by key parameters from a data base containing many incidents of no interest. Detailed data (if available at all) must generally be obtained from hard copy review of individual incident reports. Thus, all incident report summaries were manually reviewed and, in the case of the FM data, the original loss reports surveyed for the desired information. Smaller, isolated pockets of data which may exist in a nonautomated and otherwise difficult-to-retrieve format, or are proprietary in nature, were not sought. Previous experience has shown the attempted collection of such data to be time consuming and generally not fruitful.

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 temporarily inactive due to reorganization and funding cuts within the Fire Administration. However, in retrospect it is unlikely that NFIRS would have been of any additional value. 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.

3.2 NUCLEAR POWER PLANT FIRE LOSS EXPERIENCE

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 345 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 the 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.

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

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 the data elements required for making probabilistic risk assessments (as discussed in Section II). The occurrence rates for those data elements are provided in Table 1. None of the fire incidents reviewed contained an estimate of fire size. Two parameters potentially useable for estimating fire size were 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, the model is based entirely upon fire department response and requires knowledge of four specific times (ignition to detection, detection to fire department notification, notification to arrival and control time) in addition to some data on physical fire size for its application. Therefore, it did not prove to be directly applicable to the project.

Detection and suppression times were essentially absent from the data set, occurring at rates of 5/74 and 8/74 respectively. The occurrence rate of the parameter, area of fire origin, while well represented in the broad sense, did not provide sufficient detail to define the exact location of the fire.

Since data on three key parameters for PRA development (fire size, detection time, and suppression time) are essentially nonexistent, there is no question that the nuclear data in and by itself are not adequate for the generation of key parameter distributions. However, because facility startup times are provided and hence operating-year data, estimates of incident occurrence rates by certain area and equipment categories could be developed (i.e., switchgear room fires/unit time or diesel generator fires/unit time). It must be recognized that, if subgroups are made too small, insufficient incident counts will render frequencies meaningless.

For information, a summary of nuclear fire losses by year of occurrence (1978-1982) is presented in Table 2. A summary of the salient characeristics of those losses is presented in Table 3. Table 4 provides a summary of the actual detection and suppression times as recorded. Note that the term "immediate" is used for both detection and suppression times. This term clearly cannot be considered accurate and is usually equated with times less than one minute.

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	5/74	(7%)
Detection Method	55/74	(74%)
Suppression Time (from Detection)	8/74	(11%)
Extinguishment Method	37/74	(50%)
Extinguishing Agent	30/74	(40%)
Cause of Fire		
Primary	72/74	(97%)
Secondary	23/74	(31%)
Property Damage ($)	6/74	(8%)

* Obtained from Reference 5

TABLE 2. NUCLEAR POWER PLANT FIRE LOSSES BY YEAR

Year	No. of Fire Losses	Approximate Number of Plants in Operation
1978	16	65
1979	12	67
1980	18	70
1981	17	74
1982	11	76

TABLE 3. 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 (including 1 hot)	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	7	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	2
Auxiliary Boiler	1	Not Specified	5

V AREA OF FIRE ORIGIN

Diesel Generator Bldg	14	Cooling Tower	2
Yard	12	Weather Instrumentation Bldg	1
Reactor Bldg	10	Administration Bldg	1
Auxiliary Bldg	7	Control Bldg	1
Switchgear Room	6	Fire Pump House	1
Turbine Bldg	5	Security Bldg	1
Battery Room	4	Service Water Pump Room	1
Motor Control Center	2	Not Specified	6

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 4. TABULATION OF DETECTION AND SUPPRESSION TIMES AS RECORDED ON NUCLEAR LOSS INCIDENTS

Detection Times (estimated from ignition)	Suppression Times (estimated from ignition)
Immediate	Immediate
Immediate	Immediate
Immediate	1 minute
Immediate	1 minute, 7 seconds
7 minutes	8 minutes
	13 minutes
	14 minutes
	2 hours

Note: Columns not related

3.3 NONNUCLEAR FIRE LOSS EXPERIENCE (PROPOSED SURROGATE DATA)

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 the 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.

The occurrence rates of key data elements are shown in Table 5.

The dates upon which these nonnuclear plants commenced operations are not available from either the NFPA or FM data sets. Hence, total operating experience (population data) is not available for NFPA and FM data sets as is the case with nuclear facilities and, therefore, estimates of incident occurrence rates (frequency) cannot be developed from the data.

Also missing from both data sets are estimates of fire size. Other key parameters such as detection and suppression times appear with higher frequencies in these data than for the nuclear power plant data. However, suppression time does not even appear as a variable on the most comprehensive of the NFPA incident reports and therefore is absent from the NFPA data. Further, the quality of the responses for detection and suppression times also vary from incident to incident. Also, the term "immediate" was again, as with the nuclear data, used frequently in the FM incident reports to denote prompt fire detection or suppression operations.

TABLE 5. 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. Sample sizes 46 for NFPA, 40 for FM. Total populations 143 for NFPA, 136 for FM.

** Beginning of operations.

Summaries of salient characteristics of the NFPA and FM data sets are provided in Tables 6 and 7. Incident counts are again extrapolated from the samples.

It should be recognized that, due to real differences in specific equipment and areas found in the nonnuclear facilities as compared to the nuclear facilities as well as differences in coding, it is not possible to generate analogous categories for these tables compared to Table 3.

Table 8 provides a summary of detection times as recorded in the NFPA 46 incident sample. Table 9 provides a summary of the actual as-recorded detection and suppression times from the FM 40 incident sample. Recognize that the intervention of suppression would be expected to have a significant effect on fire growth and size even prior to the achievement of control.

3.4 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 hazard viewpoint, the following four parameters in the required set (Table 1) of parameters may be used to make judgments regarding the equivalence 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, initiating equipment 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 parameter, class of fire/material involved, was categorized according to the Fire Classes A, B, C, or D. Class A fires are fires involving ordinary combustibles such as paper, wood, cloth and rubber; Class B fires are those involving flammable liquids and gases; Class C fires are fires in which energized electrical equipments are involved; and Class D fires involve combustible metals such as magnesium and titanium.

Table 10 presents a comparison of class of fire for the three data sets. Table 11 is a generalized comparison of area of fire origin. Table 12 shows how the information in Table 3 was categorized in Table 11 for the nuclear incidents. Table 13 is a generalized comparison of initiating equipment for the three sets, and Table 14 again shows how the nuclear incident information in Table 3 was recategorized for Table 13.

Incident counts for NFPA and FM data have been extrapolated from sample percentages. Table 15 is a generalized comparison of primary causes of fires for the three data sets. Section IV of this report uses the data in these tables to make an evaluation about the usefullness of nonnuclear data for surrogate purposes.

TABLE 6. 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 (31%)	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 (8%)	Service Equipment Area	3 (2%)
Conveyor	3 (2%)	Not Specified	28 (20%)

V CAUSE OF FIRE

Component Failure	31 (21%)	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 (23%)
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

TABLE 7. 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/Tray	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 (43%)	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 agent

TABLE 8. TABULATION OF DETECTION TIMES AS RECORDED IN THE 46 INCIDENT NFPA SAMPLE

Detection Time (from ignition)	Frequency of Occurrence
Less than 1 minute	24
1-2 minutes	2
3-5 minutes	1
6-9 minutes	1
10-19 minutes	2
Not coded	19

TABLE 9. TABULATION OF DETECTION AND SUPPRESSION TIMES AS RECORDED IN THE FM 40 INCIDENT SAMPLE

Incident	Detection Time (from ignition)	Suppression Time (min:sec) (from ignition)
1	NC	Self-extinguished
2	IM	1:40
3	NC	Self-extinguished
4	NC	10:00
5	NC	2:30
6	IM	45:00
7	IM	NC
8	NC	60:00
9	IM	IM
10	15 minutes	NC
11	IM	30:00
12	NC	35:00
13	IM	NC
14	IM	16:00
15	NC	IM
16	IM	5:00
17	IM	NC
18	IM	NC
19	IM	10:00
20	IM	NC
21	IM	NC
22	IM	NC
23	NC	IM
24	IM	IM
25	IM	39:00
26	NC	60:00*
27	IM	90:00
28	IM	Self-extinguished
29-40	12 incidents in which neither detection nor suppression time is coded.	

IM = immediate

NC = not coded

* From initiation of suppression activity

TABLE 10. 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 11. AREA OF FIRE ORIGIN

Location	No. of Incidents (Percent of Data Set)* Nuclear		NFPA		FM	
Boiler/Heating Equipment Area	-		12	(8%)	11	(8%)
Control Areas	6	(8%)	-		17	(12%)
Electrical Generator Area (Generators, Motors)	14	(19%)	28	(20%)	-	
Fluid Pumping Area (Pumps, Compressors)	8	(11%)			3	(2%)
Office/Administration Areas	1	(1%)	3	(2%)	7	(5%)
Process, Manufacturing Area**	10	(14%)	31	(22%)	24	(17%)
Transformer/Switchgear Area (outside)	9	(12%)	28	(20%)	25	(18%)
Transformer/Switchgear Room	7	(9%)	-		11	(8%)
Turbine Room	5	(7%)	-		11	(8%)
Other	10	(14%)	12	(8%)	23	(17%)
Not Specified	4	(5%)	28	(20%)	7	(5%)

* NFPA and FM counts extrapolated from sample proportions

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

TABLE 12. COMPARISON OF NUCLEAR INCIDENT CATEGORIZATION (TABLE 3 VERSUS TABLE 11)
AREA OF FIRE ORIGIN

Location per Table 11	No. of Incidents	Corresponding Locations per Table 3	No. of Incidents
Control Area	6	Motor Control Center	3
		Cooling Tower (Control House)	1
		Control Building	1
		Not Specified (Electronic Control Panel)	1
Electrical Generator Area (Generators, Motors)	14	Diesel Generator Building	14
Fluid Pumping Area (Pumps, Compressors)	8	Auxiliary Building	6
		Fire Pump House	1
		Service Water Pump Room	1
Office/Administration Areas	1	Administrative Building	1
Process/Manufacturing Areas	10	Reactor Building	10
Transformer/Switchgear Area (Outside)	9	Yard	9
Transformer Switchgear Areas (Indoors)	7	Switchgear Room	6
		Not Specified (Bus Bar Location)	1
Turbine Room Area	5	Turbine Building	5
Other	10	Yard	3
		Cooling Tower	1
		Weather Building	1
		Battery Room	4
		Security Building	1

TABLE 13. INITIATING EQUIPMENT

	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	2 (3%)	-	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	13 (18%)	9 (6%)	41 (30%)
Transformer (w/Associated Overcurrent Protection)	8 (11%)	12 (9%)	10 (8%)
Other	9 (12%)	16 (11%)	10 (7%)
Not Specified	5 (7%)	25 (17%)	14 (10%)

* NFPA and FM counts extrapolated from sample proportions

** Locations 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 14. COMPARISON OF NUCLEAR INCIDENT CATEGORIZATION (TABLE 3 VERSUS TABLE 13) INITIATING EQUIPMENT

Equipment per Table 13	No. of Incidents	Corresponding Equipment per Table 3	No. of Incidents
Boiler/Heating Equipment	1	Auxiliary Boiler	1
Cable/Fixed Wiring	4	Cable	3
		Electrical Outlet	1
Cutting/Welding Equipment	3	Welding Equipment	3
Electric Motors	2	Valve Operator Motor	1
		Strainer Motor	1
Electronic Control/ Instrumentation Equipment	7	Exciter Controls	2
		Control Panel	2
		Electronic Display Panel	1
		Hydrogen Analyzer Cabinet	1
		Reactor Protection System (Control Valve Relay)	1
Generator/Motor Diesel	12	Diesel Generator	7
		Turbocharger	5
Pump Compressor	10	Reactor Coolant Pump	3
		Safety Injection Pump	2
		Feedwater Pump	2
		Component Cooling Water Pump	1
		Condensate Booster Pump	1
		Fire Pump	1
Switchgear, Overcurrent Protection	13	Breaker/Bus	12
		Circuit Switches	1
Transformer	8	Transformer	8
Other	10	Battery	3
		Hydrogen Gas Container	2
		Radwaste Gas Decay Tank	1
		Hydraulic Oil Line	1
		Turbine	2

TABLE 15. CAUSE (PRIMARY) OF FIRE

Cause	No. of Incidents* Nuclear	NFPA	FM
Nonelectrical Component Failure	16 (22%)	31 (33%)	20 (15%)
Electrical Failure	37 (50%)	25 (17%)	58 (42%)
Human Error/Improper Procedure	7 (9%)	24 (16%)	-
Spontaneous Heating	-	19 (13%)	-
Welding/Cutting	6 (8%)	6 (4%)	14 (10%)
Other	6 (8%)	6 (4%)	6 (4%)
Not Specified	2 (3%)	34 (23%)	37 (28%)

* NFPA and FM counts extrapolated from sample proportions

IV

EVALUATION OF NONNUCLEAR DATA FOR USE WITH NUCLEAR DATA FOR DEVELOPMENT OF PARAMETER DISTRIBUTIONS

4.1 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 3.4, the parameters which are used for 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 successfully 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 Appendix A 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 observed, the number of cell observations does not always meet the requirements as stated above. However, the problem of degree of confidence is moot since in all but one of the cases, 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. Table 16 provides a summary of the chi-square analysis. Note

*Note: detection and suppression times cannot be tested directly for surrogateness, since these data do not exist in the nuclear fire loss data base.

that the calculated value of χ^2 must be less than the theoretical value of χ^2 in order to have an acceptable outcome.

4.2 USEFULNESS OF NONNUCLEAR DATA

In general, it can be said that the nonnuclear fire loss data specifically as represented by utility, paper and pulp, and chemical industries fire loss data (from FM or NFPA data bases) cannot be considered as surrogate for nuclear fire loss data with regard to characteristics of the fires (area, class, cause and equipment involved). Hence, values for parameters of interest from the NFPA and the FM data bases cannot be used in total with data from nuclear loss experience to develop distributions. It would appear in retrospect that the selection of the utility, paper and pulp, and chemical industries for evaluation of surrogatensss may not have been the optimum selection. However, it does appear from the exercise that significant data do, in fact, exist in regard to two of the three key parameters of interest for PRA development, i.e., detection and suppression time, and that such data should be usable. It is necessary, however, before the nonnuclear detection/suppression data be used with nuclear loss data to generate distributions, that we be sure that the nonnuclear fire detection/suppression environments are sufficiently similar to the corresponding nuclear environment to assure at least reasonably close distributions, i.e., surrogate locations. Judging from results in Section 4.1, it would seem that such assurances are not possible with the broad selection of <u>any</u> occupancy classes. The only logical way to proceed would be to partition the nonnuclear locations not by occupancy per se but by specific sublocation of interest. By looking specifically at critical areas in nuclear facilities and looking at corresponding locations (if possible) in nonnuclear industrial locations, similarity of characteristics of the fire (cause, class, initiating equipment) can be assured. Fire protection engineers familiar with both nuclear and nonnuclear facilities indicate that it would then be possible to select incidents from these critical areas in the nonnuclear facilities which would also be expected to have similar detection and suppression time distributions. These incidents could then be combined with the nuclear incidents to develop distributions. The critical areas should include diesel generating rooms, control rooms, switchgear rooms, cable spreading rooms, cable tunnels, and battery rooms.

TABLE: 16 CHI-SQUARE (χ^2) ANALYSIS RESULTS

Variable	Nuclear vs NFPA χ^2 Calculated	Nuclear vs NFPA χ^2 Theoretical	Nuclear vs FM χ^2 Calculated	Nuclear vs FM χ^2 Theoretical
Class of Fire	52	6	17.8	6
Cause of Fire	20.1	7.8	10.7	7.8
Area of Fire Origin	15.9	7.8	28.9	7.8
Initiating Equipment	5	7.8	16.4	7.8

Notes: Theoretical values of χ^2 are obtained from chi-square tables. They are based upon a 0.05 level of significance for the appropriate degrees of freedom for each analysis. Degrees of freedom are dependent upon the number of values of each variable. Appendix A shows how the calculated values of χ^2 were computed for each analysis.

As far as frequency distributions of fire loss incidents are concerned, it does not appear possible to obtain additional data from the nonnuclear industrial sector due to the lack of population data as discussed in Section 3.3. Such estimates of fire frequencies must come from the nuclear data for which the population data or operating experience exists.

With regard to the development of fire size distributions, it is unlikely that fire loss data alone can provide reasonable input at this time. The dollar loss information in the nonnuclear industrial data cannot provide a uniform meaningful measure of physical fire size. Dollar loss is not only affected by physical fire size but also by values per unit area or volume (which vary greatly), by smoke and water damage, and by physical differences of the fire environment such as ceiling height, ventilation and, of course, suppression action. If partitioning of the loss data by specific equipment areas still does not allow for the development of a valid relationship between dollar loss and physical fire size, it may be necessary to use deterministic modeling to develop the desired fire size distribution. It should be recognized that if the effort is made to develop deterministic models for fire size, the same models would require detection and suppression times*. It would make sense to obtain estimates of detection/suppression times both from loss data and from modeling such that the resulting distribution may be compared.

*Estimates for this application could be made since suppression system response time test data are already available and detection system response time test data are currently being obtained at Factory Mutual.

V

FIRE PROTECTION SYSTEM RELIABILITY

Included in this general subject are sprinkler systems, special protection systems, and automatic fire detection systems. Clearly, the sprinkler system is the only system with any significant reliability data available. Unfortunately, due to differences in definitions and reporting criteria, the "numbers" range from about 95-99.6% success rate.

Automatic fire detection system reliability data are extremely limited and pertain to particular environments. Special protection system reliability data are virtually nonexistent and totally subjective.

Appendix B provides a detailed discussion of available data on fire protection system reliability.

VI

CONCLUSIONS AND RECOMMENDATIONS

The crucial parameters in the assessment of fire risk in nuclear power plants that need to be developed from data base are: (1) fire frequency, (2) detection time, and (3) suppression time. Each of these parameters is statistically dependent on a number of associated factors. To develop meaningful estimates and the associated distributions of these parameters a sufficiently large data base is needed.

Currently, the data base for nuclear power plants is not large enough to develop these parameters even at the general level, without consideration of the conditionality of the influencing factors, e.g., fuel location, fuel geometry, combustion properties, enclosure geometry, etc. This study, in its attempt to augment the nuclear data base investigated the usefulness of other nonnuclear data bases which contains fire incident loss experience of occupancy classes having (in some respects) similar physical features and fire protection engineering systems.

The evaluation of nuclear and nonnuclear data bases provide the basis for the following conclusions:

1. Nuclear loss data contain operating experience and are the only available basis for developing fire frequencies. Frequency of occurrences for various incidents cannot be gathered from nonnuclear loss data since operating experience for nonnuclear industries is not in a form compatible with loss data.
2. Data on two other critical parameters, detection and suppression times, are not adequate from nuclear fire incidents to generate distributions. For these parameters, the nonnuclear data bases can probably provide data in sufficient quantity to develop distributions.
3. The study attempts to establish the surrogateness of nonnuclear data based on statistical tests. However, because of the lack of operating experience in nonnuclear data bases, the statistical test was conducted to determine whether the relative proportion of fires for a parameter (e.g., location) is compatible in nuclear and nonnuclear data bases. The test did not, in general, result in surrogate data.

However, this test does not relate to compatability of detection and suppression times between these two data bases. The surrogateness of these parameters depends on the similarities on various factors influencing the parameters. A more specific data partition based on the influencing parameters could result in meaningful distributions.

4. Data on physical fire size is not available from either the nuclear or the nonnuclear fire loss data. It would seem that deterministic modeling could be used in conjunction with detection and suppression time data.

RECOMMENDATIONS

1. This study has unveiled a valuable data base on detection and suppression times in which nuclear data base is highly deficient. Use of this data base in nuclear fire risk assessment will significantly improve both the probabilistic analysis and the deterministic modeling of fire growth. However, this would require further data partitioning based on the similarities in nuclear and nonnuclear facilities. It is recommended that nonnuclear fire loss data are categorized by comparing specific areas in the nonnuclear environment to critical areas in nuclear facilities (i.e., control rooms, cable spreading rooms, switchgear rooms, diesel generating rooms, battery rooms and cable tunnels). By using engineering judgment pertaining to expected differences and similarities for detection times, suppression times and fire areas, certain of this nonnuclear fire loss data for the designated critical fire areas can be assumed to be surrogate for purposes of distribution generation.

2. Physical fire size distribution could possibly be developed either by appropriately partitioning the loss data or by using deterministic modeling incorporating detection and suppression time estimates obtained from both nonnuclear loss data and from response time test data. However, partitioning loss data for the development of fire size will require the establishment of correlations involving dollar-loss information.

3. This study identifies the data elements that should appear in nuclear plant fire loss reports. For future nuclear fire losses, detailed data on detection time, suppression time and physical fire size should be included with a comprehensive narrative in all LERs. In addition, the reporting of extinguishment method and the extinguishing agent used should be improved.

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 FirePrevention, 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 A

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

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

Class of Fire	Nuclear o e	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 $\chi^2 = \Sigma \frac{(o_i - e_i)^2}{i}$ where o_i = observed frequency e_i = expected frequency (for ith cell) is distributed as χ^2 with (r - 1) x (- 1) degrees of freedon (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.

Conclusion: 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 (52.04) 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 FM EXPERIENCE FOR CLASS OF FIRE

Class of Fire	Nuclear	Nonnuclear (FM) (Est. number in the population)	Total
A	7 (4)	3 (6)	10
B	29 (19)	20 (30)	49
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:

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

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

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

Conclusion: At 5% level of significance, the χ^2 theoetical value for 2 d.f. is 5.991; since the computed value (17.8) 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 NFPA EXPERIENCE FOR CAUSE OF FIRE

Cause of Fire	Nuclear	Nonnuclear (NFPA) (Est. 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)	24 (19)	31
Spontaneous Heating &			
Welding/Cutting	6 (12)	25 (19)	31
Total	66	105	171

Note: Expected values are given in parentheses.

Computation:

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

$$+ \frac{(7 - 12)^2}{12} + \frac{(24 - 19)^2}{19} + \frac{(6 - 12)^2}{12} + \frac{(25 - 19)^2}{19}$$

$$= .222 + .138 + 7.042 + 4.447 + 2.038 + 1.316 + 3.00 + 1.895 = 20.098$$

with $(4-1) \times (2-1) = 3$ d.f. χ^2 (theoretical) at .05 level = 7.815 (Reference 7, p 515)

Conclusion: Since the computed value (20) 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 FM EXPERIENCE FOR CAUSE OF FIRE

Cause of Fire	Nuclear	Nonnuclear (FM) (Est. number in the population	Total
Component Failure	16 (15)	20 (21)	36
Electrical Failure	37 (40)	58 (55)	95
Human Error			
Improper Procedure	7 (3)	0 (4)	7
Spontaneous Heating &			
Welding/Cutting	6 (8)	14 (12)	20
Total	66	92	158

Calculation

$$\chi^2 = \frac{(16-15)^2}{15} + \frac{(58-55)^2}{55} + \frac{(37-40)^2}{90} + \frac{(20-21)^2}{21} + \frac{(0-4)^2}{4} + \frac{(7-3)^2}{3} + \frac{(6-8)^2}{8} + \frac{(14-12)^2}{12}$$

$$= .067 + .048 + 0.225 + 0.164 + 4.0 + 0.5 + 0.333 + 5.333$$

$$= 10.67 \quad \text{with } (4-1) \times (2-1) = 3 \text{ d.f.}$$

χ^2 theoretical at .05 level = 7.815.

Conclusion: Since the computed value (10.67) 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-5. COMPARISON OF NUCLEAR VERSUS NONNUCLEAR NFPA EXPERIENCE FOR AREA OF FIRE ORIGIN

Location	Nuclear	Nonnuclear (NFPA)	Row Totals (R)
Control Areas	6 (3)	0 (3)	6
Machinery Areas	23 (24)	28 (27)	51
Transformer/Switchgear Areas	16 (21)	28 (23)	44
Turbine Rooms	5 (2)	0 (3)	5
Column Totals	50	56	106

$$\chi^2 = \frac{(6-3)^2}{3} + \frac{(0-3)^2}{3} + \frac{(23-24)^2}{24} + \frac{(28-27)^2}{27} + \frac{(16-21)^2}{21} + \frac{(28-23)^2}{23} + \frac{(5-2)^2}{2} + \frac{(0-3)^2}{3}$$

$$= 3.0 + 3.0 + .04 + .04 + 1.19 + 1.09 + 4.5 + 3.0$$

$$= 15.86 \text{ with } (4-1) \times (2-1) = 3 \text{ d.f.}$$

The χ^2 theoretical value at 0.05 level of significance is 7.815.

Conclusion: Since the computed (15.4) value is 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).

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

Location	Nuclear	Nonnuclear (FM)	Row Totals (R)
Control Rooms	6 (10)	17 (13)	23
Machinery Areas	23 (11)	3 (15)	26
Transformer/Switchgear Areas	16 (22)	36 (30)	52
Turbine Rooms	5 (7)	11 (9)	16
Column Totals	50	67	117

Notes: Expected values are given in parentheses. Machinery areas include both categories in Table 11 (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

$$\chi^2 = \frac{(6-10)^2}{10} + \frac{(17-13)^2}{13} + \frac{(23-11)^2}{11} + \frac{(3-15)^2}{15} + \frac{(16-22)^2}{22} + \frac{(36-30)^2}{30} + \frac{(5-7)^2}{7} + \frac{(11-9)^2}{9}$$

$$= 1.6 + 1.23 + 13.09 + 9.6 + 1.64 + 1.20 + 0.57 + 0.44$$

$$= 28.86$$

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

Conclusion: Since the computed value (28.86) of χ^2 is 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) (FM).

TABLE A-7. COMPARISON OF NUCLEAR VERSUS NONNUCLEAR NFPA EXPERIENCE FOR INITIATING EQUIPMENT INVOLVED

Equipment Involved	Nuclear	Nonnuclear (NFPA)	Total
Cable/Fixed Wiring	4 (4)	3 (3)	7
Pumps, Compressors	10 (11)	9 (8)	19
Motors (electric, diesel)	14 (10)	3 (7)	17
Transformers/ Switchgear	21 (24)	21 (18)	42
Total	49	36	85

Note: Expected values are given in parentheses.

$$\chi^2 = \frac{(4-4)^2}{4} + \frac{(3-3)^2}{3} + \frac{(10-11)^2}{11} + \frac{(9-8)^2}{8} + \frac{(14-10)^2}{10} + \frac{(3-7)^2}{7} + \frac{(21-24)^2}{24} + \frac{(21-18)^2}{18}$$

$$= 0 + 0 + 0.09 + 0.125 + 1.6 + 2.3 + .375 + .5$$

$$= 4.99$$

χ^2 = 7.815 (theoretical) with (4-1) x (2-1) = 3 d.f.

Conclusion: Since the computed value (5) of χ^2 is less than the theoretical value, accept the hypothesis that relative frequency of fire is independent of the experience (nuclear versus nonnuclear) (NFPA). However, since the expected frequencies for cable/fixed wiring are small, the test is not exact (see Reference 7).

TABLE A-8. COMPARISON OF NUCLEAR VERSUS NONNUCLEAR FM EXPERIENCE FOR INITIATING EQUIPMENT INVOLVED

Equipment Involved	Nuclear	Nonnuclear (FM)	Total
Cable/Fixed Wiring	4 (7)	14 (11)	18
Pumps, Compressors	10 (6)	7 (11)	17
Motors (electric, diesel)	14 (8)	7 (13)	21
Transformers/ Switchgear	21 (28)	51 (44)	72
Total	49	79	128

$$\chi^2 = \frac{(4-7)^2}{7} + \frac{(14-11)^2}{11} + \frac{(10-6)^2}{6} + \frac{(7-11)^2}{11} + \frac{(14-8)^2}{8} + \frac{(7-13)^2}{13} + \frac{(21-28)^2}{28} + \frac{(51-44)^2}{44}$$

$$= 1.29 + 0.82 + 2.67 + 1.45 + 4.5 + 2.77 + 1.75 + 1.11$$

$$= 16.36 \qquad \text{with } (4-1) \times (2-1) = 3 \text{ d.f.}$$

The theoretical χ^2 at .05 level is 7.813

Conclusion: Reject the hypothesis that the relative frequency of fires for the equipment involved is independent of experience (nuclear or nonnuclear-FM).

APPENDIX B

FIRE PROTECTION SYSTEM RELIABILITY

B.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.

B.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 has 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.

B.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 B.1 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.

B.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

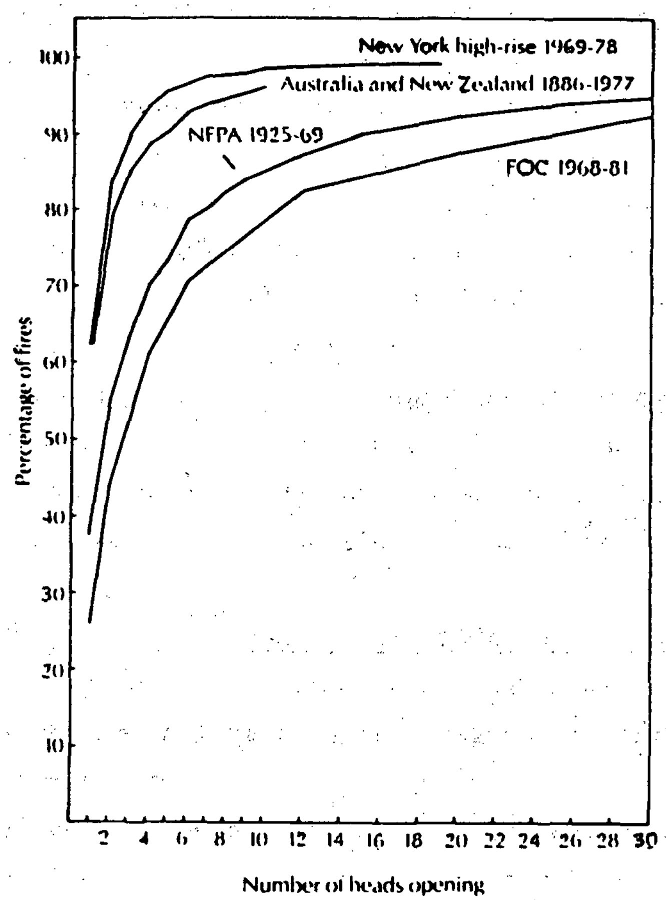

FIGURE 1 AUTOMATIC SPRINKLER PERFORMANCE FROM DIFFERENT SETS OF DATA (from ref: 8)

TABLE B.1 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 perfotmance 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

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.

B.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 B.2 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.

TABLE B.2 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

B.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 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 B.3 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 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 3).

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 B.4). 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 B.3 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 B.4 AFDS 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 B.5 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 reached in Reference 21 after a series of tests were conducted.

B.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 B.5 RELIABILITY ASSESSMENT OF SMOKE DETECTORS: TEST RESULTS PERFORMED AT UNITED KINGDOM HEALTH CARE FACILITIES

Hospital	Make of Detector	Sample Size	Normal Distribution Parameters		Threshold limit for 99% of detectors to respond
			Mean* (mg/m^3)	Standard* Deviation	
18 Oxford Road	Type A	5	73.3	19.6	117.9
Leytonstone House-1	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.

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Several crucial parameters are needed in the assessment of fire risk in nuclear power plants. Among those that need to be developed from a data base are: (1) fire frequency, (2) fire detection time, and (3) fire suppression time. Currently, the data base for nuclear power plants is not large enough to develop these parameters, considering fuel location, fuel geometry, combustion properties, enclosure geometry, etc. This study attempts to augment the nuclear data base by investigating the usefulness of other nonnuclear data bases which contain fire incident loss experience of occupancy classes having somewhat similar physical features and fire protection engineering systems normally found in nuclear power plants. This study has found that indeed some useful information can be gleaned from nonnuclear sources; in particular, detection and suppression times. However, other fire-risk data needs such as fire frequency and fire size would require other forms of data searches and data analyses that at this stage can only be conceptualized.

17. KEY WORDS AND DOCUMENT ANALYSIS

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17b. IDENTIFIERS/OPEN-ENDED TERMS

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