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Use of operational experience in fire safety assessment of nuclear power plants

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FOREWORD

Fire hazard has been identified as a major contributor to a plant's operational risk and the international nuclear power industry has been studying and developing tools for defending against this hazard. Considerable progress in design and regulatory requirements for fire safety, in fire protection technology and in related analytical techniques has been made in the past two decades. Substantial efforts have been undertaken worldwide to implement these advances in the interest of improving fire safety both at new and existing nuclear power plants.

To assist in these efforts, the IAEA initiated a programme on fire safety that was intended to provide assistance to Member States in improving fire safety in nuclear power plants. In order to achieve this general objective, the IAEA programme aimed at the development of guidelines and good practices, the promotion of advanced fire safety assessment techniques, the exchange of state of the art information between practitioners and the provision of engineering safety advisory services and training in the implementation of internationally accepted practices.

During the period 1993–1994, the IAEA activities related to fire safety concentrated on the development of guidelines and good practice documents related to fire safety and fire protection of operating plants. One of the first tasks was the development of a Safety Guide that formulates specific requirements with regard to the fire safety of operating nuclear power plants. Several documents, which provide advice on fire safety inspection, were developed to assist in its implementation.

In the period 1995–1996, the programme focused on the preparation of guidelines for the systematic analysis of fire safety at nuclear power plants (NPPs). The IAEA programme on fire safety for 1997–1998 includes tasks aimed at promoting systematic assessment of fire safety related occurrences and dissemination of essential insights from this assessment. One of the topics addressed is the collection of data related to fire safety occurrences in NPPs, the so-called operational experience and the use of such operational experience in NPPs.

This report provides good practice information on data needs, data reporting requirements and some advice on database features. In addition, this publication provides information on the applications of fire related operational experience, highlighting their benefits.

This publication has been developed to complement other IAEA publications related to fire safety analysis within the framework of the IAEA programme of fire safety.

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CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

There is a strong movement towards optimization of a plant's expenditure with respect to safety. An attempt to develop risk based or performance based regulation, which has been gathering speed in recent years, is a consequence of this movement. Fire risk assessment approach has been identified as a principal candidate for being used in such a regulation.

Operational experience related to fire safety at nuclear power plants is one of the fundamental sources used in fire safety assessment. Lessons learned from in-depth investigation of fire safety related events may lead to the identification of fire protection deficiencies that are difficult to detect through routine or periodic fire safety inspections. In addition to qualitative information, a considerable amount of quantitative data used in fire safety analysis (particularly when using a probabilistic approach) are derived from plant operational experience. To this extent, the availability of appropriate and reliable experience based data is also very important.

However, in some Member States fire safety related events are not reported in a systematic and consistent manner. Due to the lack of standardized criteria and format, a broader exchange of data at the international level and sometimes even at the national level is difficult. Moreover, availability and quality of data derived from plant operating experience are insufficient for the fire safety assessments.

As a future effort, enhancement of the current reporting process is essential to learn from past fire events. A more precise definition of reporting criteria, scope and format is needed to facilitate exchange of data nationally and internationally.

Quality of fire safety assessment can be increased by improving the availability and quality of data from plant operational experience. Improvements can be made in two areas: in data reporting systems and in the application of existing data. A good practice document providing guidance in these two areas would be very useful.

The IAEA has developed three complementary publications to facilitate the preparation of fire safety analyses of a nuclear power plant:

(1) Preparation of Fire Hazard Analyses for Nuclear Power Plants [1].
(2) Evaluation of Fire Hazard Analyses for Nuclear Power Plants [2].
(3) Treatment of Internal Fires in Probabilistic Safety Assessment for Nuclear Power Plants [3].

The first and second reports have been developed for a deterministic analysis of fire hazard. The third has been developed for probabilistic safety assessment (PSA).

In addition, the IAEA has published a technical document on root cause analysis for fire events at nuclear power plants [4].

1.2. OBJECTIVES AND PURPOSE

The objectives of this report are to provide guidance on the use of operational experience in fire safety assessment and, specifically, to:

- identify general data needs through an examination of the various fire safety assessment applications,
- provide advice on specific data collection requirements and associated database features,
- provide information concerning methods on data processing.

In this process, limitations of current data collection or reporting systems are noted and an attempt is made to reach mutual reconciliation between data collection activities and the specific requirements for fire safety assessments. The information provided is intended for plant or utility staff responsible for the collection and management of plant raw data and for technical engineering staff involved in fire safety assessment of nuclear power plants (NPPs). The information is also intended to be useful to utility group organizations or regulatory bodies responsible for collecting and analysing data for a population of nuclear power plants under their control.

The purpose of this report is to improve both data collection process and the practical use of data for the fire safety assessment of NPPs. As a result, applicable and reliable data, based on the operational experience, should increase the credibility of fire safety assessment and the safety of NPPs.

1.3. SCOPE

The present publication applies to land based NPPs with thermal neutron reactors of light water, heavy water or of the gas cooled type.

This report covers a broad range of topics relevant to the collection and use of operational experience data for fire safety assessment of NPPs. Operational experience implies the events and data in all plant states — plant test, normal plant operation, anticipated operational occurrences and accident conditions. All aspects related to fire safety in operational activities, tests and maintenance activities are addressed in this report. Information derived from other operational activities in terms of off-site impact, on-site impact or the degradation of defence in-depth is also covered in this report.

1.4. STRUCTURE

Section 2 summarizes current methods used in fire safety assessment of NPPs.

Section 3 discusses data needs for each fire safety assessment approach mentioned in Section 2.

Section 4 reviews current reporting practices of fire related events and existing data available to the safety assessments and provides general recommendations for future data collection efforts.

Section 5 describes data analysis and processing.

Section 6 provides recommendations and concludes the remarks relevant to the collection and use of operational experience in NPPs.

2. OVERVIEW OF METHODS IN FIRE SAFETY ASSESSMENT

Operational experience throughout the world has shown that fire in nuclear power plants is a significant threat to plant safety among internal hazards because of the frequency of its occurrence and because of the severity and unpredictability of its development.

In order to ensure that a fire which might occur in any location of a nuclear power plant will not jeopardize the safety of the reactor, a fire safety assessment (FSA) has to be carried out. This can be achieved through deterministic analysis which can be supplemented, if required, with probabilistic evaluations.

Fire safety assessment is a “living process” extending from the original design development, through commissioning, operation, maintenance, periodic review and backfit phases to eventual plant shutdown and decommissioning. During the design phase, reference to previous operating experience provides a means to avoid repeating earlier events and for these lessons to be included into design and regulatory standards. During operation and maintenance, operating experience reviews will further reduce plant risks and anticipate degradation of equipment or safety culture. In many countries, periodic safety reviews are required and include reviews of operating experience at the plant and elsewhere. These reviews also compare existing plant design with current standards (review against modern standards) and will draw from operating experience in justifying the need for and practicality of modifications.

Information collected from operating experience is a valuable input to fire safety assessment. Such information can be used directly for identification of plant fire protection vulnerabilities or indirectly to derive quantitative parameters and provide a basis for validating assumptions (e.g. fire frequencies associated with particular pieces of equipment, fixed fire suppression systems availability and effectiveness).

In order to draw useful data from operational experience (e.g. actual fires, deviations identified in fire protection arrangements), in-depth investigations and trend analyses can be carried out. IAEA-TECDOC-1112, “Root Cause Analysis for Fire Events at Nuclear Power Plants” [4], provides examples of application of such techniques.

The main principles of both fire safety assessment and fire event analyses are presented in this section.

2.1. APPROACHES FOR FIRE SAFETY ASSESSMENT

Both deterministic and probabilistic fire safety assessment approaches aim to examine all plant locations containing safety related equipment and systems or creating a significant fire hazard for this equipment. These approaches evaluate the impact of a fire on the availability of the safety functions necessary to reach and maintain a safe shutdown state.

It is useful to introduce and outline some steps which are common to both approaches as follows:

- identification and location of safety systems and equipment related to safe shutdown (including cables),
- division of buildings into fire cells and/or fire compartments with the goal of separating equipment belonging to redundant safety trains,

— characterizing the plant conditions that influence fire growth, e.g. ventilation, detection, and suppression systems,

— produce an inventory of combustible materials, transient fire loads, potential ignition sources, calculation of fire development, and if necessary assessment of probable fire duration,

— plant walkdowns to validate design documents and data collected.

The following steps, which are specific to each approach, are highlighted.

2.1.1. Deterministic fire safety assessment

The deterministic approach is characterized by the fact that the assumptions which are made are very conservative and that in a given plant location, a fire is postulated to occur.

For each fire cell or fire compartment, it must be demonstrated that the postulated fire will not spread beyond the fire cell or fire compartment.

For fire compartments, this demonstration is made by rating the fire resistance of the fire barriers which completely surround them and which must be compared to the duration of the postulated fires that may occur in the fire compartment itself and in adjacent compartments.

For fire cells, the demonstration should be based on different parameters, such as the type of combustible materials located in the room, the fire load densities, the existence of spaces free of combustibles, the type and location of openings in the walls and ceilings, the room layout, the type of ventilation, detection and fire suppression systems. Results of fire tests and suitably validated numerical fire models can also be used at this stage. Smoke and heat effects (e.g. smoke spreading via ventilation systems and heat transmission through otherwise intact fire barriers) have to be included in this assessment.

Once this demonstration is made, it must be ensured that a fire will not induce a common mode failure. Assuming that, in case of fire, the functionality of all equipment and cables are lost in the fire cell or fire compartment, a functional analysis must be carried out to demonstrate that the loss of this equipment will not affect all redundant safety trains. The analysis must include an evaluation of the electrical circuits for spurious equipment operation, circuit breaker co-ordination, and false instrument indications. If such situations are identified, provisions must be taken to protect one of the redundant trains (e.g. by re-routing of cables, protection of cables with fire resistant coatings, or installation of fire resistant shields). Alternatively, the existence of a functional redundancy must be demonstrated, i.e. that the safety function lost can be achieved by other means not affected by the fire.

2.1.2. Probabilistic fire safety assessment

Probabilistic fire safety assessment introduces the likelihood of fire in each plant location, and with consideration of other non-fire related unavailabilities, is used to identify and rank plant areas where risk significant fire scenarios can occur. The technique lends itself to successively more detailed fire risk analysis, to quantify the core damage frequency (CDF). Further details can be found in Ref. [3].

Four main steps can be identified in the process of such a complex assessment, in addition to those common with the deterministic approach.

The first is the determination of the PSA related equipment and cables and plant locations to be considered in the study. Based on the existing internal events PSA (or its equivalent), the plant equipment and failure modes considered to be important in the context of a fire PSA are selected. The analysis should cover all fire induced failure modes and include consideration of the electrical and control circuits for spurious equipment operation, circuit breaker co-ordination, and false instrument indications. Plant locations that do not contain any safety related equipment and cannot communicate the effects of fire to locations containing safety related equipment may be eliminated.

The next step is the identification of a restricted number of plant locations where the contribution of fire to the core damage frequency is considered as significant. At first, a fire propagation risk analysis is carried out to determine propagation zones that may not correspond to fire compartments or fire cells (for example compartments which are linked by ventilation systems). Secondly, the fire frequency has to be evaluated in each propagation zone. The data obtained from operational experience may be utilized in the evaluation of the initiator frequencies associated with different types of equipment and associated human actions (e.g. maintenance). Then, considering that the functionality of all equipment located in the propagation zone is lost, the conditional core damage probability is evaluated taking account of the failure modes (direct and indirect), malfunctions, interlocks, etc., and effects of smoke and temperature as well. Factors such as the probability and consequences of deficiencies in fire barriers which define fire compartment or fire cell boundaries and fixed fire extinguishing systems failures are also considered. At the end of this step, it is possible to screen out propagation zones for which the estimated core damage frequency is considered insignificant.

The third step concerns the remaining propagation zones for which a detailed fire risk analysis is performed. The purpose is to refine the most risk significant fire scenarios that can occur in the selected propagation zones by reducing the level of conservatism. Finally, taking into account parameters such as the position of fixed fire sources and targets or the possible presence of transient combustibles, the probability that the equipment inside a propagation zone is damaged by a fire is assessed. Data from operational experience can be used to assess the efficiency and reliability of fire detection or fire extinguishing systems which is also introduced at this stage. Fire event trees and fire simulation codes can also be used at this stage to refine the fire scenario. Thus, using a probabilistic approach, it is possible to quantify the core damage frequency due to initiating events created by a fire in each propagation zone, taking into account the impact of equipment failures and human errors coincident with, but unrelated to, the fire. In this step, operational experience can be used to revise the fire frequency due to a given fire source, to assess the times needed to detect and manually suppress the fire as well as to evaluate the reliability of plant fire protection features.

The fourth step is the complementary analysis needed for specific locations like the electrical rooms, cable spreading rooms and containment functions. Operational experience data may be used to assess the fire frequency due to specific equipment located in the electrical rooms (e.g. electrical cabinets, switchboards, control panels) and to evaluate the probability that a fire propagates from one piece of equipment to another.

2.2. FIRE EVENT ANALYSES

2.2.1. In-depth investigations

The main goals of an in-depth analysis of fire events are to give information to be used to detect precursor events (e.g. inadequate design, ignition sources, ageing processes of plant equipment) and to avoid the occurrence of similar events in order to improve the level and coherence of fire safety among nuclear power plants with equivalent fire protection design.

It must be noted that fire events covered by this type of analysis are not limited to “real” fires but should include reportable events arising from deficiencies in design or installation, near miss events, unavailability of fire protection systems, spurious alarms, spurious actuation of fire protection systems or deviations from operating procedures.

Recognizing possible limitations on resources for such analyses, a process of review and selection among fire events must be carried out so as to focus the analysis on a limited number of events which have the best potential in terms of information feedback. Particular attention should be given to high frequency events, to events not foreseen during the design stage and to incidents due to drawbacks in personnel safety culture. Useful safety related insights may be obtained from the analysis of fire events that did not have direct safety significance, but that could have had significance in other locations of the plant or under other perhaps less favourable conditions.

The collection of detailed information on the event should concern in particular the chronological sequence of occurrences, the safety functions involved, the personnel and equipment behaviour, the real consequences and the existence of similar events. In addition to analysing information gathered from documents, it is usual to visit the location of the event and to interview the plant personnel.

In order to identify the origins of the weakness that generated the event, a root cause analysis is recommended [4]. Factors related to equipment, human behavior and deviations from operating and quality assurance procedures should be examined. Plant specific aspects should be clearly separated from generic aspects. Thereafter, the potential consequences of the event under other circumstances must be analysed. Finally, the analysis should be completed by a generalization process which consists in applying the identified root causes to other equipment, systems or situations and in checking that they cannot induce completely different and safety significant consequences.

The final result of the in-depth analysis is the suggestion of corrective actions to eliminate the identified weakness and to prevent similar failures in the future. The corrective actions taken may be, for example, the replacement of a piece or of a set of equipment, the modification of a maintenance procedure or of a change in a periodic testing frequency or improved personnel training.

Guidance is given in detail in Ref. [4] on the methodology to perform a root cause analysis for fire safety related events.

2.2.2. Trend analysis

Numerical indicators to monitor operational safety performance of NPPs are used by operators and some regulators worldwide.

An operational safety performance indicator system can be established as a tool to monitor many areas of NPP operational safety performance. Fire safety is one of these areas.

The IAEA, through technical committee meetings and consultants meetings, has developed a framework for the establishment of plant specific operational safety performance indicators [5].

The basic principle of trend analysis is to use operational experience data related to fire events in order to establish possible frequency tendencies over a selected time period.

Typically, the trend analysis focuses on the identification of plant weaknesses but it can also aim at the investigation of the impact of plant modifications. The results obtained are all the more meaningful in that the fire events are recorded in comparable plants. On the other hand, common factors with other plant design and equipment types may also be identified (e.g. high fire frequency in a particular room, equipment ageing processes).

Trend analyses involve the apportionment of fire events among different categories based on factors such as fire event cause, fire duration, the fire location or the period of occurrence (e.g. before commissioning, during periodic shutdown, plant start-up, etc.), plant operational mode or consequences on plant safety. Trend analysis may be extended to cover the results of periodic tests or maintenance and inspection. Processing the available data at regular intervals may reveal the most frequent deficiencies and provide bases to implement corrective actions.

For instance, an increased number of reports of unavailability of fire detection equipment in certain plant locations may indicate that the detector type is not suitable for the environment (steam, humidity, dust). In this case, the detector type should be changed, environmental conditions should be improved (cleanliness) or the location of detectors should be changed (reduced exposure to ambient radiation or heat). Other examples might include detection of incipient electrical faults evidenced by increased temperature, deterioration in housekeeping, or increasing number of outstanding inspections.

Consistent with developing an operational, measurable safety performance indicator framework, plant specific indicators related to fire safety are proposed in Appendix I. A number of types of indicators are identified which will be of interest to plant managers in understanding the effectiveness of their policies and procedures. The general means by which these indicators may be measured is also given, suitably cross-referenced to aid implementation and development if appropriate to specific plants.

The chosen fire event indicators are expected to provide a good measure of plant safety performance.

Examples of trend analysis for fire events based on reported operational experience are given in Refs [6] and [7].

3. DATA NEEDS FOR FIRE SAFETY ASSESSMENT

3.1. DATA FOR DETERMINISTIC FIRE SAFETY ASSESSMENT

Several types of data are needed for a deterministic fire safety assessment or fire hazard analysis. Detailed data need is described in Refs [1] and [2]. These also include data from plant operational experience providing indirectly assistance in improving fire safety by deterministic analyses. These data may be revealed from deviations from the original design during the operational lifetime of the respective plants, such as:

- Data on fire loads and potential ignition sources, in particular temporary ones or those not being included in the design,
- Data on observations of ageing effects on fire barrier elements.

For the fire protection measures and equipment as well as for fire fighting capabilities, these data should include information on:

- Results from testing, inspection and maintenance giving indications on fire safety vulnerabilities for fire hazard analyses,
- Data on composition and organization of manual fire fighting teams and emergency arrangements,
- Data on the pre-fire fighting strategies for the individual plant areas and fire compartments,
- Data from fire fighting teams drills,
- Data on hot work permits,

Data on temporary fire loads and potential ignition sources include covering location, arrangement, type and amount of fire loads (including fire load density) and potential ignition sources, as well as physical and chemical properties of combustible materials.

Data on further aspects, such as failure temperatures of sensitive electric and/or electronic equipment, ventilation conditions under normal operation as well as under accident conditions, the potential for explosion risks, etc. have to be additionally collected in the frame of deterministic fire safety analyses.

Further operational aspects, such as feedback from walk-throughs, indications of deterioration in fire safety etc. have to be considered additionally for deterministic analyses. The identified weaknesses in all type of fire protection features have to be collected separately and included in the databases for deterministic fire hazard analyses.

3.2. DATA FOR PROBABILISTIC FIRE SAFETY ASSESSMENT

3.2.1. Overall data requirements

Depending on the approach selected and level of analysis, several evaluations need to be performed in a typical fire safety analysis. They include:

- Characterization of fire initiation,
- Characterization of fire growth,
- Fire confinement time line development,
- Characterization of fire induced equipment damage potential.

A brief overview of these evaluations and the description of the required associated data are provided below.

Fire initiation. This evaluation is required to obtain a realistic and verifiable estimate of the fire initiation frequency and the potential initial fire severity. The data required for this evaluation include credible fire initiators due to equipment or human actions, fuel type associated with a particular fire initiator and physical properties of the fire initiator's fuel source. Data related to fire initiation frequency are specific to the application of probabilistic approach.

Fire growth. This evaluation may be required to develop a realistic representation of the likelihood of fire development beyond the immediate source of fire (either to other fuel sources in close vicinity and/or to other locations). The data which may be required for this evaluation include structural characteristics of the fire initiator*s* (e.g. the existence, or not, of louvers or other penetrations in electrical cabinets), locations of such penetrations and the flammability characteristics of fuel sources (combustibles) in the immediate vicinity.

Fire confinement time line development. This evaluation may be required to realistically estimate the probability that the damage caused by the postulated fire would be confined within a specific plant area (fire compartment, fire cell, etc.). The required data include: physical or functional failure of fire barriers, reliability of automatic fire detection and suppression equipment, data for estimating response time for manual suppression. In addition, operational experience may also be used for verifying analytically evaluated fire detector response models, fire models and smoke propagation models, although these are probably more suited to resolution through experimental work.

Fire induced equipment damage potential. This evaluation is usually done to determine the extent of damage resulting for a postulated fire event. The data which may be required for this evaluation include damage temperature for components and cables considered as potentially at risk in a postulated fire event, smoke induced malfunction operation of equipment (mainly I&C and electrical equipment), heat induced spurious operation of motorized components, and damage caused to the components not affected by fire due to fire suppression activities (manual or automatic). Again, component fire related fragilities are probably more suited to resolution through experimentation. However, the data currently available is very limited and any qualitative or quantitative insights which can be obtained from operational experience would be valuable.

3.2.2. Experience based data

3.2.2.1. Fire event frequencies

Depending upon the level of detail to be implemented in a given fire analysis, plant specific fire frequencies will need to be estimated in terms of (1) the total fire frequency from all sources associated with individual plant locations (e.g. fire compartments or cells) or (2) the frequency associated with individual ignition sources within a given compartment (e.g. electrical cabinets or pumps). The former is used mainly when performing screening analyses, whereas the latter is used for estimating the risk associated with specific fire propagation scenarios. Either way, plant specific fire ignition frequencies are established on the basis of generic plant fire event experience in concert with information concerning the characteristics of the fire location/sources under consideration.

Existing methods for deriving fire frequencies (see Refs [8] and [9] as examples for deriving fire frequencies) have identified so-called “fire ignition bins” which are used to categorize historically occurring fire events and eventually correlate fire frequencies to plant specific locations. In earlier plant fire PSAs, fire events were often binned according only to the location where they occurred. However, this approach was found to be inadequate when attempting to account for plant and location specific characteristics, as well as any influences the plant operating mode may have had on the likelihood of fire. Thus a preferable approach is to define fire ignition source bins in terms of multiple factors which are considered to represent the significant driving influences on fire frequency. The key factors are “ignition source type”, “rating or duty of component” in combination with “plant operating mode”. An example of a bin may be:

“Motor driven pump”, “normally operating”, “applicable to shutdown condition only”.

This bin would be applicable to a residual heat removal (RHR) pump fire, but not to a safety injection pump fire.

Each bin represents a mutually exclusive subset of the total operating experience of all plants represented in the database. Every reported fire is assigned to one (and only one) of these bins. Having stated a desire to create fire event bins which accurately reflect consistent fire potential among the associated components, it is important to recognize that the creation of too many bins may lead to excessive parsing of the data, with too few events being assigned to individual bins.

Current methods for evaluating point estimate fire frequencies generally do not explicitly recognize plant-to-plant differences in fire frequency due to differences in the actual number and type of ignition sources present. As a result, the total fire ignition bin frequencies are maintained from one plant to the next, and reactor operating years of experience are used as the denominator for calculating the frequency associated with each bin. An exception to this general rule is observed for diesel generators, where component years are used. (It should be noted that if uncertainty distributions are applied to the fire frequencies, some recognition of plant-to-plant variability is attributed, but this does not necessarily accurately reflect the impact of differences in number of type of ignition sources).

Experience in performing fire IPEEEs (Individual Plant Examinations for External Events) in the USA for similar reactor types has clearly indicated that the actual number of ignition sources in each fire ignition bin varies substantially from one plant to the next. (Although some of this variation comes from inconsistencies in the methods used to count ignitions sources, there remains genuine variability.) Therefore, in future fire event database applications, the ideal approach would be to utilize the population of each ignition source, as well as the number of reactor operational years of experience, in determining the fire ignition frequency denominator. In this case, the frequency would be derived on a per ignition source basis, not a total bin frequency. This issue is of particular importance if data is to be shared and combined between reactors of different designs where the plant-to-plant variability in the number and type of ignition sources may be substantial.

Further discussion and recommendations concerning the various fire event binning and data processing are provided in Appendix II.2.1. The information provided here suffices to define the fire event and operational experience data requirements which are necessary to support the fire frequency evaluation. That data is as follows:

Fire event data (e.g. describing events after the date of first commercial operation):

- Plant type;
- Event date;
- Plant operating mode;
- Fire location (plant area or building and room);
- Ignition source *type* (component *type*/transient/human) *and details (voltage);*
- Detailed event description.

Further data to be collected *to support* fire event analysis are:

- Reactor operational years of experience for each plant in the database beginning from the date of first commercial operation, subdivided according to operating mode;
- Population of components assigned to each fire ignition source bin.

It is desirable that the fire potential associated with all components assigned to a given bin be similar. To account for variations in components size, it may be desirable to break some of the components down into subcomponents. Thus, for example, switchgear and motor control centres (MCCs) can be counted in terms of the number of individual breaker cubicles. Other electrical cabinets can be counted in terms of the number of individual panels. Other rules will need to be developed to ensure consistent ignition source counting.

Populations may be determined by review of plant drawings, equipment databases and from plant walkdowns.

A comprehensive list of data to be collected is set forth in Section 4 and Appendix III.

3.2.2.2. Fire severity factors

Severity factors can be used to overcome some of the difficulties that are experienced in predicting the likelihood of damage using computer fire simulation or experimental data. While experimental data can be used to predict the heat release rate from ignited combustibles fire sources such as electrical cabinets and cable trays, tests have normally been conducted with the aid of a substantial pilot fire. Likewise, while a computer simulation can be used to determine whether a target will be damaged by a fire and how long it will take, the model assumes the presence of an established exposure fire of a given size. In fact fires events do self-extinguish, or are self-limiting in size. To therefore assume that all fires achieve worst case predictions derived from experiments or assumed in the fire modelling is an unnecessary conservatism. A severity factor approach is often *used* to determine a relationship between conditional probability and fire size for each type of ignition source.

A concept for visualizing fire development was introduced by Berry and Minor in an early approach to fire risk assessment [9], and may be helpful in classifying fire severity. The four-stage classification scheme shown below is similar to that presented by Berry and Minor:

(1) *Pre-incipient* — ignition source present but does not succeed in igniting combustible, (e.g. small explosion, overheated component, with no fire).

(2) *Incipient* — ignition of combustible occurs but fire self extinguishes with no damage beyond initiating component, due to insufficient combustible/automatic de-energization or lack of ventilation.

(3) *Meaningful* — self-sustained growing fire, potential damage beyond initiating component.

(4) *Severe* — damage beyond initiating component requires fire brigade to extinguish; significant cost to repair.

Severity factors are determined for each fire source bin as the ratio of the number of events which fall into each severity classification to the total number of events assigned to the fire source bin.

In performing a fire PSA, the first instinct of a fire analyst might be to exclude those fire events which fall into categories one or two (since damage does not proceed beyond the initiating component), by applying a severity factor based on only those fires assigned to categories 3 and 4. However, this assumption may be erroneous if the fire retarding characteristics of the specific ignition source being evaluated are not consistent with those present during the actual fire events. For example, when performing a fire PSA of fire scenario originating in a well-ventilated cabinet, it would be inappropriate to exclude fire events assigned to category 2, if those actual fires had occurred in closed, non-ventilated cabinets. The purpose of this discussion is to illustrate the need to collect information concerning those characteristics of the initiating components which may have influenced the development of fire, in addition to information required to assess the severity of the fire.

Fire event information typically required to assess severity factors is as follows:

- Physical characteristics of fire ignition source and enclosure;
- Aspects of initiating component design which may have limited fire development;
- Fire duration;
- Self-extinguishing properties of fire;
- Method of fire detection and suppression;
- Area and mechanism of damage (fire/explosion);
- Components damaged beyond initiating component;
- Safe shutdown equipment damage;
- Post-fire plant response (manual/automatic trip);
- Type and severity of damage;
- Fire protection features available;
- Fire protections features used/not used.

A standardized reporting scheme is discussed in Section 4 and Appendix III.

3.2.2.3. Fire detection and suppression times

Fire brigade response time data from actual nuclear power plant fire incidents can be used to predict probability distributions for the likelihood of detection and manual fire suppression with respect to time. An example of such a distribution is shown in Appendix II.4.3. These generic distributions, in combination with known room characteristics (e.g. detector type and location with respect to the fire source being evaluated) and physical models which predict fire growth rates are used in Fire PSAs to develop statistical models which predict the probability of failure to extinguish the fire within the time required to avoid damage to specific equipment.

While many nuclear power plant fire incidents have been documented, the information on the actual time to fire suppression is often very limited or unavailable. This often arises from the uncertainty about the length of time the fire had been in the development stage prior to detection and from uncertain estimates of the time factors by individuals involved in responding to and investigating fire incidents.

To support the development of suppression-time distributions, fire incident reports should include actual fire duration expressed in terms of the time between initial detection of the fire to the point at which the fire is extinguished and no further plant damage is sustained. Some estimate of the time the fire may have been developing prior to detection should also be provided.

An example of the approach for collecting and analysing such data can be found in Annex V.

3.2.2.4. Reliability of fire protection features

For a probabilistic risk assessment, the reliability of both active and passive fire protection features is a principal input.

For fire detection and suppression systems (and if necessary smoke extraction systems), system unreliability may be determined through fault tree analysis accounting for component failures to respond on demand and continue to operate, maintenance outages, human errors (e.g. component misalignment following test or maintenance) and support system failures.

For active and passive fire barrier elements data (e.g. dampers, fire doors and penetration seals) unreliability is generally derived and applied on a per component basis.

To derive information on *the unavailability* of the fire protection equipment, two types of data are needed:

1. *Equipment exposure data*

- Operating years of the plant to be analysed, starting with the date of first commercial operation, subdivided according to mode of operation, if necessary for the periods of availability/unavailability.
- Period of plant operational years to be analysed, if other than the reactor operational years.
- Population of components assigned to a monitored group of the same type with equivalent operational and failure characteristics as well as almost equivalent inspection and maintenance procedures and intervals. (*Populations may be determined by review of schematic plant systems drawings, equipment databases and/or further equipment documentation and additional plant walk-throughs.)*
- Number of component demands during surveillance testing.

2. *Data on observed failures, and further observations during plant operation*

It is desirable that the potential for operational failures associated with all components assigned to a given group be similar. To account for variations in components design and testing, it may be desirable to subdivide some components groups into sub-groups. Thus, for example, fire dampers can be subdivided into those which are only actuated thermally and those with additional remote controlled electrical actuation.

Concerning failure data and the reliability of the different types of fire protection features, the data can be derived from several sources of plant documentation, as mentioned in Section 4.3.

The probability of human error causing fire protection system failure can be assessed using methods such as ASEP-HRA [10] and THERP [11] (see also IAEA Safety Series No. 50-P-10, Human Reliability Analysis in Probabilistic Safety Assessment for Nuclear Power Plants).

3.3. DATA FOR IN-DEPTH INVESTIGATION

In-depth investigations involving root cause analysis are performed in three distinct phases, as discussed in Section 2.2.1: collection of information, analysis and suggestion of corrective actions. In principle the information collected within the fire event reporting scheme advocated in this TECDOC can be used to support the first phase of a fire event in-depth investigation. However, such studies require very detailed information concerning the nature and chronology of events during the period leading up to the incident, as well as during the incident itself. Information sources consulted during in-depth investigation include for example:

- Station operating log;
- Plant control log;
- Workshop logs and journals;
- Fire brigade team logs;
- Fire brigade team incident reports;
- Incident reports (may be several at different times of origin);
- Investigation reports;
- Interviews with plant personnel involved directly by the analysts or mentioned in other parts of the investigation/inquiries;
- Plant inspections;
- Plant Safety Analysis Report and Technical Specifications;
- Manufacturing, construction, maintenance records, etc.

The type of information which is critical to one particular in-depth investigation may not satisfy the needs of another, and typically the information needs for such an investigation are determined on a case by case basis. Consequently, the scope of event data required to satisfy in-depth investigation in a comprehensive manner is not amenable to collection and management within the proposed event reporting scheme.

Root Cause Analysis for Fire Events at Nuclear Power Plants [4] gives worthy examples in this connection and provides a standardized assessment scheme.

3.4. DATA FOR TREND ANALYSIS

There are no special requirements concerning the scope and level of data required for trend analyses. However, the potential insights from trend analysis depend on the level of detail and type of information available for such analyses.

Trend analysis needs in general all fire related data from NPP operation to establish possible frequency trends over the time period considered.

These data should mainly include information available on fire compartments and cells, permanently as well as temporary present fire loads and all type of observations from testing, inspection and maintenance of fire protection equipment. Consideration should be given to including indicators which may predict an ageing related degradation. Audits of plant internal documents and reports (e.g. on violations of procedures) related to fire protection have also to be addressed.

Results of event analyses (e.g. by ASSET methodology [12]) are to be considered, as well as observations from accident management actions and training of the fire brigade and plant personnel.

The following are examples of data which can be used for trend analysis:

- increasing of fire load densities in fire compartments/cells;
- identification of transient combustibles (location, fire load, combustible type);
- hot work permit violations;
- fire doors found blocked open;
- passive fire barriers deteriorations (walls, penetration seals, fire resistant cable wrappings);
- fire protection equipment ageing degradation;
- failures during testing of active fire barrier elements (fire dampers, doors), fire extinguishing systems and equipment or smoke and heat removal systems;
- malfunctions during testing of fire detection systems;
- errors during fire fighting brigade drills.

Examples of data requirements for trend analyses of fire events can also be found in Appendix I and Ref. [12].

Data on fire safety related events, deficiencies in fire protection systems, periodic test results, maintenance programme and maintenance reports for fire safety related systems should be available for regulatory inspection and for other external fire safety reviews. Arranging this information in a systematic way, preferably in a computerized database, greatly facilitates the retrieval and processing of data for the preparation of plant inspections and fire safety reviews.

Properly chosen and correctly collected and evaluated fire safety related indicators provide the fundamental elements for analyses to identify the deficiencies in the fire protection and to implement suitable corrective action.

Finally, it should be noted that while precursors to fire protection equipment and ageing programme can be trended by individual plants, actual fire event data is generally too scarce to track for individual plants and is more suited to trending by industry groups and regulators for an entire population of plants.

4. OVERVIEW OF PLANT OPERATIONAL EXPERIENCE DATA COLLECTION

For reporting of fire related events in nuclear power plants, it is necessary to distinguish between voluntary reporting on a plant/utility internal basis and the mandatory reporting of deviations from normal operation and of events. Concerning the analysis of plant data to be applied to probabilistic safety analyses for example, data on the availabilities of fire related equipment and components, different sources of unfiltered, unprocessed so-called “raw” data are available.

4.1. GENERAL HIERARCHY OF DATA COLLECTION

An example of the general hierarchy of data collection is shown in Fig. 1.

4.2. SOURCES OF RAW DATA

To support the existing databases for mandatory as well as for voluntary reporting and to create more sophisticated, further developed new databases on NPPs, specific fire related data sources, from which the necessary raw data identified in Section 3 can be obtained, have to be addressed.

Two sources of raw data can be distinguished:

- Plant specific internal documents, and
- Documents available external to the plant.

For fire related events, internal sources of data include records of fires and occurrence of abnormal operational conditions, design basis and beyond-design-basis accidents, as well as the reports which have to be prepared for national authorities and for the internationally accepted reporting systems, such as INES (International Nuclear Event Scale) [13] of IAEA and IRS (Incident Reporting System) [14] of IAEA/OECD for real incidents or accidents.

External sources of data include national fire statistics, publications of national and international fire protection associations and technical journals.

The following data sources provide the basic data for assessment of reliability of fire protection equipment. These data sources may be available for equivalent equipment in the plant under consideration, in other NPPs or in industry at large, including e.g. manufacturers and insurance companies, if plant specific information is not sufficient or not available:

- Inspection requests and orders and reports/protocols of in-service inspections including inspection periods;
- Work and maintenance orders (including bills of material);
- Test reports;
- Documentation on deficiencies, deterioration, degradation (equipment tag-out records);
- Repair reports/protocols;
- Monthly/yearly plant reports;
- Control room logs for unavailability or malfunction of fire protection equipment in the course of a fire event;
- Systems documentation (including system description, operating manuals, testing, inspection and maintenance procedures, equipment manuals, schematic system drawings).

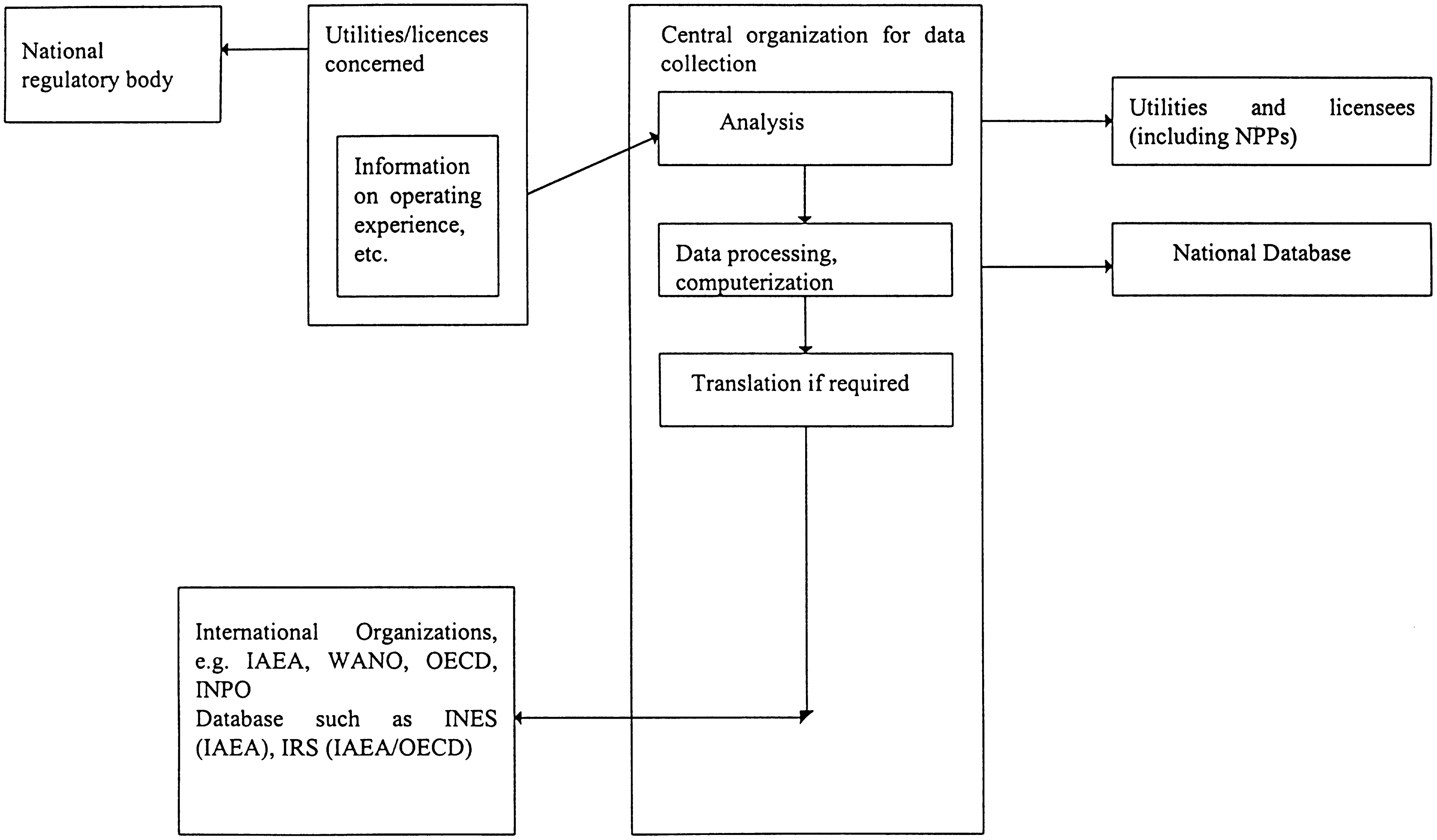

FIG. 1. An example of the general hierarchy of data collection.

- These documents include the possible observations of deteriorations, functional deficiencies (incl. malfunction) and/or failures.

It has to be considered that, contrary to most operational systems being continuously operated, i.e. active, fire protection equipment is principally requested and/or actuated in case of periodic inspections or due to spurious alarms, i.e. is reactive. Therefore, as a definite statistical basis, only observations from regular testing, inspection and maintenance can be used. Other data from plant operational observations can be used mainly as indications for deterioration in the plant fire protection equipment.

Plant specific internal fire related data from plant operational experience, such as data on fire loads and potential ignition sources permanently and temporarily present at the plant site, general information on the plant operational experience, such as reactor operational years of experience, populations of components, or information on fire compartments and fire cells as well as on fire related equipment and components can be derived from the plant as well as from the manufacturers documentation. These data can mainly be found in the plant records.

4.3. CURRENT VOLUNTARY REPORTING AND DOCUMENTATION PRACTICE

The utilities have their own data reporting systems and documentation for all types of plant operational occurrences, findings in inspection, testing and maintenance, which include fire related information. Additionally, background information, such as that which covers fire related equipment and components or procedures and human actions related to fire protection, is available in the plant records, protocols, etc. These databases are generally not publicly available, although some of them are accessible. Nevertheless, some utilities, as well as utility and insurance organizations/associations (e.g. EPRI (USA, see [15]), NEIL (USA, see [16]), SNL (USA, see [17]), WANO (see [7]), VGB (Germany), EdF (France), CRIEPI (Japan)) have made efforts to collect such information and process it in a database.

Lessons learnt from NPP operational experience showed repeat and similar events do occur. In this regard, the availability of the kinds of data mentioned above is very important to provide a larger statistical database for a reliable fire safety analysis.

4.4. CURRENT MANDATORY REPORTING PRACTICE FOR FIRE RELATED EVENTS

The event reporting systems recently available and applied in the IAEA member states for mandatory reporting of events to the supervisory authorities strongly differ. In some countries nearly all fires occurring on the site of a NPP have to be reported (e.g. India, see [18]), in other Member States the criteria for mandatory reportable events in NPPs do not cover all plant internal fires, although some of these events could be precursors for safety significant fire related events.

On an international basis two systems are available for mandatory reporting of NPP events, the IRS [14] and the INES [13]. While the IRS database includes only safety significant incidents, the INES scale to some extent also covers events with very low safety significance giving an indication on a lack of safety culture, etc. Both databases were not created for fire specific use only and therefore the level of detail in the information available from these databases is relatively low. Furthermore, it is out of the scope of these databases to provide data for analytical use.

It can be generally stated that the criteria for reporting of fire related incidents in NPPs vary strongly from country to country. For the international reporting systems the criteria also vary from database to database depending on the main goals of the database.

For the analysts these data are often not sufficient to clearly identify the weaknesses and deteriorations in plant fire protection and to give an assessment of the consequences in detail. Furthermore, the differing reporting criteria do not always allow an independent analyst to compare the plant specific as well as event specific sequence and consequences of the event to other plants of non-equivalent design and operating conditions without detailed expert knowledge on the incident in the respective plant considered. Because of the different levels of background information and knowledge of the event available (including the boundary conditions), the level of uncertainty for this type of data is relatively high.

4.5. GENERAL RECOMMENDATIONS FOR DATA COLLECTION AND RECORD KEEPING SYSTEMS

When defining the structure of a fire-related database it is necessary to consider:

- the requirements for individual data fields within the database;
- data field length, recommended input format for each data field and acceptable types of input data;
- the structural relationship between data fields.

The intended use of the database should be defined at the outset, for example, the extent to which it covers some or all of the following:

- actual fire events;
- degradation in fire protection, such as reports of open fire doors, degradated electrical cable insulation, accumulations of transient combustibles or poor control of hot work;
- defects and failure of fire protection equipment and systems.

Consideration must be given to the access rights to the data. The widest possible access to the information should be encouraged so that it may be pooled with data from elsewhere, thus producing a larger overall population and reducing the uncertainties in the subsequent statistical analyses. However, the knowledge that access to the information will be open can inhibit reporting, especially of apparently low-significance items. For this reason, database access may be normally restricted to the plant, utility or utility groups, with access rights granted to analysts by special permission.

In principle, the information needed for the different types of fire related databases (e.g. event databases, databases on fire related equipment, etc.) has to be categorized in a certain manner.

Furthermore, it is necessary due to the recent state of the art to create a computerized database which can be entered by any analyst with permission to receive such information. Such a database should be arranged in a user-friendly manner giving assistance on the use of the various data fields and possible entries. In addition it should include descriptive parts, e.g. for event description.

4.5.1. Actual fire events

It is recommended that all fire events, however small, be included in the database.

As discussed in Section 4.3, efforts have been made by regulators and/or utility groups in the USA, Germany, France and Japan to collect and analyse nuclear power plant fire event data. However, comprehensive event reporting schemes to which access is available are attributable to efforts in the USA, namely those proposed and implemented by the Electric Power Research Institute (EPRI Fire Event Database [15]), the Nuclear Regulatory Commission (Sandia National Laboratory Fire Event Database [17]) and Nuclear Electric Insurance Limited (Electrical Generation Plant Fire Incident Database [16]). Annexes I, III and IV discuss in further detail the event categorization and reporting schemes.

The NEIL database (see Annex IV and [16]) is the most recent and the most comprehensive one, having built upon the experience of its predecessors. The information provided generally satisfies the specific data needs of the applications which have been described in Section 3.

It is highly desirable that information concerning electrical cabinet configurations involved in fire incident be included in the event reporting. This is because it is important to recognize the threat due to fires in electrical cabinets which may be located in close proximity to exposed cables which may be ignited and form a secondary fire source. The potential for such fires to become severe is a significant input into a fire PSA, as discussed in Section 3.2.2.2. It has been recognized that the potential for fire spread from cabinets is highly dependent upon the type of cabinet ventilation and the rating (if any) of its associated penetration seals. The heat release rate from such fires is also dependent upon these factors as well as the combustible loading and compartmentation of the cabinet. Finally, the potential for damage in adjacent cabinets, or cubicles of the same cabinet, is dependent upon the degree of separation. For example two cabinets may be separated by double steel walls, with an intervening air space, or there may only be a partial intervening wall.

4.5.2. Plant fire protection features

A database on plant fire protection features should include as much information on the individual equipment and components as available. It should include or provide traceable reference to original manufacturer's information supplied with the equipment, such as test data and quality assurance information. It should also include the operational history of the equipment, such as records of periodic inspection, testing and maintenance and records of defects and their repair.

Furthermore, more general data from plant operation experience, such as operational years of experience for the equipment considered and populations of components assigned to groups of components with equivalent design and operating and maintenance conditions, have to be included in such databases. Details on the sources of raw data for plant fire protection features databases can be found in Section 4.3. Guidance on the development of detailed specifications for data systems to satisfy multiple purposes, also covering data on plant fire protection features, is given in Ref. [19].

4.5.3. Fire related indicators and trend analysis

Fire related trend data is relevant both to probabilistic and deterministic fire safety analyses.

There are no general rules defining responsibilities for collection and evaluation of trend data, taking into account the needs of plants, utility groups and regulators. It is important to establish a database of fire safety related indicators to allow trend analysis to be performed. Sources of information which can be noted in deriving the relevant data include: plant inspections, quality management records, test records, operating statistics, etc. as described in more detail in Appendix I to this publication.

5. DATA ANALYSIS AND PROCESSING

Unprocessed data from power plants can be analysed to produce structured information on fire events and fixed fire protections systems. In the case of fire events the data can be used to:

- establish fire frequencies for plant locations and components;
- quantify the severity of the fire;
- assess the likelihood that detection and manual fire fighting will be successful with respect to time.

For fire protection systems the data can be used to establish failure rates and unavailabilities per demand.

5.1. FIRE EVENTS

5.1.1. Frequency analysis

Evaluation of fire frequencies can be divided into the following stages:

- categorization of events;
- quantification of equipment populations and their operating time;
- calculation of point estimates;
- uncertainty estimation using Bayesian analysis.

These stages are described briefly below, but are discussed in more detail, with examples in Appendix II.4.1 to this publication.

The unprocessed fire event data are categorized into ‘bins’ by subdividing the plant into recognizable plant areas which are representative of the population of nuclear power plants as a whole.

Example of separate bins are:

- reactor building;
- auxiliary building;
- control room;
- switchgear room;
- cable spreading room.

Data can also be processed by component rather than location, for example: switchgear cubicles, motor, pumps, gas turbines, diesel generators, etc. In these cases, account must be taken of the total population of components, weighted according to the local population in plant areas.

A number of binning schemes have been developed to cover ignition sources, plant location and plant operational status (i.e. at power operation, shutdown). The merits of these schemes are discussed in Appendix II.

After consideration of the available alternatives, it is recommended that a data collection binning scheme based on that developed by the Nuclear Electric Insurance Ltd (NEIL — the US mutual insurance of nuclear power plants) should be adopted. This scheme uses a standard reporting form based on US NFPA standard 902 [20]. The scheme is described in detail in Appendix III hereto.

Point estimates of fire frequencies are derived by dividing the number of incidents in each bin by the total number of reactor operating years associated with each bin; these estimates may be made on a plant specific or generic basis. However, point estimates give no indication of the extent of their uncertainty due to factors such as the low number of incidents and variations between plants. Estimation of uncertainty requires advanced statistical analysis, for example using Bayesian methods. An example of their use is presented in Appendix II.4.1. When Bayesian analysis is used, it is generally found that plant specific mean values for fire frequencies are consistently higher than generic point estimates based on the population of events at all plants.

5.1.2. Fire severity

The concept of analysing fire severity is discussed in Section 3.2.2.2, which describes the qualitative categorization scheme developed by Berry & Minor [9]. The purpose of categorizing fires by severity is to derive a meaningful estimate of the likelihood that fire damage will spread beyond the immediate point of ignition, based on experiential data.

An alternative set of severity categories is described in Appendix II.2.2. However, whatever the categorization scheme adopted, the numerical severity factor associated with a particular ignition source type can be calculated as a function of the number of fires which have occurred for that ignition source. An example of this type of analysis is given in Appendix II.4.2.

5.1.3. Success of fire fighting activities

The effectiveness of fire fighting will derive from a number of factors as discussed in the present section. Account will be taken of automatic and human/manual actions regarding detection and suppression in response to the various fire severities and fire growth rates.

In order to estimate the likelihood that fire fighting activities will be successful, it is necessary to compare:

(1) The time (t1) at which damage will occur to equipment important to safety in the fire compartment or cell under consideration.

(2) The time (t2) which will elapse before effective fire fighting will occur, taking into account the following factors:

— the time between ignition and detection of the fire
— the time between detection and initiation of the fire fighting response
— the time taken for the fire brigade to reach the building where the fire has occurred
— the time taken to identify the compartment(s) or cell(s) where the fire is in progress

- the time taken to commence extinguishing operations
- the time taken to extinguish the fire or bring it under substantial control.

If t2 <t1, successful fire fighting can be expected but if t2 ≈t1 or t2 >t1, such an outcome becomes less certain.

Both the time to damage (t1) and the time to extinguishment (t2) are location dependent and therefore must be specifically estimated for each fire compartment or cell. The quantity t1 can be estimated by calculation (see for example [21]) or by fire modelling; techniques for determining the consequences of fire are discussed in Refs [1] and [3]. The various elements which comprise t2 must be determined separately. The time to detection for a particular fire scenario can be estimated using deterministic fire models. Fire brigade response can be determined using data recorded in site logs, making allowances for access restrictions, travel distances and fire fighting facilities in the vicinity of the fire event.

The assessment technique is outlined in Appendix II.4.3 hereto, and a practical example is presented in Annex V.

5.2. PLANT FIRE PROTECTION FEATURES

Statistical analyses are performed to evaluate failure rates for active equipment and to estimate mean values for repair and restoration time. The data analyses can also be performed to determine so-called “best estimates” for predictive purposes, outliers, and failure trends.

The raw data to be assessed have to be taken from the existing plant documentation and have to be reviewed carefully. The plant fire protection features include:

- Fire barriers/passive equipment and components;
- Active fire protection equipment and components.

Two different types of technical reliability data for equipment and components are in principle used for PSA studies:

- failure rate (λ); or
- unavailability per demand (p).

The expected values and their distribution can be determined for failures rate and/or unavailabilities per demand using statistical analysis, for example the Bayesian approach.

Because of the uncertainties of statistically estimated values due to several factors influencing the estimations, the Bayesian estimation reveals subjective probability distributions, quantifying partly these uncertainties.

If it is intended to obtain reliabilities for plant fire protection feature also considering human interactions, the Swain approach [10] mentioned in Section 3.2.2.4 has to be applied. The influence factors resulting from human action for manually operated fire protection equipment are in principle estimated applying methods such as ASEP-HRA [10] and THERP [11].

It is then possible to determine reliability distributions for the plant fire protection features considering the technical reliabilities on the one hand and the human factor influencing the failure rates and/or unavailabilities per demand on the other. The application of these techniques is discussed in Appendix II.3 hereto using fire dampers as an example.

6. CONCLUDING REMARKS

There is a paucity of international data exchange and collaboration in the area of NPP fire safety. This derives partly from the lack of coherent or agreed reporting systems in plants, operating companies and national bodies, or from an unwillingness to share such information. The fact that significant fires are rare events at NPPs is testimony to the lessons learned and experience gained to date. However, operational experience has also shown that repeat or similar events do occur and that with greater attention to this experience, commercial and human potential risks may be further reduced. In this respect, there is a need to recognize and look at small events not related to the realization of a fire, which provide useful precursor experience. Such data should be subject to regular trend and root cause analysis.

This TECDOC provides a common framework and guidance in this area, which if adopted by Member States, would provide a means of sharing and understanding experience of fire related events. The collection and examination of experience and data is targeted at event avoidance and identification of precursors. This should not be seen solely as a task to provide numerical data for PSA: deterministic lessons and conclusions are equally to be found in the proposed framework.

Additional guidance and experience, however, are needed in the following area:

(1) Information and data on collateral damage caused by fires and operation of fire fighting systems, for example, corrosion damage by smoke, fire fighting agents, etc., spraying or flooding of equipment by fire brigade actions.

(2) Reviews of levels of guidance provided to fire brigades in respect of levels of fire hazard, safety importance of equipment in certain areas to optimize responses consistent with minimizing reactor risk.

(3) Generic data on the effectiveness and reliability of fire protection features in response to observed events. For example, performance of fire barriers, effectiveness of detection in operation, adequacy (and magnitudes) of fire fighting methods used.

(4) Feedback of insights from fire event investigations.

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Appendix I
APPROACH USED FOR FIRE RELATED INDICATORS

The numerical value of any indicator may be of no significance if treated in an isolated manner. On the other hand, an indicator trend over a period of time should provide an early warning to plant management to investigate the reason behind the observed changes.

However, plant managers have to develop their own plant specific targets in order to establish a plan for decision-making and implementation of corrective actions. Therefore, in addition to monitoring the changes and trends, it may also be necessary to compare the indicators against such objectives or targets.

This appendix is based on the concepts presented in Ref. [I.1].

I.1. TYPE OF INDICATORS

The following eight topics could be introduced as fire related indicators.

(a) state of equipment
(b) fire events
(c) initiating fire event
(d) plant ability to respond to a challenge
(e) attitude towards fire safety
(f) ‘striving for improvement’ attitude
(g) plant risk associated with fire
(h) initiating events frequency due to fire.

Note that some indicators may relate to more than one of the above topics, that other types of indicators can be added to this list, and that no indicators for topics “g” and “h” were introduced as examples as PSA indicators were not specifically addressed in the present report.

I.2. EXAMPLES OF INDICATORS

(a) State of equipment

The detection and correction of deficiencies is a part of normal day to day activities at a nuclear power plant. The objective of plant surveillance and maintenance programmes related e.g., to fire protection equipment, is to maximize the availability and reliability of such equipment. Operations and maintenance personnel are responsible for assuring the operability of fire protection components, systems and structures.

TABLE I.1. INDICATORS FOR STATE OF EQUIPMENT

Indicators	Identified by
Number of corrective work orders issue for fire protection systems/equipment	QM(rev/audit)
Number of pending work orders for more than X months for fire protection systems/equipment	QM(rev/audit)

(b) Fire events

Every fire event is an indicator of some plant deficiency. Some events, such as fire, could challenge multiple plant systems and cause disturbances that may not be easily mitigated.

TABLE I.2. INDICATORS FOR FIRE EVENTS

Indicators	Identified by
Number of fire related events	QM(rev/audit)
Number of burned fuses (or cables)	QM(rev/audit)
Number of fire events reported	Stat. eval.
Number of fires due to hardware/design related causes	Stat. eval.
Number of fires due to human related causes	Stat. eval.
Number of fires due to external or internal causes	Stat. eval.
Numbers of incipient fires which self extinguished due to lack of local combustible material or were de-energized by over current or over temperature protective devices (fuses, breakers, etc.)	Stat. eval.

Remark: the intent of indicators *a* and *b* is to monitor both the events of higher significance, namely those of interest to other organisations such as the specific regulatory body or other nuclear operators through WANO, and also to account for those events which, although they are not necessarily reportable (externally), can nevertheless be very useful for utilities with several power plants or as indicators for regulatory purposes. As an example, lower level events can be used as plant specific indicators for early warnings that may help to prevent the future occurrence of fire events.

(c) Initiating fire events

A low number of challenges to a plant translates into a lower possibility of having nuclear transients and/or accidents due to a reduced number of accident initiators.

Remark: it has to be stressed that fires themselves do not represent the totality of possible fire initiating events. This means that fire events in an NPP do not necessarily have to cause challenges to the safety systems. In fact, location and amount of combustibles, fire protection systems, location of cables and safety equipment, ability of operators (fire brigade/team) to mitigate that fire, are aspects necessary to be considered for the definition of fire scenarios, and therefore to be considered for the analysis of fire caused initiating events that will challenge the plant and may lead to nuclear accidents. Therefore, the existence of an undue amount of combustibles, the lack of adherence to procedures during welding or grinding activities, the unavailability of fire protection systems, the inability to suppress fires by fire crews, etc., are *events* that might not seem to be relevant in principle since they do not seem to pose challenges to the plant if they are considered isolated events. However, they contribute to the increment of risk from fire. They may be called *precursors* to initiating events caused by fire. It is important to find indicators for monitoring these aspects because poor performance in these areas contributes to the risk by increasing initiating event frequencies. Since these indicators would give an early warning of future plant challenges, it also seems to be logical that their contribution to the risk may not be negligible.

TABLE I.3. INDICATORS FOR INITIATING FIRE EVENTS

Indicators	Identified by
Increasing amount of fire loads (combustibles) in fire compartments	QA/inspection
Number of fire doors found blocked open.	QA/inspection
Number of deteriorated passive fire barrier elements (walls, penetration seals, cable retardant coatings or wraps, etc.)	QA/inspection
Number of cases in which undue combustible material has been detected	QA/inspection
Number of poorly signalled access/escape routes for fire fighting and rescue personnel	QA/inspection
Number of fire protection procedural violations (e.g. related to hot work such as welding, cutting, grinding, etc., combustible control, etc.)	QA/inspection
Number of missing portable fire extinguishing means	QA/inspection
Degradation by ageing (visual)	QA/inspection
Additional cables or cable ways in safety related rooms	QA/inspection
Number of failures during testing of active fire barrier elements (fire dampers, doors etc.), fire extinguishing systems and equipment or smoke and heat removal systems	Testing
Number of malfunctions during testing of fire detection and alarm features	Testing
Number of failures during testing of communications systems used for fire incidents	Testing
Number of failures during testing of emergency lighting systems	Testing
Number of failing extinguishing water supplies or sources	Testing
Number of I&C malfunctions by ventilation systems important for fire protection (e.g. automatically switch off on demand by fire indication)	Testing
Number of failures during testing of portable fire extinguishing means	Testing
Ageing degradation (during equipment tests)	Testing

(d) Plant ability to respond to a challenge

When a challenge to the plant occurs, the plant should respond in such a way as to prevent any damage to the reactor core, and in the event that some damage occurs, the plant should mitigate the consequences to prevent radioactive releases to the environment.

TABLE I.4. INDICATORS FOR PLANT ABILITY TO RESPOND TO A CHALLENGE

Indicators	Identified by
Number of hours devoted to training fire scenarios	Organization
Number of errors during training of fire fighter brigade	Organization
Number of errors during accident management exercises (fire scenarios)	Organization
Poor performance (timing) in responding to fire induced scenarios during simulator exercises	Organization
Number of times a lack of electrical separation has been found	Stat. eval.
Number of misrouted cables found	Stat. eval.

Advice: fire related indicators defined to monitor this area should be aimed at monitoring the plant ability and the operator preparedness to respond to a challenge initiated by a fire event.

Remark: operator actuation during the course of a scenario initiated by an abnormal event such as fire may be much more challenging than during other non-hazard initiated events due to the possible unavailability of instrumentation systems and mitigation systems caused by the fire. Therefore, indicators monitoring this domain can potentially detect areas of deficiency before they become a problem.

(e) Attitude towards fire safety

The purpose of these indicators is to assess how well personnel maintain the plant within licensing *requirements* and comply with other procedures and rules. Licensing requirements include, for example, the fire protection programme. As a vital part of safety culture, it is essential that plant personnel understand the reasons for the safe limits of operation and the consequences of license violations. This is also an indication of the attitude of the personnel as a consequence of administrative control policies, level of safety culture, and/or adequacy of training.

TABLE I.5. INDICATORS FOR ATTITUDE TOWARDS FIRE SAFETY

Indicators	Identified by
Number of deviations (related to fire safety) found in the frame of Q&A audits	QM(rev/audit)
Number of violations of the licensing requirements related to fire protection	QM(rev/audit)
Number of temporary modifications in fire protection systems and equipment	QM(rev/audit)
Number of fire related events due to human error	Stat. eval.
Number of fire related events due to training deficiencies	Stat. eval.
Number of fire related events due to deficiencies in procedures	Stat. eval.

(f) Striving for improvement attitude

Safety reviews and audits are a very important part of plant self-assessment activities. Internal safety reviews and audits are performed to assess the effectiveness of the plant programmes and procedures, to verify by examination and evaluation of objective evidence that elements of the programmes and procedures conform to specified requirements, to assess the effectiveness of controls and verification activities, to report findings and deficiencies to all levels of management who need to be informed and who take corrective action, and to verify that corrective actions have been planned, initiated, or completed.

TABLE I.6. INDICATORS FOR STRIVING FOR IMPROVEMENT ATTITUDE

Indicators	Identified by
Number of repeated findings related with fire safety identified in internal reviews and audits	QM(rev/audit)
Number of similar or repeated fire related events	QM(rev/audit)
Number of own plant fire events that undergo root cause analysis	QM(rev/audit)
Number of analysis of fire events at other plants	QM(rev/audit)
Number of dedicated fire protection engineers	Organization
Number of fire fighters in the brigade	Organization

Remarks:

— Operating experience feedback (OEF) can play an important role in fire safety. OEF is based on reviews of actual events which have happened either at the plant or at other installations. Failure to apply lessons learned from the OEF system or its inadequate implementation would be indicated by the occurrence of similar events. Indicators in this area should also be sought.

— The 'striving for improvement' attitude regarding fire safety can also be reflected in the number of staff dedicated to the control and improvement of the fire protection programme at the plant.

(g) Plant risk associated to fire

Risk can be readily measured at the plant level by performing a plant specific PSA. Depending on the scope of the PSA, this attribute can be measured in terms of individual risk, population risk, frequency of release categories or core damage frequency (CDF) associated to fire. For a given PSA study, specific contributors to CDF which are explicitly important indicators can be identified and applied for monitoring purposes.

(h) Initiating events frequency due to fire

Initiating event frequencies are defined by unique plant design characteristics and operational controls often implemented with the intent of minimizing such frequencies. These design and operational features are part of the preventive characteristics of the plant. Maintaining these characteristics consistent with their original design contributes to keeping the potential number of challenges to the plant at acceptable levels.

Advice: several possibilities exist for plant personnel to inadvertently and significantly affect (fire related) initiator frequencies, because these are often influenced by the existence of transient combustibles, transient ignition sources and by the availability and/or performance of the fire protection equipment. Initiator frequencies can be increased by different means, e.g. by not promptly restoring fire protection equipment to service; by maintenance activities on systems and components; by testing; plant modifications; and/or operator errors.

Actual (fire related) initiating event frequencies, can be monitored. An analysis can be performed to determine which routine plant activities or events may affect the initiating events on the basis of fire frequencies. Dedicated analysis or operating experience can be used as the basis for defining this indicator.

REFERENCE TO APPENDIX I

[I.1] INTERNATIONAL ATOMIC ENERGY AGENCY, Operational Safety Performance Indicators for Nuclear Power Plants, IAEA-TECDOC (in preparation).

Appendix II
DATA ANALYSIS AND PROCESSING

II.1. INTRODUCTION

The present appendix is divided into three main sections concerned with the analysis and processing of operational experience related to fires and plant fire protection features. Sections II.2 and II.3 discuss the process. Section II.4 provides some practical examples.

II.2. FIRE EVENTS

As discussed in Section 3.2 of the main text, fire event data are used to:

- Establish fire frequencies for individual plant locations and ignition sources,
- Determine the likelihood that fire damage will be self-limiting in terms of severity factors,
- Assess the likelihood of successful detection and manual suppression with respect to time.

The fire event processing required to support each of these uses is discussed below:

II.2.1. Fire event frequencies

Evaluation of fire frequencies can include several stages:

- Binning of fire events into ignition source bins,
- Evaluation of exposure times and populations,
- Evaluation of point estimate generic fire frequencies,
- Evaluation of point estimate plant/location/ignition source specific fire frequencies,
- Bayesian updating to derive plant/location specific fire frequencies.

II.2.1.1. Fire event binning

In some previous applications fires have been binned according to their location or ignition source type:

Fire location bins are created by subdividing the plant into recognizable plant areas in which the equipment inventory and plant personnel activities within each given area and are similar at most NPPs. Thus for example; switchgear room, control room, cable spreading room, auxiliary building, reactor building or diesel generator rooms have been defined as separate bins in Ref. [II.1]. The generic annual fire frequency associated with each location bin is then derived from the ratio of the number of assigned fire incidents, to the total number of years of plant experience associated with the location.

However, fire frequencies are also required for many specific plant compartments which are clearly not uniform from one plant to another in terms of fire potential (e.g. pump rooms, corridors, general equipment rooms). In such cases some studies have determined individual fire compartment frequencies by partitioning the frequency associated with the associated recognizable plant area (such as the reactor building) among constituent fire compartments according to specific weighting factors. Earlier studies defined simple location weighting factors such as, the inverse of the number of compartments in the area, or the combustible loading fraction. However, these factors, used in isolation, tended to oversimplify the influences which determine the relative fire frequency, leading to over- or under-estimation of the frequency in individual plants. Furthermore, the combination of generic area fire frequencies and plant specific compartment weighting factors does not provide the analyst with a method which can easily account for plant to plant variations in the location of major ignition sources. For example, if a particular plant under examination had a relatively large number of electrical cabinets in the cable spreading room compared with the average plant, the fire frequency assigned using this method would be significantly underestimated in the plant specific analysis.

Thus, while the above approach is relatively simple and efficient to implement, there are clear disadvantages in terms of the reliability and usefulness of the results.

Ignition source type bins. Ignition source bins can be created by defining a set of fixed and transient ignition sources which adequately characterize all sources of fire within a nuclear power plant. Thus, high voltage switchgear, batteries and indoor dry transformers are typical examples of fixed ignition sources. Transient material fires induced by welding/hot work activities are examples of transient fire sources. The annual fire frequency associated with a given ignition source type (Ci) is then derived as a function of the number of events allocated to the ignition source bin and the number of reactor years of operating experience. This approach has the advantage of precisely accounting for plant to plant variability in the location of ignition specific sources as well as enabling the determination of the fire frequency associated with individual fire sources if required for detailed analysis of the compartment.

The EPRI Fire Event Database ([II.2] and its summary in Annex I). The EPRI Fire Event Database with associated event binning scheme [EPRI event binning scheme] is the most widely used approach for power plants in the USA. Here the binning scheme is essentially a hybrid of the two approaches mentioned above. Fire events are binned according to general plant location with ignition source types as subcategories. A so-called “plant wide” location bin also subdivided according to selected ignition sources is also included. This binning scheme is illustrated in Annex I. This approach allows the analyst to distribute the general location fire frequency among the constituent compartments according to the type and number of ignition sources present. Plant wide ignition sources are distributed to individual compartments in a similar fashion, which permits some flexibility to address the plant to plant variation in the fire frequency of general plant locations.

However, the approach was designed with the preconception that the plants which would be analysed using the data scheme would have essentially similar layouts and that the amount of equipment (and presumably the fire frequency) would be similar among all units and, to some respect, equal among like general locations of all units. In practice, significant variations in location specific equipment inventory (i.e. not plant wide) were identified. For example, at some plants the cable spreading room may contain one or two small electrical cabinets, whereas at another plant, it may contain five or six Motor Control Centres. A literal interpretation of the EPRI approach would assign the same cable spreading room fire frequency in both cases, which is clearly inappropriate.

Low power and shutdown probabilistic risk assessment programme [II.3]. Most fire event binning schemes have been created with at power fire risk analyses in mind and have included all operating experience since the first commercial operation in deriving fire frequencies. This essentially assumes a negligible difference in fire potential between operating modes. In this study, fire events contained in the updated Sandia Fire Database ([II.4] and its summary in Annex II) were binned according to ignition source type, fire severity and applicable plant operating mode with the aim of accounting for any specific mode to mode fire frequency variations. The ignition source type and severity classifications have already been addressed. However, a review of the operating mode classification applied in Ref. [II.3] provides some additional insights.

Three operating mode bins were identified:

- Fire events which can occur only at shutdown and not in power operation,
- Fire events which can occur during both power operation and shutdown,
- Fire events which can occur during power operation only.

The exposure times for each category are: the total plant shutdown time for the first category, the total shutdown plus operational time for the second category, and the total plant operational time for the third category.

While this scheme introduces a degree of judgement in determining which events to include in category 2, the effect is to increase the fire experience base applicable to shutdown modes where far fewer applicable events have been recorded.

Improved fire event binning scheme

The ideal binning scheme attempts to group together ignitions sources which have a similar potential for initiating fires. The characteristics of each bin should correlate to the type and number of ignition sources present in plant specific fire compartments.

While plant location was used as a factor in defining the fire ignition source bins in Ref. [II.2] to delineate possible differences in fire frequencies associated with components of similar types but operating under different conditions (e.g. pumps in the auxiliary buildings may have a different unit fire frequency from those in intake structures), the approach has some distinct disadvantages in terms of accounting for plant to plant variations. *With one exception*, plant location is therefore not suggested as a binning factor. Instead, only the ignition source type should be used. In cases where some possible differences in fire potential due to operating conditions or component rating are recognized, they should be used explicitly as the delineating factors. Thus for example, instead of binning motor driven pump fires according to their plant location, they should be binned according to whether they are associated with normally running or standby pumps. Another example would be to bin electrical cabinet fires according to whether they are associated with high or low energy electrical supplies (over or under 480 V), rather than by plant location.

The exception referred to above is related to transient combustible fires where the potential is related to the types of ongoing maintenance activity and the types of combustible control in place. These factors are often a function of the general plant location (e.g. turbine building, control building, reactor building, containment). In the case of transient fires, general plant location is a suitable binning factor.

If the database is to be used for shutdown fire PSAs, the binning scheme derived from [II.3], described above, should be superimposed on each of the ignition source type bins.

Recommendation

If information concerning the total population of components and years of operating experience for the plants represented in the data collection effort is available, the improved binning scheme is recommended. If only the total number of years of operating experience is known, then the scheme derived from Ref. [II.3] would be the most appropriate, albeit less accurate.

II.2.1.2. Exposure times and populations

The exposure times for each ignition source bin is equivalent to the number of reactor operation years (RY).

The exposure time for each individual fixed ignition source (Ei) is represented by the product of the number of ignition sources in each bin at an individual plant multiplied by the operating years of experience of that plant, summed over all plants in the database.

A further breakdown of operating experience, according to operating mode can be performed as described in Ref. [II.3] and summarized above in Appendix II.2.1.1.

II.2.1.3. Evaluation of point estimate fire frequencies

The annual fire frequency associated with a given ignition source bin (Bj) is derived as:

$$F(Bj) = Nj / RY \text{ per reactor year}$$

where Nj is the number of events allocated to the ignition source bin and

RY is the *exposure* time for each ignition source bin.

The annual fire frequency associated with an individual ignition source (Ci) associated bin (Bj) is derived as:

$$F(Ci) = Nj / Ej$$

where Nj is the number of events allocated to the ignition source bin and, Ej is cumulative exposure time for all components in the bin (j).

The fire frequency associated with a given ignition source (Ci) in a particular location (k) can then be determined from:

$$F(Cik) = F(Ci) \times N(ik)$$

where N(ik) is the number of ignition sources of type (i) in location (k).

The total frequency of a compartment fire is then determined from the sum of the contributions from each resident fire source type.

In cases where the fire ignition frequencies have been derived for the different operating modes using [II.3], the frequencies are simply added together, i.e.

The total frequency for shutdown = (frequency for operation or shutdown)
+ (frequency for shutdown only)

The total frequency for operation = (frequency for operation or shutdown)
+ (frequency for operation only)

II.2.1.4. Uncertainty issues

For calculating a fire frequency distribution taking into account plant to plant variation and the experience of the specific plant under evaluation , a two stage Bayesian process can be employed. An example of the process is shown in Appendix II.4.1 and the results compared with the simple point estimate approach described in Appendix II.2.1.3.

II.2.2. Fire severity factors

The underlying rationale for developing severity factors has been discussed in Section 3.2.2.2 of the main report. The first step in performing this analysis is to define a set of fire severity categories for each ignition source type. The precise definition of these categories depends upon the characteristics of each ignition source and the intended application of the severity factor which is to be derived.

A typical set of severity categories might be:

(1) Fires which self-extinguished without causing damage beyond the initiating component.

(2) Fire which were extinguished using hand held extinguishers.

(3) Fires which required the application of hose streams or triggered automatic suppression systems.

(4) Fires which involved liquid or gaseous combustibles.

(5) Fires which resulted in an explosion.

(6) Fires which caused equipment loss in excess of a prescribed monetary value.

The severity factor associated with a given severity category (j) for ignition source type (i) is then determined from:

$$SFij = 1 - \frac{A}{B}$$

where A = (Number of fires assigned to category j or categories of severity less than j),
and B = (Total number of fires assigned to ignition source type i).

Thus the frequency of fires of type i which exceed the severity of j:

$$Fij = Fi \times SFij$$

where Fi is the frequency of fires of type i.

For example, if we wish to determine a screening value for the frequency of fires originating in one component that might cause damage to an adjacent but well separated component, it would be prudent to use a fire severity factor applicable to severity category 2, providing appropriate automatic fire detection and unrestricted access are available on the fire location.

II.3. PLANT FIRE PROTECTION FEATURES

Statistical analyses are performed to evaluate failure rates for active fire protection components and equipment and to estimate mean values for repair and restoration times from the plant operational experience available. Furthermore, data analyses can also be performed to determine so-called “best estimates” for predictive purposes, outliers within a group of identical components, and failure trends.

For a given fire protection feature type, the failures corresponding to each group is statistically analysed to determine whether there are outliers within the target group, significant time dependent failure trends, and significant differences between the respective group and other groups for the assumed failure modes.

The raw data to be assessed have to be taken from the existing plant documentation and have to be reviewed carefully considering the expert knowledge of the analyst as well as information from the responsible plant personnel involved in testing and maintenance of the respective fire protection features. These plant fire protection features include:

- fire barriers/passive equipment and components,
- active fire protection equipment and components,
- data on active fire protection features are mainly used in probabilistic fire risk analyses.

Two different types of reliability data for equipment and components are in principle used for PSA studies:

- failures rates λ, or
- unavailabilities per demand p.

The following expected values and their distributions can be determined for failures rates and/or unavailabilities per demand using the Bayesian approach [II.5]:

The expected value $E(\lambda)$ of the failure rate is determined for a number of failures k for a defined time period T as

$$E(\lambda) = (k + 0.5)/T$$

The expected value E (p) of the unavailability per demand is determined for x failures and a number of component demands n as

$$E(p) = (2x + 1):2(n + 1)$$

Because of the uncertainties of statistically estimated values due to several factors influencing the estimations, such as rough model assumptions, limited observation time period, boundary conditions being not identical for the nearly identical components to be assessed, etc., the Bayesian estimation reveals subjective probability distributions, quantifying partly these uncertainties.

If it is intended to obtain reliabilities for plant fire protection feature also considering human interactions, the Swain approach mentioned in Section 3.2.2.4 has to be applied. The influence factors resulting from human actions for manually operated fire protection equipment are in principle estimated applying the THERP methodology [II.6] widely accepted for assessing human/personnel actions.

Applying this methodology, information from plant documentation and additional information from plant walk-throughs and discussions with the plant personnel involved (see [II.7] and [II.6]) have to be used to create a so-called action model in a first step. In a second step, all human actions explained by the action model have to be subdivided into subtasks and the consequences of potential faulty actions have to be assessed. In a last step, subtasks relevant for the assessment have to quantified corresponding to the procedures outlined in Ref. [II.6].

It is then possible to determine reliability distributions for the plant fire protection features considering the technical reliabilities of the equipment on the one hand and the human factor influencing the failure rates and/or unavailabilities per demand on the other hand.

II.4. EXAMPLES OF DATA ANALYSIS

II.4.1. Analysis of event data to determine fire ignition frequencies

The following presents an example of a Bayesian updating scheme to derive the fire frequency distributions for one fire ignition type; namely transient fires during plant shutdown. The example is taken from data provided in NUREG/CR–6144 and is pertinent to the Surry nuclear power plant. The results of this approach are then compared with a simple point estimate analysis of the generic fire frequency.

Since it was believed that plant location has a strong influence on the propensity for transient fire, three subgroups were evaluated separately as follows:

- transient fires in the turbine building (TB),
- transient fires in the containment (CT) or reactor building (RB),
- transient fires in switchgear room (SWGR).

(Note: in the preceding example, other nuclear power plant areas were not addressed.)

For fixed ignition source types, fire location should not be as significant.

Overall operational experience

In order to calculate the frequency of fires, the exposure time of US nuclear power plants and Surry has to be known. The time is calculated for each plant as the difference between the date of decommissioning or December 1989 (the cut-off date for including events in the fire event database) and the date of initial criticality of the plant. The results were as follows:

TABLE II.1. EXPOSURE TIME OF ALL USA PLANTS UP TO 12/1989

Mode of operation	Exposure time
Power + Shutdown	1396
Shutdown only	490

TABLE II.2. EXPOSURE TIME FOR BOTH SURRY UNITS 1 AND 2 UP TO 12/1989

Mode of operation	Exposure time
Power + Shutdown	34.2
Shutdown only	13.7

For all US plants, the time in shutdown was estimated assuming an average down time of 35%. For Surry, an actual shutdown time was determined from plant records.

Note: for fixed component ignition sources, the exposure time would be the product of the number of plant years and the number of components assigned to the ignition source category being evaluated. Ideally, the number of components at each plant in the database would be known. Otherwise an average value should be assigned.

Pertinent events from database events

Specific criteria were applied in selecting events to be included.

(1) Since we are concerned with fires that can occur at ‘power and at shutdown’ or ‘at shutdown only’, events which can occur only during power operation would be excluded. In fact no *transient combustible* fire events were excluded on this basis. However, a typical example of an event which would be excluded on this way would be reactor coolant pump (RCP) electrical fires, or RCP oil coming into contact with hot piping. Construction events were excluded.

(2) Events which occurred in irrelevant areas were also excluded. That is, in the analysis the *transient combustible* fire frequency was location specific rather than plant wide.

Fires that were not severe enough to cause damage were disregarded. Hence, in this case a severity factor is already incorporated in the fire frequency.

The results were as follows:

TABLE II.3. TRANSIENT FIRE EVENTS FROM THE SANDIA FIRE DATABASE (UPDATED SNL DATABASE)

Event No.	Plant/(plant area)	Years of plant operation
57[s]	Point Beach (TB)	18.9
80	Robinson (CT)	19.2
87	Unknown PWR (TB)	11.1
105	Unknown PWR (?)	11.1
128	Browns Ferry (CT)	16.3
137	Fort Calhoun (CT)	16.3
158	Brunswick (TB)	13.2
270	Pilgrim (RB)	17.5
275[s]	Ginna (RB)	20.1
288	Browns Ferry (?)	16.3
309	San Onofre (SWGR)	22.5
431[s]	Wolf Creek (TB)	4.6
438	Dresden (CT)	18.9

[s] indicates this fire is applicable to shutdown only.

RB = reactor building; CT = containment; TB = turbine building; SWGR = switchgear room.

There was one transient event at Surry which was applicable to shutdown conditions only and occurred in the containment.

For calculating the fire frequency distribution, a two-stage Bayesian updating programme was used with a non-informative prior (1\lambda) and a Poisson likelihood function ([II.8]). The number of events and the number of corresponding plant years were input. The resulting generic fire frequency distributions arising from the first stage were as follows:

TABLE II.4. PARAMETERS OF GENERIC FIRE FREQUENCY DISTRIBUTION FOR TRANSIENT FIRES

Type of fire	Plant area	Events	5%	50%	Mean	95%	μ	σ
Transient fire at power or shutdown	CT/RB	5	1.4E–03	3.4E–03	3.6E–03	6.7E–03	–5.79	0.472
	TB	2	2.6E–04	1.2E–03	1.4E–03	3.7E–03	–6.93	0.807
	SWGR	2	2.4E–04	1.2E–03	1.4E–03	3.7E–03	0.807	0.807
Transient fire at shutdown only	CT/RB	2	7.3E–04	3.5E–03	4.1E–03	1.0E–02	–5.91	0.796
	TB	2	7.3E–04	3.5E–03	4.1E–03	1.0E–02	–5.91	0.796
	SWGR	1	1.1E–04	1.5E–03	2.0E–03	6.5E–03	–7.08	1.24

For the purpose of the example, we assume that the two fires of unknown locations occurred in switchgear rooms and one of this was applicable to shutdown only.

These lognormal distributions were input as priors together with the Surry evidence and plant years for the applicable mode in a second Bayesian updating process. The resulting Surry specific fire frequency distributions were as follows:

TABLE II.5. PARAMETERS OF SURRY SPECIFIC FIRE FREQUENCY DISTRIBUTION FOR TRANSIENT FIRES

Type of fire	Plant area	Surry events	5%	50%	Mean	95%
Transient fire at power or shutdown	CT	0	1.5E–04	1.2E–03	2.4E–03	8.7E–03
	TB	0	8.4E–05	6.1E–04	1.3E–03	4.5E–03
	SWGR	0	9.2E–05	6.4E–04	1.3E–03	4.4E–03
Transient fire at shutdown only	CT	1	2.6E–03	9.8E–03	1.4E–02	3.7E–02
	TB	0	1.1E–04	8.3E–04	1.7E–03	6.2E–03
	SWGR	0	1.9E–04	1.6E–03	3.8E–03	1.4E–02

The *frequency per shutdown year* (mean value) is derived by summing the frequencies for (operation and shutdown) and for (shutdown only).

Generic point estimate values can be calculated as the ratio of the total number of events from all plants (including Surry experience) and the total exposure time. Point estimate values derived in this way are compared with the plant specific mean values as follows:

TABLE II.6. POINT ESTIMATE VALUES FOR TRANSIENT FIRE

Type of fire	Plant area	Mean	Point estimate
Transient fire at shutdown	CT	1.6E–02	5.8E–03
	TB	3.0E–03	2.8E–03
	SWGR	5.1E–03	2.2E–03

As can be observed, the plant specific mean values are consistently higher than the generic point estimates.

II.4.2. Analysis of event data to determine severity factors

In Section 2.1.2 the severity factor is defined as the fraction of fires which exceed a given severity level, or

$$SFij = 1 - \frac{A}{B}$$

where A = (Number of fires assigned to category j or categories of severity less than j),
and B = (Total number of fires assigned to ignition source type i).

Thus, if we are interested in the fraction of fires which were so severe that they could not be suppressed using portable extinguishers and required other means, the applicable severity factor may be evaluated according to the following examples:

TABLE II.7. SEVERITY FACTOR IN EACH SEVERITY CATEGORY

	Number of fires in each severity category						Severity factor
Type of fire	Self-extinguished (a)	Hand-held extinguisher (b)	Hose station (c)	Automatic suppression (e)	Unknown means[1] (f)	Total number of events (N)	SVib = 1 – (a +b +0.5f)/N
Dry transformer	3	3	0	3	1	10	1–(6.5/10) = 0.35
Motor driven pumps	6	4	2	0	3	15	1–(11.5/15) = 0.23
Turbine generator oil fires	0	7	5	0	5	17	1–(9.5/17) = 0.44

[1] Invariably the data on means of suppression of other severity indicators will not be complete. Though by no means perfect, one solution is to assume that 50% of the unknown events are severe.

II.4.3. Analysis of event data to determine likelihood of detection and suppression

A detailed review of the fire occurrences reported in the Sandia Fire Event Database revealed that a total of 69 events included information concerning fire suppression times [II.9]. Most of the events identified involved manual detection and suppression of the fire with suppression times ranging from 2 minutes to 7½ hours. A limited number of events involved automatic detection and suppression with suppression times ranging from several minutes to 1¾ hours.

In developing such detection and suppression distributions, two points of caution should be noted. Whereas in the example all fire events are utilized in developing a single distribution, this approach does not allow for consideration of the actual detection and suppression systems available or the accessibility of the specific plant location under investigation. A more accurate approach would be to subdivide the fire brigade response into the following phases:

- establish burning to detection;
- detection to alarm;
- fire brigade response to the building entrance (if applicable);
- arrival at the room of origin;
- finding the fire;
- suppression agent application;
- extinguishment or substantial control of the fire.

Fire code modelling such as the ASET computer code developed by the United States National Institute of Standards can be employed to estimate fire size and depth of smoke and to predict the time of fire detection, finding the fire, applying extinguishing agent and extinguishing the fire. Plant specific drill records provide information regarding time for fire brigade response and arrival at the room of origin. A detailed description of this method of estimating fire brigade response is provided in Annex V to this publication.

II.4.4. Example of data on fire barrier failure rates

Data on fire barrier failure rates are available in Ref. [II.8] and are summarized in the following table:

TABLE II.8. FIRE BARRIER FAILURE RATES

Barrier type	Failure rate (per reactor-year)
Fire, security and water tight doors	7.4E–03
Fire and ventilation dampers	2.7E–03
Penetration seals, fire walls	1.2E–03

In the above generic failure rates, the analyst should verify that there are no plant specific fire barrier problems identified by the plant fire protection staff. If any specific barrier problems are identified, a Bayesian updating process can be utilized to develop plant specific fire barrier failure rates.

REFERENCES TO APPENDIX II

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Appendix III
SUGGESTED FIRE EVENT DATA COLLECTION SCHEME

As discussed in Annex IV to the present publication, Nuclear Electric Insurers Limited (NEIL) have developed and are currently managing a fire event data collection effort for nuclear power plants in the USA. The event reporting forms utilized by NEIL have been reviewed and minor alterations made to suit the needs of the applications being addressed within the present TECDOC. The resulting forms are presented in this appendix and offered as a reasonable approach for fire event data collection.

Note that this fire event data collection scheme has been prepared based on that which applies to PWRs and BWRs: some modifications should be needed for other reactor types such as PHWRs, gas cooled reactors and liquid metal cooled reactors.

Nuclear Electrical Generation Plant Fire Incident Database Report Form

A	Incident No:	Company:	
B	Plant Name/Unit:	Plant Type:	
C	Date of Fire:	Time of Fire:	Country:
D	Plant Status:	Location of Fire:	
E	Fire Origin:		
F	Ignition Factor (Cause):	Type of Material Ignited:	
G	Was oil involved:	If yes, oil source:	
H	If yes, type of oil:	If yes, type of oil source:	
I	Quantity of oil:	Surface area of oil:	
J	How Reported:		
K	Fire Detection System Present:	Fire Detection System Operated:	
L	Fire Detection System Type:	Fire Detection System Performance:	
M	Fire Detection System Performance:		
	If the fire in the room of origin did not operate the detection system, enter the reason why:		
N	Fixed Fire Suppression System Present:	Fixed Fire Suppression System Operated:	
O	Fixed Fire Suppression Type:	Fire Suppression System Actuation:	
P	Fixed Fire Suppression System Performance:		
Q	Fixed Fire Suppression System Performance:		
	If the fire in the room of origin did not operate the suppression system, enter the reason why:		
R	Fire Brigade Response:		
S	Specify time first member of the fire brigade reached the scene:	Did high temperatures prevent personnel from entering the room where the fire occurred without protective clothing:	
T	Did smoke prevent personnel from entering the room where fire occurred without breathing apparatus:		
U	Did smoke completely obscure the compartment preventing fire fighting activities:		
V	Did first member attempt to fight fire:	Time full brigade reached the scene (hours:minutes):	
W	Extent of fire/smoke damage:		
	What were the indications of the fire:	If flames were visible, characterize the flames:	
X	Did an explosion occur:	If yes, indicate whether it occurred before or after the onset of the fire:	
Y	Duration of vigorous burning (hours/minutes):	Flame height during period of vigorous burning (m)	
Z	How long did fire burn:		

AA	Specify time from detection to start of suppressant application (hours:minutes):	Specify time from detection to extinguishment (or self-extinguishment) (hours:minutes):
AB	Specify time from detection to control of the fire (hours:minutes):	
AC	Type of extinguish action:	
AD	How extinguished:	
	Was the application of suppressants delayed for any reason:	What suppressant agent was used to extinguish the fire:
AE	Potential Impact on Safe Shutdown Capability:	
AF	Manual or Automatic Plant Trip	
AG	Injuries/Fatalities:	Estimated Dollar Loss:
AH	Extent of Fire/Smoke Damage:	
AI	Other fire damaged equipment:	
AJ	If damage extended beyond the equipment of origin, what caused the damage:	
AK	If damage was due to heat, was there observable evidence of heat damage after the fire:	
AL	If yes, at what elevation above the base of the fire was heat damage observed (m):	
AM	At what radius around the centerline of the fire was heat damage observed at the base (m):	
AN	At what radius around the centerline of the fire was heat damage observed at the ceiling (m)	
AO	If damage extended beyond the equipment of origin, did combustibles ignite beyond equipment of origin:	
AP	If yes, at what elevation above the base of the original fire was secondary ignition observed (m)	
AQ	At what radius around the centerline of the original fire did secondary ignition occur at the base (m)	
AR	At what radius around the centerline of the original fire did secondary ignition occur at the ceiling (m)	
AS	Did the fire result in spurious operation of equipment:	
AT	Pumps or other components bearing oil: enter data below:	
	Horsepower:	Voltage:
AU	Transformers: enter data below for fire involving transformers:	
	Equipment type:	Transformer type:
AV	Voltage	Was oil involved:
AW	Electrical cabinets: enter data below for fires involving electrical cabinets:	
	Equipment type:	Voltage:
AX	Ignition source:	Was an explosion involved:
AY	Describe cabinet fire load	Cabinet ventilation:
AZ	Did the fire spread from the ignition source to combustibles within the cabinet:	Type of ventilation:

AAA	Electrical wiring and cable:		
	State:		
AAB	Diesel generators:		
	Part of the diesel generator that was the origin of the fire:	Was oil involved:	
AAC	Lessons Learned Report Data developed		
AAD	Data/Remarks		
AAE	Name of Reporter		
AAF	Approved by:	Department/Division:	Date:
AAG	Can this information be made public:	Department/Division:	Date:

FIRE INCIDENT DATABASE – CODING LEGEND

LINE A DATA

Incident No.

Leave blank, will be filled in by database manager.

Company

Enter name of the utility.

LINE B DATA

Plant Name/Unit

Enter plant name and unit where fire originated.

Plant Type

Enter the correct code for the type of reactor.

01 – BWR
02 – PWR
03 – PHWR
04 – other reactor type (specify the reactor type)

LINE C DATA

Date of Fire

Enter date of fire.

Time of Fire

Enter by 24 hour clock – Examples:

1:00 AM = 0100
1:00 PM = 1300
12:00 Midnight = 2400
12:01 AM= 0001

Country

Enter country code (phone, country code)

LINE D DATA

Plant Status

Enter operating status of the plant at the time of the fire.

01 – Construction
02 – Pre–Operation Testing
03 – Power Operation
04 – Maintenance Outage
05 – Refuelling Outage
06 – Hot Shutdown
07 – Cold Shutdown
08 – Other (specify)
09 – Not Available

Location of Fire

Enter building area where fire originated

01 – Containment (PWR)
02 – Reactor Building (BWR)
03 – Drywell (BWR)
04 – Radwaste Building/Area
05 – Auxiliary Building
06 – Fuel Handling Building/Area
07 – Service Building
08 – Turbine Building
09 – Control Room/Building
10 – Diesel Generator Building/Area
11 – Switchgear Room
12 – Battery Room
13 – Cable Spreading Room
14 – Intake Structure
15 – Transformer Yard
16 – Switchyard/Substation
17 – Boiler
18 – Oil Storage Tanks
19 – Scrubber
20 – Administration Building/Area
21 – Training Building
22 – Security Building
23 – Warehouse
24 – Maintenance Shop
25 – Cooling Tower
26 – Fire Pump House
27 – Intermediate Building
28 – Other (specify)
29 – Not Available

LINE E DATA

Fire Origin

Enter equipment or item where fire originated:

01 – Reactor Coolant Pump (PWR)
02 – Reactor Recirculation Pump (BWR)
03 – Feedwater Pump/Motor/Turbine
04 – Auxiliary Feedwater Pump/Motor/Turbine
05 – Other Safety Related Pump/Motor/Turbine (specify)
06 – Main Turbine
07 – Main Generator
08 – Main Exciter
09 – Transformer
10 – Turbine Lube Oil System
11 – Switchgear
12 – Diesel Generator
13 – Hydrogen Seal Oil System
14 – Condensate Pump/Motor
15 – Circulating Water Pump/Motor
16 – Boilers
17 – Batteries
18 – Motor Generator Sets
19 – HVAC Equipment
20 – Oil Circuit Breakers
21 – Boiler Feed Pump/Motor/Turbine
22 – Scrubber
23 – Miscellaneous Motors (specify)
24 – Compressors
25 – Battery chargers
26 – Pumps (specify)
27 – Hydrogen Recombiner
28 – Electrical Cable/Wiring
29 – Electrical Cabinet
30 – Bus Duct/Cable Bus
31 – Isophase Duct
32 – Flammable Gas Storage Tanks

33 – Off Gas System (nuclear)
34 – Hydrogen Recombiners (nuclear)
35 – Transient Combustibles
36 – Other (specify)
37 – Not Available
38 – None

LINE F DATA

Ignition Factor (Cause)

Enter ignition factor/cause of the fire

01 – Incendiary
02 – Suspicious
03 – Mobile/Portable Heating Devices
04 – Hot Work (CuttingWelding/Grinding/etc.)
05 – Personal Error
06 – Mechanical Malfunction/Failure
07 – Electrical Malfunction/Failure
08 – Design/Construction/Installation Deficiency
09 – Operational Deficiency
10 – Spontaneous combustion/ignition
11 – Overheated material (e.g. oil leakage on hot surface)
12 – Explosion
13 – Lighting
14 – External Plant Fire (which can impair plant operation)
15 – External Hazards (e.g. aircraft, seismic, and transportation accidents)
16 – Smoking
17 – Other (specify)
18 – Not Available

Type of Material Ignited

Enter type of material ignited for the originating fire.

01 – Transformer Oil
02 – Lubrication Oil
03 – Fuel Oil
04 – Flammable Liquid
05 – Combustible Liquid
06 – Electrical Wiring
07 – Wood
08 – Paper/Cardboard
09 – Trash
10 – Plastic Sheets
11 – Hydrogen Gas
12 – Other Gas (specify)
13 – Radiation Work Clothing (nuclear)
14 – Charcoal
15 – Ventilation filters
16 – Other (specify)
17 – Not Available

LINE G DATA

Was oil involved?

01 – Yes 02 – No 03 – Not Available

LINE H DATA

If yes, enter the type of oil:

01 – lube oil
02 – fuel oil
03 – other (specify)
04 – not available

If yes, enter the type of oil source:

01 – pressurized spray
02 – oil soaked insulation
03 – oil seepage
04 – spilled oil (confined)
05 – spilled oil (unconfined)
06 – other (specify)
07 – not available

LINE I DATA

Enter the quantity of oil:

01 – < 0.5 l (little)
02 – 0.5 – 1.0 l
03 – 1.0 – 2.0 l
04 – 2.0 – 4.0 l
05 – > 4.0 l (specify the quantity of oil)
0.6 – unknown

Enter the surface area of the oil:

01 – < 0.5m^2
02 – 0.5 to 1.0m^2
03 – 1.0 to 2.0m^2
04 – > 2.0m^2

LINE J DATA

How Reported

Enter method by which the fire was reported

01 – Detection System Alarm
02 – Suppression System Alarm
03 – Fire Watch (continuous)
04 – Fire Watch (roving)
05 – Security Personnel
06 – Maintenance/Operations Personnel
07 – Control Room Indication (other than detection or suppression system alarms)
08 – Space permanently occupied
09 – Other (specify)
10 – Not Available

LINE K DATA

Fire Detection Present

01 – Yes 02 – No 03 – Not Available 04 – Not Applicable

Fire Detection System Operated

Indicate whether fire detection operated as designed.

01 – Yes 02 – No 03 – Not Available 04 – Not Applicable

LINE L DATA

Fire Detection System Type

Enter type of fire detection system if present

01 – Smoke, ionization
02 – Smoke, Photoelectric
03 – Heat, Rate of Rise
04 – Heat, fixed temperature
05 – Flame
06 – Infrared
07 – Combination system
08 – Local, e.g. In Cabinet (specify)
09 – Other (specify)
10 – None
11 – Not Available

Fire Detection System Performance

Indicate the performance of the fire detection system if present

01 – In Room of Fire: Operated
02 – In Room of Fire: Fire too small to operate
03 – In Room of Fire: Did not operate
04 – Not in Room of Fire: Operated
05 – Not in Room of Fire: Did not operate
06 – None
07 – Not Available

LINE M DATA

Fire Detection System Performance

If the fire was in the room and the detection system did not operate (02), enter the reason the detection system did not operate:

01 – unavailable due to maintenance
02 – local detector failure
03 – detection system failure
04 – other (specify)
05 – not available

LINE N DATA

Fixed Fire Suppression System Present

Indicate whether area of fire origin had a fixed fire suppression system.

01 – Yes
02 – No
03 – None
04 – Not Available

LINE O DATA

Fixed Fire Suppression System Type

Indicate type of fixed fire suppression system, if present.

01 – Wet sprinklers
02 – Dry sprinklers
03 – Preaction sprinklers
04 – Deluge sprinklers
05 – Carbon dioxide
06 – Halon
07 – Dry chemical
08 – Combination system
09 – Foam
10 – Water sprays
11 – Other (specify)
12 – None
13 – Not Available

Fixed Fire Suppression System Activation

Indicate activation method of fixed fire suppression system

01 – Automatic 02 – Manual

LINE P DATA

Fixed Fire Suppression System Performance

Indicate performance of fixed fire suppression system, if present

01 – In Room of Fire: Operated
02 – In Room of Fire: Did not operate
03 – In Room of Fire: Fire too small to operate
04 – Not in Room of Fire: Operated
05 – Not in Room of Fire: Did not operate
06 – None

LINE Q DATA

Fire Suppression System Performance

If the fire was in the room and the suppression system did not operate (02), enter the reason the suppression system did not operate:

01 – unavailable due to maintenance
02 – local detector failure
03 – detection system failure
04 – valve failed to open
05 – isolation valve left closed
06 – other (specify)
07 – not available

LINE R DATA

Fire Brigade Response (identify which responder has extinguished the fire)

01 – local operator/maintenance personnel
02 – fire watch
03 – plant fire brigade
04 – external fire brigade

LINE S DATA

Fire Brigade Response

Specify time first member of the fire brigade reached the scene (hours/minutes): ___ : ___
Did high temperatures prevent/delay personnel from entering the room where the fire occurred (without protective clothing)?

01 – Yes 02 – No 03 – Not Available

LINE T DATA

Did smoke prevent/delay personnel from entering the room without breathing apparatus?

01 – Yes 02 – No 03 – Not Available

LINE U DATA

Did smoke completely obscure the compartment preventing or delaying fire fighting activities?

01 – Yes 02 – No 03 – Not Available

LINE V DATA

Did first brigade member attempt to fight the fire?

01 – Yes 02 – No 03 – Not Available

Specify time full brigade reached the scene (hours : minutes) ___ : ___

LINE W DATA

Extent of Fire/Smoke Damage

What were the indications of the fire?

01 – odour
02 – visible smoke
03 – sparks
04 – crackling or sizzling sounds
05 – momentary arcing
06 – prolonged arcing
07 – flash of light
08 – visible flames
09 – explosion
10 – other (specify)
11 – none
12 – not available

If flames were visible, characterize the flames as one of the following (if known):

01 – intermittent or 02 – continuous
03 – slow or 04 – vigorous
05 – brief or 06 – prolonged

LINE X DATA

Did an explosion occur?

01 – Yes 02 – No 03 – Not Available

If yes, indicate whether it occurred before or after the onset of the fire:

01 – explosion preceded onset of the fire
02 – explosion followed onset of the fire
03 – fire did not occur
04 – not available

LINE Y DATA

What was the duration of vigorous burning (hours : minutes) ___ : ___

If during the period of vigorous burning visible flames were observed, what was the flame height (m)?

LINE Z DATA

How long did fire burn?

Enter range of time the fire burned before being declared under control.

01 – 0–5 mins
02 – 6–15 mins
03 – 16–30 mins
04 – 31–60 mins
05 – 60+ mins
06 – Not Available

LINE AA DATA

How long did the fire burn?

Specify time from detection to start of suppressant application (hours:minutes): ___ : ___

Specify time from detection to extinguishment (hours:minutes) ___ : ___

LINE AB DATA

Specify time from detection to control of the fire (hours:minutes) ___ : ___

LINE AC DATA

How extinguished:

Type of Extinguish Action

Indicate how the fire was extinguished

01 – Automatic Fire Suppression System
02 – Manual Fire Suppression System
03 – Manual Hose Streams
04 – Portable Fire Extinguishers
05 – Power/Fuel Supply Removed
06 – Self Extinguishment
07 – Other (specify)
08 – Not Available

LINE AD DATA

Was the application of suppressants delayed for any reason?

01 – Yes
02 – No
03 – Not Available

What agent extinguished the fire?

01 – water
02 – CO_2
03 – halon
04 – dry chemical
05 – foam
06 – other (specify)
07 – none
08 – not available

LINE AE DATA

Potential Impact on Safe Shutdown Capability

Enter potential impact on safe shutdown capability for nuclear plants.

01 – Yes
02 – No
03 – Not Available
04 – Not Applicable

LINE AF DATA

Manual or automatic plant trip

01 – Yes
02 – No

LINE AG DATA

Injuries/Fatalities

Indicate if any injuries/fatalities resulted from the fire.

01 – Yes
02 – No
03 – Not Available

Estimated Dollar Loss

Enter range of estimated dollar loss.

01 – None
02 – $1 – 10 000
03 – $10 001 – 50 000
04 – $50 001 – 100 000
05 – $100 001 – 500 000
06 – $500 001 – 1 000 000
07 – $1 000 001 – 10 000 000
08 – $10 000 001 – 50 000 000
09 – $50 000 001+
10 – Not Available

LINE AH DATA

Extent of Fire/Smoke Damage

Indicate extent of fire/smoke damage.

01 – Confined to the object of origin
02 – Confined to part of room or area of origin
03 – Confined to room of origin
04 – Confined to fire rated compartment of origin
05 – Confined to floor of origin
06 – Confined to structure of origin
07 – Extended beyond structure of origin
08 – No Damage
09 – Not Available

LINE AI DATA

Other Fire Damaged Equipment

Enter other equipment damaged by the fire other than the fire originating piece of equipment.

01 – Reactor Coolant Pump (PWR)
02 – Reactor Recirculation Pump (BWR)
03 – Feed water Pump/Motor/Turbine
04 – Auxiliary Feedwater Pump/Motor/Turbine
05 – Other Safety Related Pump/Motor/Turbine (specify)

06 – Main Turbine
07 – Main Generator
08 – Main Exciter
09 – Transformer
10 – Turbine Lube Oil System
11 – Switchgear
12 – Diesel Generator
13 – Hydrogen Seal Oil System
14 – Condensate Pump/Motor
15 – Circulating Water Pump/Motor
16 – Boilers
17 – Batteries
18 – Motor Generator Sets
19 – HVAC Equipment
20 – Oil Circuit Breakers
21 – Boiler Feed Pump/Motor/Turbine
22 – Miscellaneous Motors (specify)
23 – Compressor
24 – Battery chargers
25 – Pumps (specify)
26 – Hydrogen Recombiner
27 – Electrical Cable/Wiring
28 – Electrical Cabinet
29 – Bus Duct/Cable Bus
30 – Isophase Duct
31 – Flammable Gas Storage Tanks
32 – Off-gas System (nuclear)
33 – Hydrogen Recombiners (nuclear)
34 – Transient Combustibles
35 – Other (specify)
36 – Not Available
37 – None

LINE AJ DATA

If damage extended beyond the equipment of origin, what caused the damage?

01 – Heat
02 – Smoke
03 – Explosion
04 – Water
05 – Chemical extinguishing agents

LINE AK DATA

If damage was due to heat, was there observable evidence of heat damage after the fire (e.g. scorching, charring, warping, melting)?

01 – Yes 02 – No 03 – Not Available

LINE AL DATA

If yes, at what elevation above the base of the fire was heat damage observed (m)?

Describe type of damage due to heat loading.

LINE AM DATA

At what maximum radius around the centerline of the fire was heat damage observed at the base (m)?

Describe type of damage due to heat loading.

LINE AN DATA

At what maximum radius around the centerline of the fire was heat damage observed at the ceiling (m)?

Describe type of damage due to heat loading.

LINE AO DATA

If damage extended beyond the equipment of origin, did ignition of combustibles beyond the equipment of origin occur?

01 – Yes 02 – No 03 – Not Available

LINE AP DATA

If yes, at what elevation above the base of the fire did secondary ignition occur (m)?

LINE AQ DATA

At what radius around the centreline of the fire did secondary ignition occur at the base (m)?

LINE AR DATA

At what radius around the centreline of the fire did secondary ignition occur at the ceiling (m)?

LINE AS DATA

Did the fire result in spurious operation of equipment?

01 – Yes 02 – No 03 – Not Available

LINE AT DATA

Fire Origin:

For pumps or other components bearing oil:

Enter the power (kW):

01 – <3.5
02 – 3.5 to 35
03 – 35 to 730
04 > 730 (specify)
05 – not available

Enter the voltage:

01 – specify (V/kV)

LINE AU DATA

For transformers:

Enter the equipment type

Yard transformer
01 – main transformer
02 – startup transformer
03 – station service transformer
04 – auxiliary transformer
05 – other yard transformer (specify)

Indoor transformer
06 – load centre transformer
07 – lighting transformer
08 – transformer inside cabinet (e.g. control power transformer)
09 – neutral ground transformer
10 – other indoor transformer (specify)

Enter the transformer type

01 – oil　02 – dry　03 – not available

LINE AV DATA

Enter the voltage

01 – specify (V/kV)
02 – not available

Was oil involved:

01 – Yes　02 – No　03 – Not available

LINE AW DATA

For electrical cabinets:

Enter the equipment type

01 – switchgear
02 – motor control centre
03 – load centre
04 – DC load centre
05 – inverter
06 – lighting panel
07 – control panel
08 – relay cabinet
09 – termination cabinet
10 – other (specify)
11 – not available

Enter the voltage

01 – specify (V/kV; AC/DC)
02 – not available

LINE AX DATA

Enter the ignition source:

01 – breaker
02 – relay
03 – control power transformer
04 – wiring
05 – terminal block
06 – resistor
07 – circuit card
08 – CRT (screen)
09 – computer
10 – personnel
11 – other (specify)
12 – not available

Was an explosion involved:

01 – Yes   02 – No   03 – Not Available

LINE AY DATA

Describe cabinet fire load

01 – low
02 – ordinary
03 – high
04 – other (specify)

Cabinet ventilation

01 – Yes   02 – No

LINE AZ DATA

Did the fire spread from the ignition source to combustibles within cabinet, (e.g. cable)?

01 – Yes   02 – No   03 – Not Available

Type of ventilation

01 – Mechanical   02 – Nature

LINE AAA DATA

For electrical cable/wiring state:

01 – cable type (e.g. fire rating)
02 – power
03 – control
04 – instrumentation

LINE AAB DATA

For diesel generators:

Enter the part of the diesel generator that was the origin of the fire:

01 – engine
02 – generator
03 – turbocharger
04 – exhaust manifold
05 – exhaust stack (downstream of the manifold)
06 – shaft/bearing
07 – heater
08 – fuel pump
09 – other pump
10 – control panel
11 – starting battery
12 – other electrical (specify)
13 – fan
14 – other (specify)

Was oil involved:

01 – Yes 02 – No 03 – Not Available

LINE AAC DATA

Lessons Learned Report Developed

Indicate whether a Lessons Learned Report was developed for this fire.

01 – Yes 02 – No

LINE AAD DATA

Enter any additional remarks or comments

01 – short narrative description of the event (0.5 page max)
02 – Eventual references (e.g. detailed report, root cause analysis, etc.)

LINE AAE DATA

Persons Making Report/Report Date

Enter name and position of person making the report and report date.

LINE AAF DATA

Enter name and position of person verifying the report and report date.

LINE AAG DATA

Can this information be made public?

Indicate whether this report, including data from Lines, A, B, AAC, AAD, AAE, and AAF, can be made available to the system users.

01 – Yes 02 – No

Annex I
EPRI FIRE EVENTS DATABASE

This annex is a summary of Ref. [I–1].

In order to assist utilities, Electric Power Research Institute (EPRI) initiated a co-ordinated research programme to develop fire risk tools. A primary objective of the programme was to provide an appropriate methodology that would enable licensees to efficiently identify potential fire related vulnerabilities. Another objective was to improve realism of Fire Probabilistic Risk Assessments (FPRA). To reach these objectives, the quality and completeness of data were to be improved. The first attempt to gather fire events data resulted in the “HTGR” fire database which contained roughly 60 events. In 1983, EPRI published its own database on 116 fires which occurred between February 1965 and February 1982.

In 1986, the US Nuclear Regulatory Commission published NUREG/CR-4586, often referred to as the “Wheelis Database”, which covered 354 fire events from February 1965 through June 1985. In order to make Individual Plant Examination for External Events (IPEEE) searches more contemporary, the Wheelis database was updated. Fire events which had occurred between 1985 and 1988 were included and other sources were tapped for new information. Lastly, EPRI sent a questionnaire to utilities requesting them to fill in incomplete fields for previously reported events. The result was a Fire Events Database (FEDB) containing 753 fire events which had occurred in PWRs and BWRs between February 1965 and December 1988. The reactor low-power operating license date for each plant was the principal screening criterion used to identify events for inclusion in the database. The EPRI FEDB contains 35 fields which describe different parameters related to each fire. Table I–1 shows the 35 fields of the database.

TABLE I–1. FIRE DATABASE STRUCTURE

Field	Field name	Type	Width in dBASE structure	Description
1	INCIDENTNO	Character	5	The number assigned to each fire incident chronologically.
2	STATE_TOWN	Character	35	The state and town in which the town is located.
3	PLANT_UNIT	Character	30	The plant name and unit number where the fire occurred.
4	CAPACITY	Character	10	The reactor output, expressed in net megawatts (electric).
5	UTILITYPRN	Character	60	The principal utility that operates the plant.
6	REACTORTYP	Character	8	The type of reactor.
7	REACTORSUP	Character	35	The nuclear reactor supplier.
8	OL_ISSUED	Character	10	The issuance date of a reactor low power operating license.
9	INITIALCRT	Character	10	The date the nuclear reactor first went critical.
10	COMMEROPER	Character	10	The date the reactor was formally connected to a commercial power grid.
11	DATE	Date	8	The date of the fire.
12	TIME	Character	10	The time the fire occurred.
13	LOCATION	Character	40	The location of the fire.

Field	Field name	Type	Width in dBASE structure	Description
14	LOC_TAB12	Character	40	The location assigned in the binning process.
15	DURATION	Character	10	The duration of the fire.
16	DUR_FLAG	Numeric	2	A number from 1 to 6 that corresponds to the time that a fire burned.
17	MODE_OPER	Character	40	The plant status at the time of the fire.
18	CAUSE_FIRE	Character	67	The cause of the fire.
19	TYPE_FIRE	Character	20	The type of fire that occurred in reference to NEPA/NFPA standards.
20	EXTINGUISH	Character	67	The persons, systems, or methods used to extinguish the fire.
21	DETC_MEANS	Character	67	The method by which the fire was initially detected.
22	SUPP_TIME	Character	10	The time taken to extinguish the fire once suppression personnel equipment responded.
23	SUP_FLAG	Numeric	2	A number from 1 to 6 that corresponds to the time it took to suppress the fire.
24	AGENT_USED	Character	67	The extinguishing agents used to suppress the fire.
25	EQUIP_USED	Character	67	The equipment used to extinguish the fire.
26	INITCOMPON	Character	40	The equipment or item that initiated the fire.
27	INIT_TAB12	Character	40	The ignition source assigned in the binning process.
28	INITCOMBUS	Character	40	The substance that initiated the fire.
29	COMPEFFECT	Character	120	The equipment items affected by the fire.
30	POWERDEGRA	Character	10	The percentage power degradation of the reactor unit that resulted from the fire.
31	FORCEDOUTG	Character	10	The number of days of outage caused by the fire.
32	DIRECTLOSS	Character	15	The dollar value loss incurred because of the fire.
33	REFERENCE	Character	50	The source material in which the fire incident was documented.
34	EXT_SYS_F	Character	2	Did the extinguishing system fail?
35	UTL_UPD	Character	50	Utility response.

FEDB was created to supply EPRI member utilities with a generic data source to support fire protection engineers and fire risk analysts. For example, a fire risk analyst can calculate fire frequencies for specific locations and ignition sources, using the fire events database.

A fire ignition frequency method was developed that recognized plant to plant and fire area differences. It achieves this by identifying a set of components which are likely to cause fires, but whose locations often vary among plants.

The EPRI method also uses more locations for determining electrical cabinet and pump fire frequencies which should improve the accuracy of the ignition frequency indicator. The method also apportions the number of fires by the number of units at a site, as well as the number of buildings. Past approaches have assumed that each “typical” location in every plant contained the same number of ignition sources regardless of whether there was more than one unit or one location, even though the number of equipment items in a location varied from plant to plant. The EPRI method currently uses the assumption that the number of equipment items is equal among units. While this assumption is not perfect, it is believed to be better than that previously used: specialists believe it is the most accurate for safety related equipment, the total numbers of which are more likely to be controlled by regulation. Safety related equipment ignition sources are most likely to be in places containing safety related power and control circuits.

Finally, the FEDB has proven to be a useful source of information for fire risk and other analysts. For example, a review of fire events experience for deluge and pre-action systems is the primary source of reliability information for these systems. Concerning selected ignition sources or specific issues, it can also provide valuable insights and sanity checks. The information contained in the FEDB can be used to focus more quickly on the dominant causes of fire risk and hence, lead to a more realistic analysis as well.

Future uses of the database include performance based regulation, improved fire risk studies, cost effective fire protection programmes, fire brigade training guidance and insurance and fire detection/suppression system optimization.

REFERENCE TO ANNEX I

[I–1] OEHLBERG, R., MARTEENY, M., BATEMAN, K., NAJAFI, B., PARKINSON, W., EPRI Fire Events Database, San Diego, CA (1994).

Annex II
SUMMARY OF A USERS' GUIDE FOR A PERSONAL COMPUTER–BASED NUCLEAR POWER PLANT FIRE DATABASE

(NUREG/CR-4586 SAND86-300)

II–1. OVERVIEW OF THE DATABASE

This users' guide discusses in-depth the specific features and capabilities of the various options found in the database. Capabilities include the ability to search several database files simultaneously to meet user-defined conditions, display basic plant information, and determine the operating experience (in plant operation years) for several nuclear power plant locations. Step-by-step examples are provided for each data search to allow the user to learn how to access the data.

The principle sources of the SNL fire database are based on Refs [II–1] to [II–7]. The data applied were cross-checked against references [II–8] to [II–10].

II–2. STRUCTURE OF THE DATABASE

This database has in total five options, four of which are search options which can be accessed from the Main Menu of the computer code.

Option 1. Fire event search
Option 2. Fire event descriptions
Option 3. Operational experience data
Option 4. Basic plant information
Option 5. Modify programme display options

The basic structure of the database is shown in Fig. II–1.

II–3. FIRE EVENT SEARCH

This menu provides access to following five options designed to search the database exclusively for the specifies of a fire event.

Option 1. Full Fire Event Data Display: As much information as possible concerning a particular fire event will be displayed. In this option, there are 29 separate categories that include, but are not limited to, plant name, fire location, plant operational mode at the time of the fire, and the reference sources for these data. The more detailed description of the fire events can also be displayed.

Option 2. Essential Fire Event Display: This option is similar to option 1, except that it is scaled down. Its purpose is to display "the who, what, when, and where" of a fire. Six categories are displayed for a fire event: plant name, date of fire, location of fire, probable cause of fire, reactor type, and mode of plant operation at the time of fire. The description of the fire events can also be displayed.

Option 3. Fire Duration/Suppression Time Search: The database can be searched for fire events that match time ranges specified for either the duration or suppression time of a

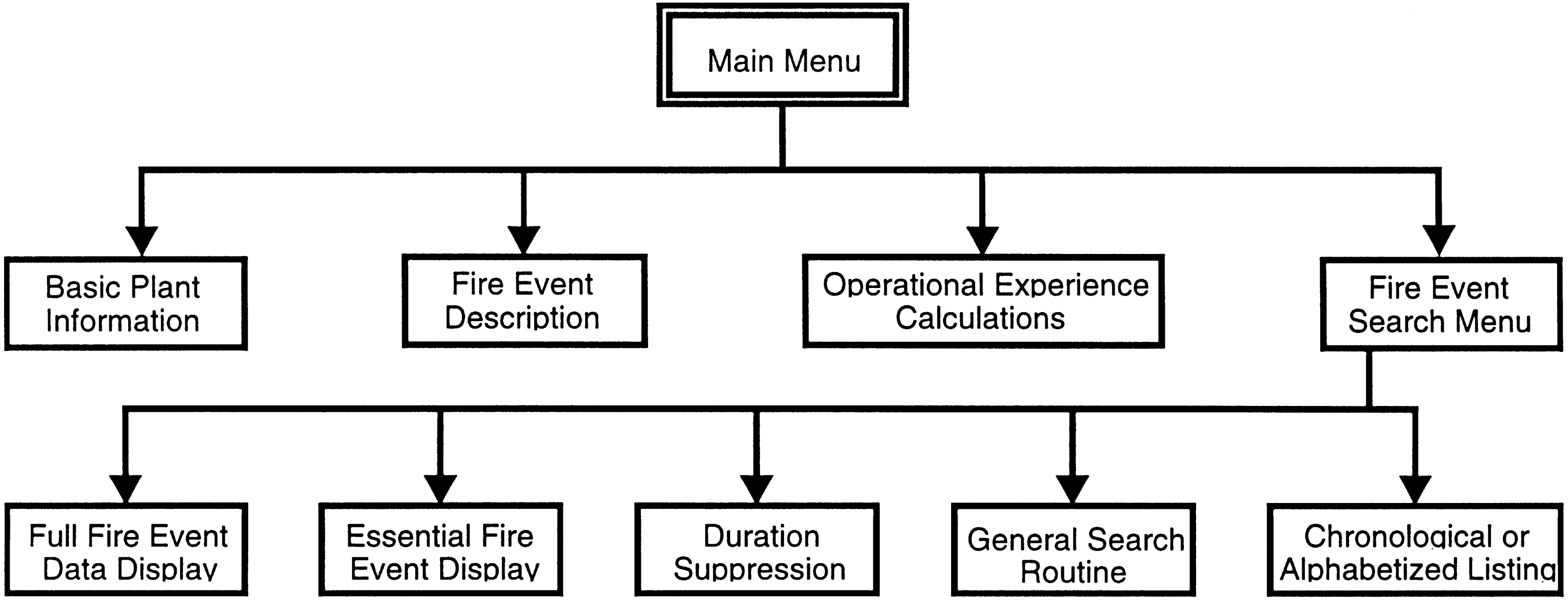

FIG. II–1. Basic structure of the database.

fire. In addition, fire events can be culled on four additional criteria: reactor type, mode of plant operation, extinguish method, and detection method. The description of the fire events meeting the specified conditions can also be displayed.

Option 4. General Search Routine: The database can be searched on up to five different parameters (or one parameter for five different cases) at once. There are 18 different parameters shown in Table II-1. Search parameters can be “and–ed” or “or–ed” in any desired order to search for fire events meeting the specified criteria. The description of the fire events meeting the specified conditions can also be displayed.

Option 5. Chronological Fire Event Display: A chronological date listing, as well as an alphabetized listing of fire events based on plant names, can be obtained from this option. The output from this option gives the plant name, fire location, date of the fire and the incident number associated with the fire event.

Figure II–2 shows the outline of ‘Full Fire Event Data Display’ flowchart. The following example shows the output of the ‘Full Fire Event data Display’ following the selection of incident number 330 (INO: 330) in the chronological fire events list.

```
0 PLANT NAME: Peach Bottom 2      CAPACITY: 1065 MWe  IND: 330
0 PRINCIPAL OWNER UTILITY: Philadelphia Electric Company
0 PLANT LOCATION: NJ, Peach Bottom
0 NSSS VENDOR: General Electric      REACTOR TYPE: BWR
0 OPERATING LICENSE ISSUED: 08/08/73
0 INITIAL CRITICALITY: 09/16/73   DATE OF COMMERCIAL OPERATION: 07/??/74
0 FIRE LOCATION: Diesel Generator Building   DATE OF FIRE: 09/07/83
0 TIME OF DAY OF FIRE:     FIRE DURATION:
0 MODE OF PLANT OPERATION: Maintenance Outage
0 PROBABLE CAUSE OF FIRE: Component Failure
0 TYPE OF FIRE: Class B
0 DETECTED BY: Plant Personnel
0 EXTINGUISHED BY: De-Energized
0 SUPPRESSION EQUIPMENT: None
0 SUPPRESSION AGENT(S): None
0 SUPPRESSION TIME:
0 INITIATING COMPONENT: Engine
0 INITIATING COMBUSTIBLE: Oil
0 COMPONENTS AFFECTED BY FIRE: Engine
0 POWER DEGRADATION (%): 0%   FORCED OUTAGE: 0 Days  $ Loss:
0 REFERENCES: NPE, LER
0 Event Description:
0 During surveillance testing of E–3 diesel, operators noted output power was swinging and
0 exhaust temperature was high. Investigation revealed that there was a fire in the exhaust.
0 It was determined that one Elliott turbocharger had failed causing a power reduction. The
0 governor increased the fuel flow as a result. Excess fuel ignited in the exhaust.
```

Figure II–3 shows the outline of the ‘General Search Routine’ flow chart. This option is used for the most general purpose search in the database. Therefore, its usage is a little more complicated than that of other options. The following example demonstrates the total capability of the option to search simultaneously for two different sets of fire events in the database.

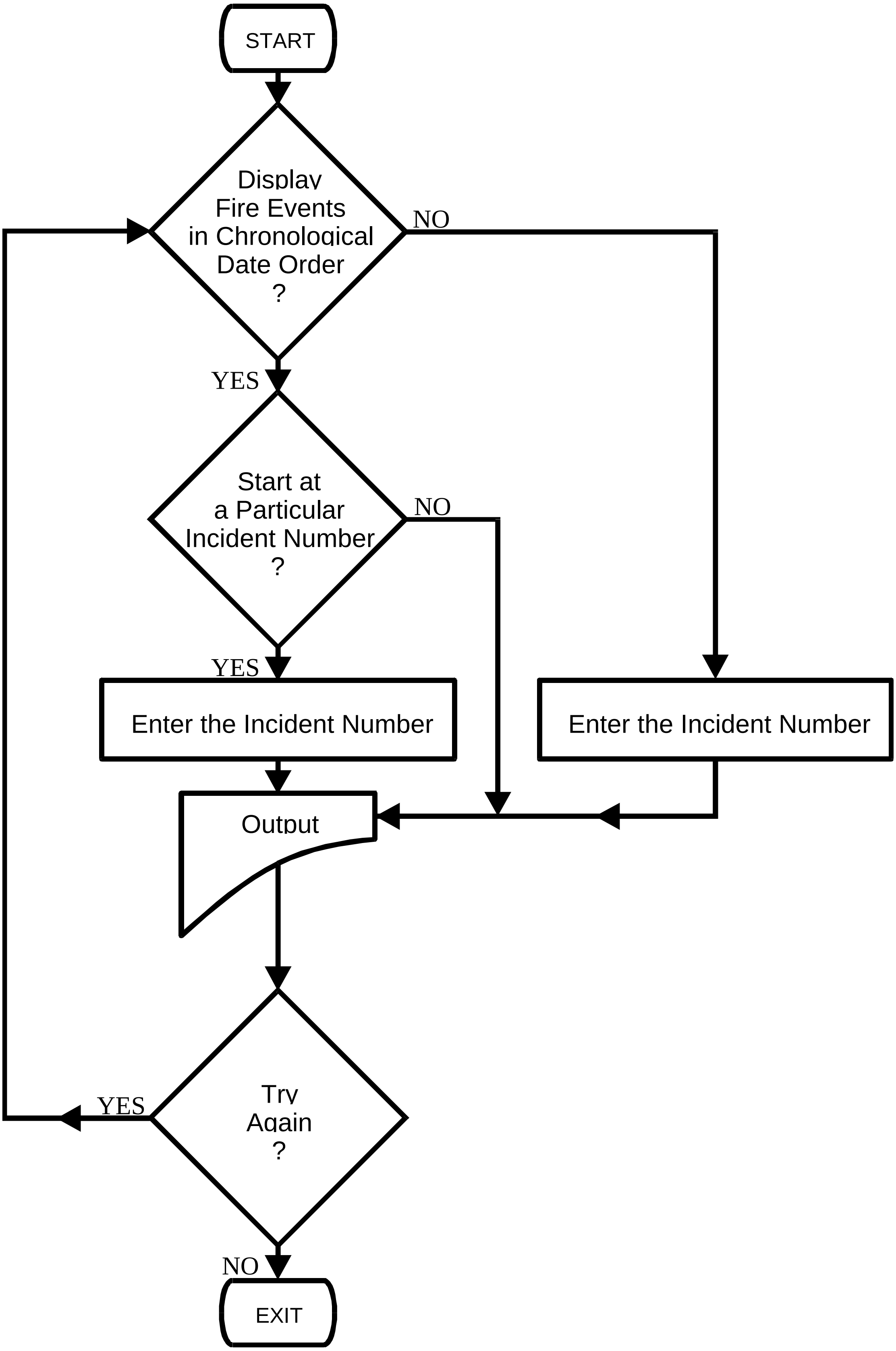

FIG. II–2. Outline of ‘Full Fire Event Data Display’ flow chart.

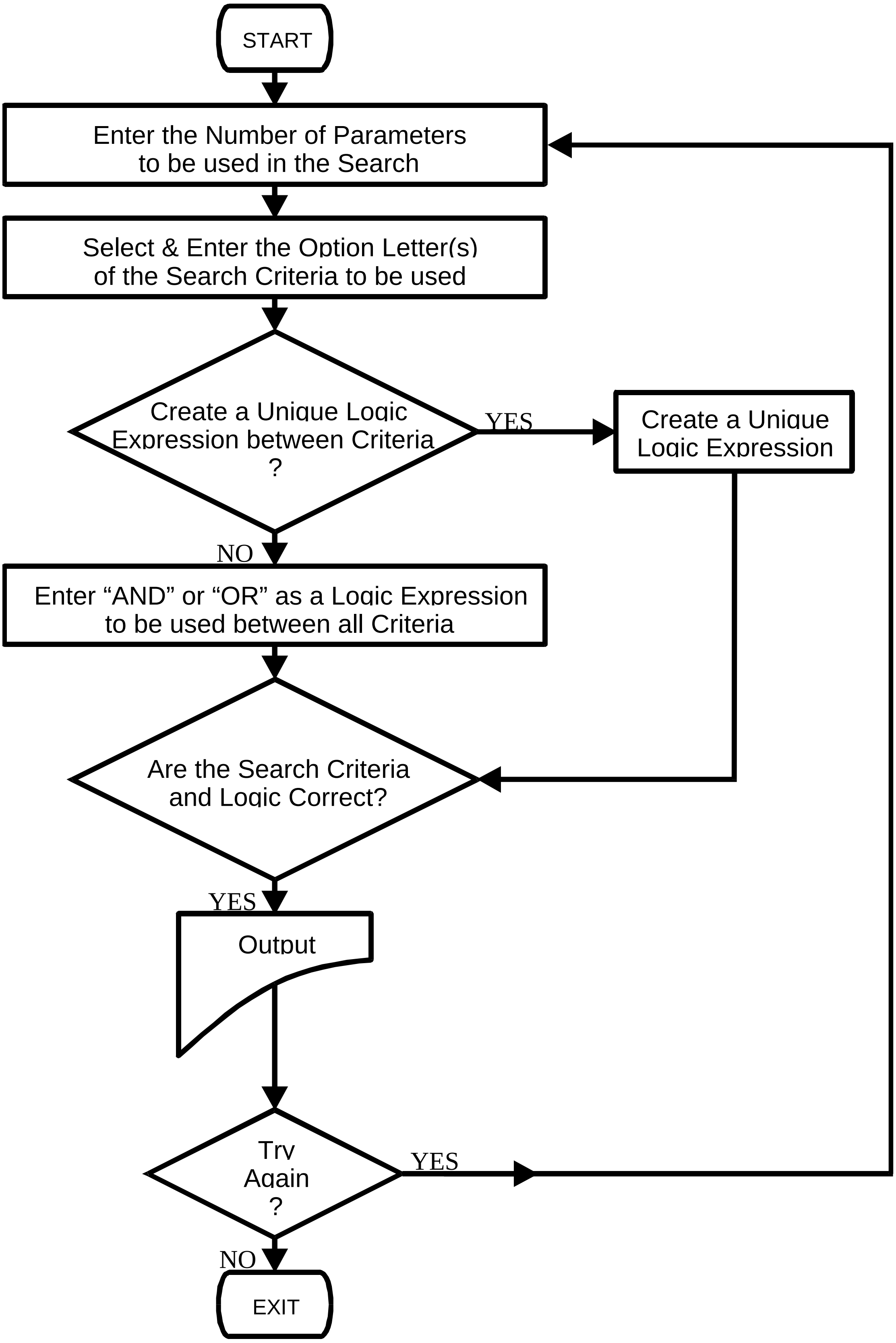

FIG. II–3. Outline of 'General Search Routine' flow chart.

The conditions to be met are:

(a) At Peach Bottom 2, you know that a fire occurred in the Diesel Generator Building and you would like to see the fire event specifics.
(b) You are also interested in seeing whether there were any fires at High Temperature Gas Reactors (HTGR) while they were at power operation during the period January 1, 1965, to January 1, 1985.

With these conditions, you can identify and select the following five criteria from the Table II–1 to search the database.

A – Plant Name	Peach Bottom 2
D – Location of Fire	Diesel Generator Building
B – Reactor Type	HTGR
C – Mode of Plant Operation	power operation
F – Date of Fire	01/01/65 to 01/01/85

TABLE II–1. PARAMETERS FOR GENERAL SEARCH

```
          You can search on up to five (5) of the following areas at any given time

A – Plant Name                                  J – Owner Utility
B – Reactor Type                                K – Type of Fire
C – Mode of Plant Operation                     L – Detection Method
D – Location of Fire                            M – Extinguishing Method
E – Cause of Fire                               N – Equipment Used
F – Date of Fire                                0 – Agents Used
G – Initiating Component                        P – Components Effected
H – Initiating Combustible                      Q – Direct Loss
I  – Reactor Supplier                           R – Reference

                      Enter the number of areas you want to search on:

                           (Press "RETURN' after your entry)
```

Since you have five criteria of which two do not meet simultaneously, you should create a unique logic expression as follows:

Peach Bottom 2 .AND. Diesel Generator Building .OR. HTGR .AND. power operation AND. 01/01/65 to 01/01/85

In this example, only one event meets the criteria and the same output as shown above is given.

The flow chart and data search idea for Options 2, 3, and 5 are similar to those of Option 1. Example outputs for Options 2, 3 and 5 are shown below.

Example Output of ‘Essential Fire Event Display’:

```
0 PLANT NAME: Peach Bottom 2          IND: 331
0 DATE OF FIRE: 09/07/83
0 LOCATION OF FIRE: Diesel Generator Building
0
0 PROBABLE CAUSE OF FIRE: Component Failure
0
0 REACTOR TYPE: BWR
0 MODE OF PLANT OPERATION: Maintenance Outage
0
0 Event Description:
0
0 During surveillance testing of E–3 diesel, operators noted output power was swinging and
0 exhaust temperature was high. Investigation revealed that there was a fire in the exhaust.
0 It was determined that one Elliott turbocharger had failed causing a power reduction. The
0 governor increased the fuel flow as a result. Excess fuel ignited in the exhaust.
```

Example Output of ‘Fire Duration/Suppression Time Search’:

```
0 PLANT NAME: Fitzpatrick          IND: 154
0
0 DATE OF FIRE: 04/04/77       TIME OF DAY OF FIRE:
0 FIRE DURATION: 00:10
0 LOCATION OF FIRE: Auxiliary Building
0 TYPE OF FIRE: Class C
0
0 DETECTION SPECIFICS
0 FIRE DETECTED BY: Plant Personnel
0
0 SUPPRESSION SPECIFICS
0 SUPPRESSION TIME: 00:03
0 FIRE EXTINGUISHED BY: De–Energized
0 EQUIPMENT: None
0 SUPPRESSION AGENT(S): None
0 REFERENCE(S): NPE, EPRI
```

Example Output of ‘Chronological Fire Event Display’:

```
0 Chronological Listing of Fires which have Occurred at Nuclear Power Plants
0 Plant Name               Date       Location                      INO #
0 Arkansas Nuclear One     03/20/78   Diesel Generator Building     183
0 Arkansas Nuclear One     08/16/78   Auxiliary Building            196
0 Arkansas Nuclear One     11/15/78   Diesel Generator Building     198
0 Arkansas Nuclear One     07/27/81   Diesel Generator Building     284
0 Arkansas Nuclear One     04/15/82   Other Building                303
0 Arkansas Nuclear One     02/22/81   Diesel Generator Building     242
0 Arkansas Nuclear One     06/30/81   Diesel Generator Building     278
0 Beaver Valley 1          01/03/72   Containment                    42
0 Beaver Valley 1          10/04/72   Other                          53
0 Browns Ferry 1           03/22/75   Cable Spreading Room          100
0 Browns Ferry 1           5/04/76    Containment                   128
0 Browns Ferry 1           01/21/80   Turbine Building              240
0 Browns Ferry 1           08/22/81   Other Building                288
0 Browns Ferry 3           07/17/77   Radwaste Building             165
0 Browns Ferry 3           07/15/79   Recombiner Building           224
0 Brunswick 1              05/15/77   Turbine Building              158
0 TO PREVENT LOSING ANY DATA YOU SHOULD PRINT SCREEN CONTENTS NOW
0 DO YOU WANT A PRINTOUT? (Y = YES; Any key for NO)
```

II–4. FIRE EVENT DESCRIPTIONS

The written description(s) for fire event(s) is (are) displayed. These descriptions can be found either by the use of an Incident Number (INO) or by displaying all descriptions that match a key word or phrase which is entered to search the descriptions. Fig. II–4 shows the outline of the ‘Fire Event Description’ flow chart.

An example output is shown in the following.

```
0        INO # :1
0        At 12:10 an alarm was received Indicating a fire within the containment vessel. The fire
0        was located In electrical cables In the nitrogen space between the outer shell and the
0        control rooms. Employees attempted to extinguish the blaze with hand CO2
0        extinguishers but were unsuccessful. The local Fire Department was contacted and
0        responded, extinguishing the fire. A total of ten tons of CO2 had been used. Dense
0        smoke left deposits throughout the containment vessel. 891 cables and penetration
0        seals were damaged. The cause of the blaze is believed to have been sparks from a
0        cutting operation in the area above the site of the Incident.
```

II–5. OPERATIONAL EXPERIENCE DATA

The outline of the ‘Operational Experience Data’ flow chart is shown in Fig II–5. The operational time period for either boiling water reactors (BWR), pressurized water reactors (PWR), or all further commercial US nuclear reactors can be calculated. Five plant locations shown in Fig. II–5 are available for the calculation of the operational time period. The operational time period of a plant location can be calculated either as individual site years or as the sum of years of all sites.

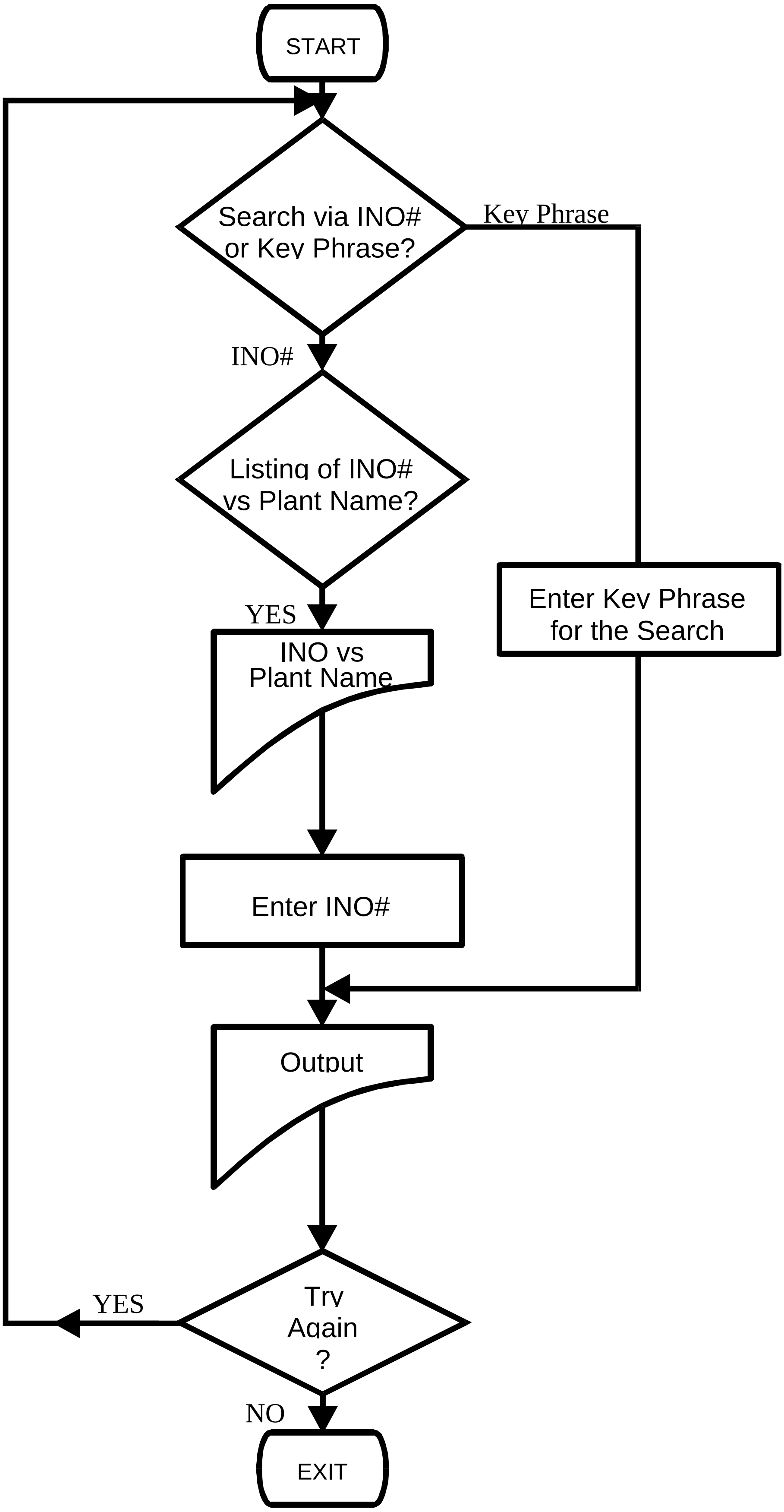

FIG. II–4. Outline of ‘Fire Event Description’ flow chart.

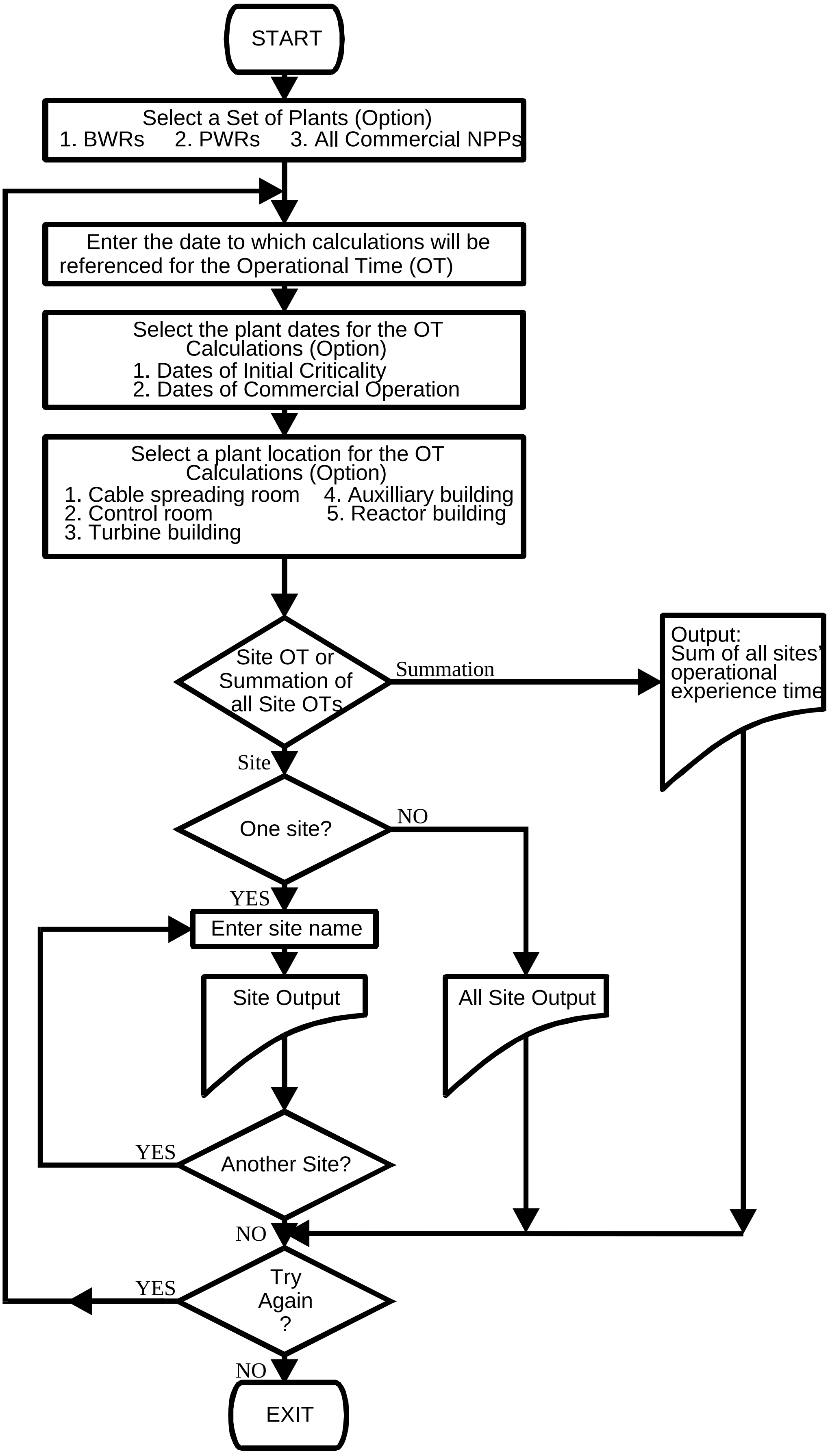

FIG. II–5. Outline of 'Operational Experience Data' flow chart.

An example output of the operating time years of the Cable Spreading Room is shown below.

```
0      Cable Spreading Room Operating Experience Data (YEARS through 10/01/85)
0
0     SITE NAME          UNIT 1      UNIT 2    UNIT 3  SITE TOTAL    NUMBER
0     Big Rock Point       23.0         0.0       0.0        23.0         1
0     Browns Ferry         12.1        11.2       9.1        32.5         3
0     Brunswick            10.5         9.0       0.0        19.5         2
0     Clinton               0.0         0.0       0.0         0.0         1
0     Cooper               11.6         0.0       0.0        11.6         1
0     Dresden              19.0        15.7      14.7        26.0         1
0     Duane Arnold         11.5         0.0       0.0        11.5         1
0     Fermi                 0.0         0.0       0.0         0.0         1
0     Fitzpatrick          10.9         0.0       0.0        10.9         1
0     Grand Gulf            3.1         0.0       0.0         3.1         2
0     Hatch                11.1         7.2       0.0        11.1         1
0     Hope                  0.0         0.0       0.0         0.0         1
0     Humboldt Bay         13.4         0.0       0.0        13.4         1
0     La Crosse            18.2         0.0       0.0        18.2         1
0     La Salle              3.3         1.6       0.0         8.1         3
0     Limerick              0.8         0.0       0.0         0.8         2
0      TO PREVENT LOSING ANY DATA YOU SHOULD PRINT SCREEN CONTENTS NOW
0      DO YOU WANT A PRINTOUT? (Y = YES; ANY KEY = NO)
```

```
0      Cable Spreading Room Operating Experience Data (YEARS through 10/01/85)
0
0     SITE NAME          UNIT 1      UNIT 2    UNIT 3  SITE TOTAL    NUMBER
0
0     Oyster Creek         16.4         0.0       0.0        16.4         1
0     Peach Bottom         12.0        11.2       0.0        12.0         1
0     Perry                 0.0         0.0       0.0         0.0         1
0     Pilgrim              13.3         0.0       0.0        13.3         1
0     Quad Cities          14.0        13.4       0.0        14.0         1
0     River Bend            0.0         0.0       0.0         0.0         1
0     Shoreham              0.6         0.0       0.0         0.6         1
0     Susquehanna           3.1         1.4       0.0         4.5         2
0     Vermont Yankee       13.5         0.0       0.0        13.5         1
0     WNP                   1.7         0.0       0.0         1.7         1
0     ——————————————————————————————————————————————————————————————-————-
0                         Total operating experience:       311.5
```

II–6. BASIC PLANT INFORMATION

The outline of the ‘Basic Plant Information’ flow chart is shown in Fig. II–6. An example of the output is shown in the following:

```
0      PLANT NAME:                       Arkansas Nuclear One 1
0      CAPACITY:                                   836 MWe
0      LOCATION:                                   AR, Russelville
0      PRINCIPAL OPERATING UTILITY:      Arkansas Power and Light Company
0      NSSS VENDOR:                                Babcock and Wilcox
0
0      MAJOR MILESTONE DATES:
0
0      OPERATING LICENSE ISSUED:         05/21/74
0      INITIAL CRITICALITY:              08/06/74
```

```
0     COMMERCIAL OPERATION:        12/19/74
0     DECOMMISSIONING DATE:
0
0     PLANT NAME:                  Arkansas Nuclear One 2
0     CAPACITY:                         858 MWe
0     LOCATION:                         AR, Russelville
0     PRINCIPAL OPERATING UTILITY: Arkansas Power and Light Company
0     NSSS VENDOR:                      Combustion Engineering
0
0     MAJOR MILESTONE DATES:
0
0     OPERATING LICENSE ISSUED:    07/18/78
0     INITIAL CRITICALITY:         12/05/78
0     COMMERCIAL OPERATION:        03/26/80
0     DECOMMISSIONING DATE:
0
```

II–7. ‘MODIFY PROGRAMME’ DISPLAY OPTIONS

This option allows you to change how the Heading Block, Preliminary Information, Informational Prompts, and Completion Messages will appear while using the database.

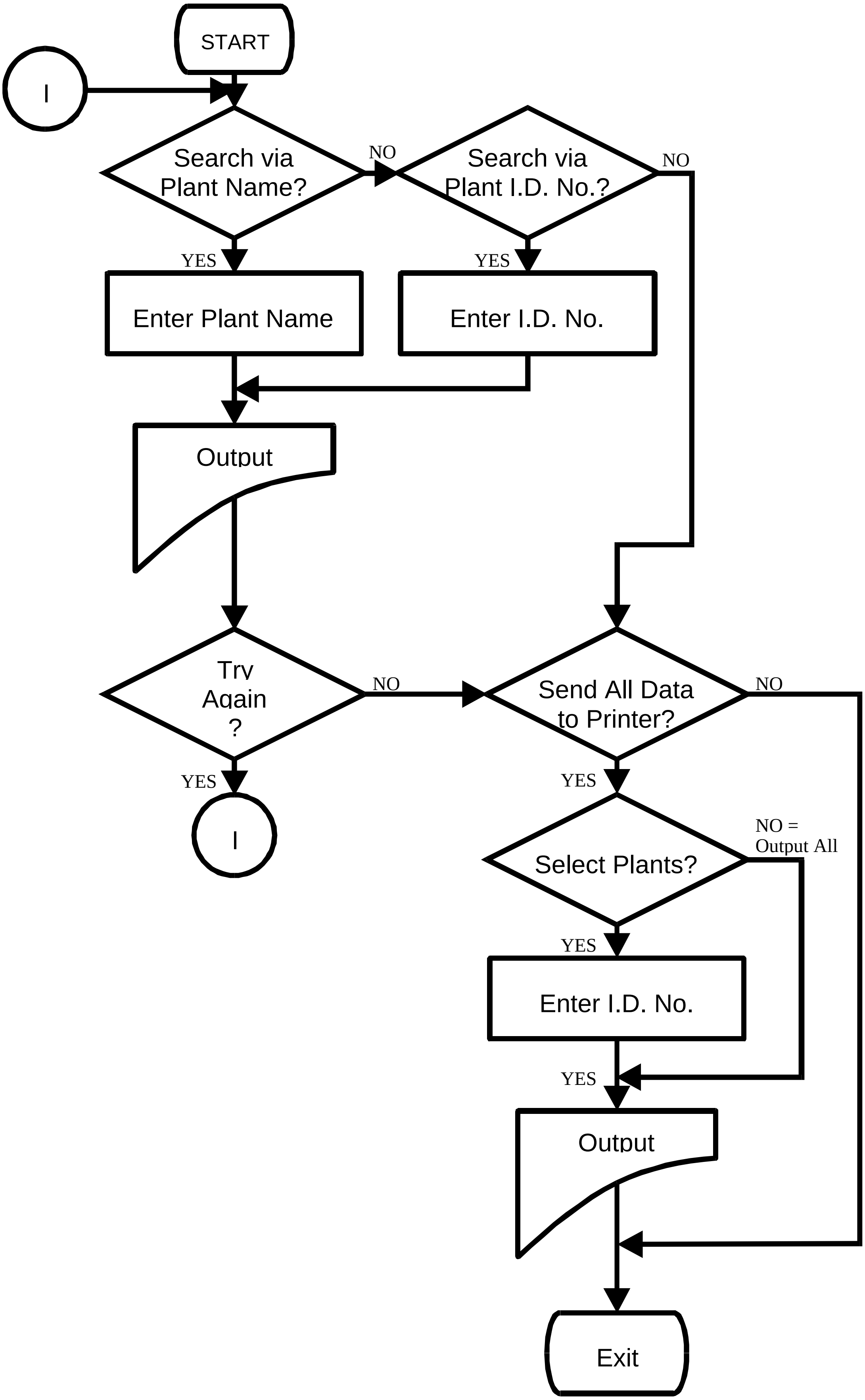

FIG. II–6. Outline of 'Basic Plant Information' flow chart.

REFERENCES TO ANNEX II

[II–1] AMERICAN NUCLEAR INSURERS (ANI), Computer Listing of Fire Events Occurring at Nuclear Power Plants, obtained from W. H. Bornhoeft, ANI (1985).

[II–2] NUCLEAR REGULATORY COMMISSION, Licensee Event Reports (LERs), reported to the Nuclear Regulatory Commission (NRC) in accordance with the Code of Federal Regulations, Title 10 – Energy, Sections 50.72 and 50.73, USNRC, Washington, DC, various dates.

[II–3] Nuclear Power Experience (NPE), a Division of Petroleum Information Corporation, Nuclear Power Experience, various dates.

[II–4] ELECTRIC POWER RESEARCH INSTITUTE, Nuclear Power Plant Fire Loss Data., Rep. EPRI-NP-3179, July (1983).

[II–5] "World List of Nuclear Power Plants, Operable, Under Construction, or on Order (30 MWe and Over) as of June 30, 1985," Nuclear News, August 1985.

[II–6] Southern Science, Office of Black and Veatch, "Nuclear Power, '85," 1985.

[II–7] NUCLEAR REGULATORY COMMISSION, "Licensed Operating Reactors, Status Summary Report, Data as of 08-31-85", NUREG-0020, Volume 9, Number 9, USNRC, Washington, DC (1985).

[II–8] PHILADELPHIA ELECTRIC COMPANY, "Severe Accident Risk Assessment Limerick Generating Station," Chapter 4, Main Report, Rep. #4161, PEC, April 1983.

[II–9] NUCLEAR REGULATORY COMMISSION, "Power Reactor Events," NUREG/BR-0051, USNRC, Washington, DC, various dates.

[II–10] NUCLEAR REGULATORY COMMISSION, Internal Memo from W. J. Dircks to Commissioner P. Bradford, June 9, 1981.

Annex III
FIRE PROTECTION AS PART OF A WANO PEER REVIEW

The World Association of Nuclear Operators (WANO) was established following the accident at the Chernobyl NPP. WANO's mission is to maximize the safety and reliability of the operation of nuclear power plants by exchanging information and encouraging communication, comparison and emulation amongst its members.

Membership of WANO is voluntary and is open to all companies which operate electricity producing nuclear power plants and organizations representing nuclear operators. WANO has a non-profit status, has no commercial ties and is not a regulatory body; it has no interests other than nuclear safety.

One of WANO's five main programmes is the Peer Review Programme where, at the request of a member, a team of experts from other WANO members carries out a review at a plant to assess the performance of personnel, the condition of systems and equipment, the quality of programmes and the effectiveness of plant management against best international practice. The review aims to identify weaknesses and their root causes. Suggestions to help the host plant in addressing and fixing any problems may be made by the review team, but it is up to the plant to decide whether or not to make use of them. The results of a Peer Review are confidential and divulged only to the host plant.

Fire protection has been added to the list of subjects which can be included within the scope of a Peer Review. Performance objectives and criteria have been developed against which the review of fire protection can be based. These take into account internationally accepted publications such as:

— IAEA Safety Guide "Fire Protection in Nuclear Power Plants" 50–SG–D2, Rev.1 [III–1];
— International Guidelines for the Fire Protection of Nuclear Power Plants, published on behalf of the national nuclear risk insurance pools and associations [III–2].

The ***Performance objectives*** state, in broad terms, what is meant by excellence in the specific management area. (It should be noted that 'excellence' in this context is not perfection, but a dynamic performance goal that is always higher than the current level of performance.)

Criteria are assigned to each performance area to help in defining what attributes of that management area contribute to the performance objective; typically, they describe specific fire protection activities.

The complete list of performance objectives is:

FP1 Fire Protection Organization and Administration
FP2, FP3 Fire Protection Surveillance, Testing and Maintenance Programme
FP4 Fire Protection Work Practices
FP5 Fire Protection Facilities and Equipment
FP6 Fire Protection Personnel Knowledge and Performance

(An explanation of the performance objectives and criteria for each of these categories is appended at the end of this annex.)

In addition to the performance objectives and criteria, fire protection guidelines have been written to assist peer reviewers in their work. These cover the following:

- review of plant documentation, which begins in advance of the Peer Review itself;
- review of plant specific operational experience and comparison with external experience;
- plant inspections and walk-throughs;
- control of combustible materials and ignition sources;
- guidance on fire protection practices for specific plant areas such as the main control room, electrical switch rooms, diesel generators, fuel oil storage areas, etc.;
- inspection, maintenance and testing of fire protection equipment, identification of anomalies and treatment of deficiencies;
- general employee knowledge and training;
- qualification of fire protection personnel;
- self-assessment of the fire protection programme;
- the control of modifications which directly or indirectly affect fire protection.

The Peer Review itself is a time consuming, interactive process. Staff at the host plant is fully involved and issues are discussed in detail on a daily basis as the review proceeds. Preparation of the Peer Review usually lasts one week, the review itself ordinarily two weeks. There is also strong interaction between members of the review team so that issues which arise in one review area can be tracked across plant functions wherever necessary. For example, an observation about the maintenance of fire protection equipment may have wider implications which should be followed up in the maintenance review area.

The outcome of the Peer Review is an agreed Report of Strengths and Areas for Improvement supported by specific references to observed conditions on the host plant. It is for the plant to decide what actions to take upon the findings, but it is normal practice to hold a follow-up review some 18 months to two years later to observe the progress made.

FP1 Fire protection organization and administration

Performance objective

Fire protection organization and administration ensures effective implementation and control of fire protection activities.

Criteria

A. The organization structure is clearly defined.
B. Staffing and resources are sufficient to accomplish assigned tasks.
C. Responsibilities and authorities of all plant personnel involved in Fire Protection (including co-ordination of on-site and off-site fire fighting preparedness) are clearly defined and understood. Authorities are commensurate with responsibilities. Personnel are held accountable for carrying out assigned responsibilities.
D. Contractor tasks, responsibilities, authorities and interfaces are clearly defined and understood.
E. Interfaces with insurers and official safety organizations are clearly defined and understood. Actions items and recommendations receive appropriate priority and approval, and are scheduled and tracked to completion.
F. Interfaces with supporting groups, including headquarters organisations, are clearly defined and understood.
G. Managers and supervisors demonstrate and require a conservative approach concerning fire protection activities. High performance standards are established, communicated and reinforced. Managers and supervisors routinely observe activities to ensure adherence to station policies and procedures, and to identify and correct problems.
H. Administrative controls are effectively implemented in the conduct of fire protection activities. Examples of such activities include control of combustible materials, use of procedures to control the fire safety aspects of process changes and hot work activities.
I. Contractors and other non-station personnel use the same (or equivalent) approved policies, procedures, control and workmanship standards as station personnel.
J. Fire protection problems and fire events are documented, evaluated and reported. These evaluations are reviewed for trends and actions taken to correct the causes.
K. Lessons learned from in-house fire event investigations and other industry operating experience are used to improve fire safety.
L. Personnel are actively encouraged to develop improved methods and a questioning attitude towards meeting safety, reliability and quality goals.
M. Fire safety training programmes are systematically evaluated and revised to ensure training is adequate and appropriate and that personnel are well trained.
N. Emergency plans for responding to fire are in place and are reviewed regularly for their efficiency. The arrangements cover fire alone and fire occurring at the same time as a nuclear accident.
O. Modifications and design changes are reviewed appropriately to address the effects of the modification on fire safety. Staff assigned to undertake this activity are suitably qualified and experienced.

FP2 General employee knowledge in fire protection

Performance objective

Station personnel, contractors and visitors have the knowledge necessary to implement fire protection practices associated with their work in an effective manner.

Criteria

A. Station personnel, contractors and visitors have a job-related fire protection knowledge and practical abilities, especially regarding the following:
   1. actions to reduce ignition sources and fire hazards during routine operations
   2. action to minimize the accumulation of combustible materials
   3. actions to be taken in the event of a fire
   4. action to control and avoid the spreading of a fire.

B. Job-related knowledge and practical ability are maintained in the following areas:
   1. basic fire protection subjects
   2. pertinent changes in fire protection procedures
   3. lessons learned from in-house and industry operating experience.

C. Personnel are aware of the fire protection requirements for the jobs they perform. Hot work permit procedures and their requirements are implemented during job performance. Proficiency is demonstrated in using extinguishers, fire hose stations or installed fire fighting equipment.

FP3 Fire protection surveillance, testing and maintenance programme

Performance objective

A surveillance, testing and maintenance programme ensures optimum performance and reliability.

Criteria

A. Codes, regulations and standards applicable to the fire protection systems and equipment are clearly understood.
B. All spurious fire alarms are reported and investigated. Deficiencies are corrected as soon as possible.
C. A comprehensive surveillance, maintenance and testing programme is established and implemented to cover both active and passive fire protection features of the plant.
D. The frequency and scope of inspection, maintenance and testing activities are appropriate to the individual parts of the fire protection system and are in accordance with best international practice.
E. Inspection, maintenance and testing activities are carried out by suitably qualified and experienced staff.

FP4 Fire protection work practices

Performance objective

Station fire protection work practices and conditions achieve a high degree of safety.

Criteria

A. The use and storage of combustible materials (solids, liquids, gases) is minimized. Accumulations of transient combustible materials and wastes are controlled. Safe practices are used in the storage, handling, use and transportation of combustible substances. Storage areas are routinely monitored and precautions taken to limit the potential consequences of a leakage (for example use of drip trays for combustible liquids and sufficiently ventilated areas for flammable gases).

B. The use of ignition sources associated with hot work processes (cutting, welding, grinding, hot roofing work, etc.) is adequately controlled to prevent fire from starting.

C. Fire protection systems are maintained operable and reliable to the maximum possible extent. Controls are established to ensure plant safety is maintained. Compensatory measures are implemented when fire protection systems are found to be defective or placed out of service.

FP5 Fire protection facilities and equipment

Performance objective

Fire protection facilities and equipment of appropriate capability and capacity reduce the probability and consequences of fires to a minimum.

Criteria

A. A comprehensive evaluation of fire hazards is available for the plant and kept up to date. The scope of the evaluation covers the threat of fire to personnel, to nuclear safety and to the operation of the plant.
B. The passive fire protection features are well defined, well identified and maintained in order to prevent fire spread. The plant is subdivided into individual fire compartments and fire cells to reduce risk of spread of a fire and to prevent common mode failure of redundant nuclear safety related systems.
C. An adequate fire detection and alarm system is operational and efficient.
D. An adequate gas detection and alarm system is operational and efficient.
E. Fixed fire extinguishing systems are appropriate for the hazard they protect, readily identified, and are in operational service. Their failure, rupture or inadvertent operation does not impair the operation of safety systems required to achieve safe shutdown of the plant.
F. Portable fire extinguishers of appropriate types, fire hydrants and hose reels are suitably located and provided in a sufficient number to ensure efficient and rapid manual fire fighting according to the size and nature of the fire load.
G. The fire fighting team is provided with sufficient mobile equipment to allow fires to be fought in all parts of the plant.
H. Emergency lighting and communication devices are operational and efficient. Escape routes and access routes for fire fighting are clearly marked and free of obstruction.
I. Suitable and sufficient personnel protective equipment is provided for the fire fighting team. Storage areas are easily accessible and well known by the fire fighting team.
J. NTOL: During the construction stage, a provisional system of fire hydrants is made available as soon as possible and emergency protection in the form of fire extinguishers and hose lines is provided.
K. NTOL: If nuclear fuel assemblies have to be stored on site before the facilities in the fuel building are ready, the temporary storage facility should be protected against fire and the storage arrangement should be such that water used for fire fighting cannot lead to criticality conditions.

(NTOL: Near Term Operating Licence, i.e., before plant operation commences.)

FP6 Fire protection personnel knowledge and performance

Performance objective

Fire protection personnel knowledge, training, qualification and performance support effective implementation of fire protection and fire fighting practices.

Criteria

A. Fire protection activities are performed by or under the supervision of personnel who are qualified for the tasks they perform.

B. The fire safety training programme is documented and includes:

   Practical training:

   1. practical training and exercises on fire fighting techniques, including the use of breathing apparatus;
   2. the actions of the fire team in the event of a fire, including muster, deployment, command, control and liaison with off-site brigades.

   Theoretical training:

   1. general information and functions such as: plant layout and emergency evacuation routes, reporting relationship, communication methods, document and procedure issue and revision, record management, material procurement and industrial safety practices;
   2. plant components and system fundamentals, including nuclear and fire related hazards;
   3. performance of fire prevention surveys, including data collection, analysis and documentation and the selection, inspection, use and care of appropriate fire fighting equipment;
   4. fire protection theory and techniques (fire safety culture), including fire protection standards, regulations, work control and other job responsibilities;
   5. plant specific application of appropriate lessons learned from in-house and industry operating experience.

C. On the job training requirements are identified, completed and documented prior to assignment to perform tasks independently.

D. Continuing training addresses areas that include hardware and procedural changes, and infrequently used skills.

E. Fire protection personnel are capable of diagnosing and initiating corrective actions for unusual conditions during routine and accident conditions.

F. The knowledge and practical abilities of contract fire protection technicians are equivalent to those of station fire protection personnel for the function to which they are assigned on the station.

G. NTOL: Inexperienced personnel assigned to fire protection functions are instructed and given practical experience with fire protection equipment similar to that found in power plants.

REFERENCES TO ANNEX III

[III–1] INTERNATIONAL ATOMIC ENERGY AGENCY, Fire Protection in Nuclear Power Plants, Safety Series No. SG-50-D2 (Rev.1), IAEA, Vienna (1992).

[III–2] AMERICAN NUCLEAR INSURERS, International Guidelines for The Fire Protection of Nuclear Power Plants, revised edition, American Nuclear Insurers (ANI), West Hartford, CT (1997).

Annex IV

DEVELOPMENT OF A FIRE INCIDENT DATABASE FOR THE UNITED STATES NUCLEAR POWER INDUSTRY[1]

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IV–1. BACKGROUND

Several years ago, the nuclear power industry in the United States began considering "performance based" or "risk based" approaches to many aspects of nuclear plant operation and equipment maintenance. In addition, the US Nuclear Regulatory Commission (NRC) started reviewing performance based or risk informed regulation approaches to replace some of its traditionally prescriptive regulatory methods. Both the utility industry and the NRC identified fire protection programmes as a candidate for performance based consideration.

When the industry began looking at performance based approaches to fire protection issues, it was recognized very early in the process that a comprehensive fire events database would be an essential element needed to support these types of programmes. Accurate information on the frequency and severity of fire occurrences would be critical, and the database would need to be viewed as comprehensive and unbiased by regulators and other outside agencies. In addition, the database must be directly available to any utility company or any utility industry organization with a legitimate need to access the data.

There had been several previous efforts to collect utility industry fire incident information; however, each of those was found to have certain drawbacks. The Fire Protection Committee of the Edison Electric Institute (EEI), a US utility industry organization, has been collecting reports on utility fire incidents for many years. These narrative reports pertaining to both nuclear and non-nuclear facilities are voluntarily submitted to promote information sharing, and are discussed by the EEI Fire Protection Committee during its periodic meetings. However, not all US utilities are members of EEI, and therefore not all fires are reported under this programme. In addition, the fire incident information collected by the EEI is not computerized, making it difficult to retrieve, sort, and analyse the data.

In the late 1980s, The Electric Power Research Institute (EPRI), another US utility industry organization, was commissioned to develop a computerized database to support industry efforts in performing Individual Plant Examinations of External Events (IPEEE) and plant assessments using the Fire-Induced Vulnerability Evaluation (FIVE) methodology. EPRI developed this database by reviewing fire related Licensee Event Reports that had been submitted to the NRC, reviewing available literature, and by soliciting information from its member utilities. To the extent possible, this effort collected information on fires that occurred in the US nuclear power industry from the mid-1960s through the end of 1992. While the data collected by EPRI was reasonably comprehensive, the analyses done and the products developed by EPRI based on this data were available only to EPRI members who had contributed to funding the project.

In early 1995, representatives of the utility fire protection community approached Nuclear Electric Insurance Limited (NEIL) to determine if NEIL would be interested in

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[1] Reproduced from: "Upgrading of Fire Safety in Nuclear Power Plants", IAEA-TECDOC-1014, IAEA, Vienna (1998).

participating in the development and ongoing maintenance of a new database for the US nuclear power industry. NEIL is a mutual insurance company that was established by the US nuclear power industry to provide insurance for risks identified in the wake of the 1979 accident at Three Mile Island. A mutual insurance company is simply one that is owned and operated by the companies it insures, its “member companies”. NEIL’s member companies include every utility company licensed to operate a nuclear power plant in the USA, and NEIL provides some form of insurance coverage for every operating US nuclear power plant. Neil’s overall loss control programme includes periodic in-plant evaluations to assess conditions and to verify compliance with established standards. These evaluations are conducted by NEIL Loss Control Representatives (LCR) who are fire protection professionals. During each plant evaluation, the LCR routinely review a plant’s fire incident log. Thus, the programme provides a built-in mechanism to virtually assure that all future fire incidents will be included in the database. If a fire event occurred that was not reported, it would be identified by the LCR during the normal course of business, and efforts would be initiated to collect the necessary information. With Neil’s involvement at every operating US nuclear plant and its interest in fire protection, it was viewed as a logical participant in the efforts to develop a new database.

IV–2. FIRE INCIDENT REPORTING FORM AND DATABASE DEVELOPMENT

Some of the initial questions that needed to be addressed included the level of detail needed regarding each fire incident and how the information would be reported and tracked. A task group comprised of utility fire protection professionals was formed to study these issues. One of the first issues that arose was a recognition that a consistent industry definition for a “fire” did not exist. A survey of several nuclear power plants revealed wide variations in how “fire incidents” were defined. The spectrum ranged from one plant that recorded as “fire incidents” all instances where the plant fire brigade was dispatched, regardless of whether or not an actual fire had occurred, to another plant that did not log events as “fire incidents” unless an actual fire burned for longer than ten minutes. Obviously, in order to obtain consistent and meaningful data, a standard definition was needed. The task group drafted a “fire incident” definition and solicited comments and input from other utility industry fire protection professionals. Ultimately, the following definition of a “fire incident” was adopted:

“A reportable fire incident is one which results in the use of manual fire suppression activity; or, results in the activation of an automatic fire suppression system; or, shows visible flame or evidence of prior flaming.”

Reportable fire incidents are not intended to include overheating of equipment, smoked components, steam leaks, false alarms, or unfounded odours. This definition is intentionally broad and is intended to capture all actual fire events, regardless of whether or not they caused damage or were significant from a safety standpoint.

Once the definition of a reportable fire was established, attention then turned to the development of a standardized reporting form. Based on input from the utility industry fire protection community, it was decided that a common reporting form pertaining to both nuclear and non-nuclear electric generating facilities would be useful and less confusing to the industry. It was recognized that information on fire incidents in conventional portions of a plant, such as the turbine building, would be applicable to either type of facility. By collecting information from both nuclear and non-nuclear plants, the utility industry would benefit from having one central location in which to store and from which to query fire incident data.

The primary goal was to make the reporting form comprehensive, yet easy to use. Everyone involved agreed that the likelihood of having reports voluntarily submitted would increase significantly if the report form was user friendly and uncomplicated. After identifying the critical data elements, a reporting form modelled after the example forms contained in National Fire Protection Association (NFPA) Standard 902 “Fire Reporting Field Incident Guide” was developed. The reporting form consists of a single page report intended to collect basic information about the fire, and a multiple page nuclear supplement intended to gather more detailed information about fires occurring in nuclear power plants. To help maintain consistency, a numerical coding legend was established for each option that could be entered into a given field. These numerical codings also facilitated the computerization of the form using commercially available software that will allow reports to be filled out and submitted electronically.

With the critical data elements identified, development began on the database itself. Key criteria included the ability to easily retrieve, sort and trend the data. The ultimate goal was to make the database directly and easily available to any legitimate user while protecting it against inappropriate uses. Once again, commercially available software was used to construct a database that will allow remote users to electronically submit incident reports and also to conduct queries. Several standard queries and reports are being developed; however, a user will eventually have the capability to construct customized queries and obtain customized reports.

It is intended that access to the database will be available via a secure Web site on the Internet. Users will be issued a password that will allow queries to be made and reports to be obtained based on whatever criteria they desire. However, for data security purposes, it will not be possible for a user to download the entire database.

IV–3. DATA COLLECTION EFFORTS

Data collection for new fire incidents began in early 1996. As noted above, an earlier database developed by the Electric Power Research Institute included data through the end of 1992, and efforts were also made to collect and reconstruct data for the period 1993–1995. NEIL’s LCR also began collecting information on past fire incidents during routine plant evaluations. Copies of the new fire incident report form were distributed to nuclear plant fire protection personnel, and presentations explaining the new database and report form were conducted at several meetings of industry fire protection organizations. As anticipated with any new programme, direct submission by the plants of fire incident reports has been somewhat slow. NEIL’s LCR continue to identify recent incidents which have not been reported. However, it is anticipated that the submission of reports will become more routine as the programme becomes better known and the electronic submission process is available to all plants.

IV–4. CURRENT STATUS

Information on approximately 200 fire incidents that occurred during the period 1993 through mid-1997 have been collected. The reports are currently being reviewed for consistency and completeness, and efforts are under way to fill gaps in information concerning many of these fires. In addition, an agreement was recently reached with the Electric Power Research Institute (EPRI) whereby EPRI will make available all data from their earlier database so that it can be included in the new database. Thus, the new database will represent a reasonably comprehensive collection of information on fires that have occurred in the US nuclear power industry starting in the mid-1960s.

Software packages have been provided to some ten plants to test the electronic incident report form and the electronic submission procedure. In addition, NEIL is in the process of developing an Internet Web site where it is anticipated that access to the database will be provided. Users will be able to open an electronic version of the reporting form, enter the necessary information, and submit the report electronically. Querying of the database will also be possible from the Web site. It is anticipated that access to the database via the Internet will be available near the end of the first quarter 1998. While NEIL will act as the custodian of the database, it does not intend to trend, interpret or analyse the data for other than its own interests. Interpretation of the data for industry use will be left to industry users or to other industry organizations such as EPRI.

All efforts to date have been directed toward obtaining fire incident data from US nuclear power plants. The reporting form has also been provided to the fire protection group within the Edison Electric Institute, and it is anticipated that in the future, incident reports pertaining to non-nuclear electric generating facility fires will be submitted for inclusion in the database. However, for the non-nuclear plant incidents, all reporting will be strictly voluntary and there will be no mechanism in place to assure accuracy or completeness of the data.

IV–5. CONCLUSION

The availability of a comprehensive, unbiased fire incident database will be critical to the successful future implementation of performance based fire protection programmes at US nuclear power facilities. While the database currently under development should provide the industry with an essential tool, success will be dependent upon participation by the entire industry. Failure by some to report fire incidents will render the database less comprehensive, and therefore, less useful or effective.

Fire incident information gathered to date confirms the intuitive notion that fires in nuclear power facilities are relatively rare, and those which occur are usually minor and have little or no safety significance. However, a few recent fires have identified certain plant vulnerabilities that had not been previously identified or considered. The collection and sharing of information on these types of incidents can only serve to benefit the entire industry.

In addition to supporting performance based programmes as discussed above, the availability of a comprehensive fire events database could be useful in other areas. Accurate information on fire frequencies and probabilities could be used to make better informed decisions on resource allocations, capital expenditures, etc.

Annex V
USE OF NPP KRŠKO PLANT SPECIFIC DATA TO MODEL FIRE BRIGADE RESPONSE[1]

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V–1. INTRODUCTION

Nuclear Power Plant (NPP) Krško is a Westinghouse-designed, single-unit, 1882 megawatts thermal, two-loop, pressurized water reactor. Construction of the plant was started in the mid-1970s and initial criticality was reached in September 1981. The Krško NPP is located on the north bank of the River Sava about two kilometres Southeast of Krško, Slovenia.

The on-site fire brigade consists of five members, of whom three are professional fire fighters and two are local operators. The off-site brigade is comprised of nine members, of whom at least three are professional fire fighters. In a fire incident, the on-site brigade members are officially notified of a fire condition by an alarm station located in the fire brigade station and in the main control room. Upon receiving an alarm, the shift supervisor dispatches a local operator to the suspected fire location to determine fire conditions. The on-site fire brigade immediately begins to suit up and gather equipment. After assessment of the fire condition, the local operator notifies the shift supervisor of the fire location and needed fire brigade response. The shift supervisor then notifies the on-site and off-site fire brigades to respond. If the fire can be easily extinguished, the local operator will then extinguish the fire, otherwise the operator awaits the arrival of the fire brigade. This twofold action minimizes time in the assessment of fire conditions and establishment of the fire location.

Fire brigade training and drills are held for both on-site and off-site personnel. Drills are both announced and unannounced (one drill per month is announced and four drills per year are unannounced — one for each shift). In the past year, two drills were held using a combined response of both on-site and off-site brigades. Response times were four minutes for arrival of the off-site crew and 90 seconds for on-site crew dressout and equipment preparation. Transit time from the on-site station to plant entry was one minute.

Entry into all areas of the plant is unimpeded for on-site fire brigade personnel with the exception of the auxiliary building, where thermoluminescent device (TLD) badges are required. TLD badges are issued to fire brigade personnel at the entry point. No data is taken upon entry other than issuing the TLDs. This allows faster response to the fire location. Drill times for access through the entry point varied from one minute to three minutes. For off-site fire brigade personnel, to reduce delay time in response, personnel are accompanied by a security escort or by a qualified escort from their time of arrival at the plant until their exit.

A method for modelling fire brigade response which was initially developed during the LaSalle Unit 2 NPP Internal Fire Analysis [V–1] was modified to model the probability of manual fire suppression in the NPP Krško Level 1 Fire Probabilistic Safety Assessment (PSA) [V–2]. This method will be described in detail in Section V-3 below.

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[1] Presented at the IAEA Technical Committee Meeting on Use of Operational Experience in Fire Safety Assessment of Nuclear Power Plants, 7–11 December 1998, Vienna, Austria.

V–2. MODELLING OF FIRE BRIGADE RESPONSE IN THE UNITED STATES FIRE IPEEES

An important component in the determination of fire-induced core damage frequency (CDF) is the ability of the plant fire brigade to respond to and extinguish fires in a timely fashion before damage can occur to plant systems and components important to safety. Most United States fire IPEEEs [V–3] have employed simplified methods to model fire brigade response which have utilized either plant specific fire drill data or only credited manual fire suppression in continually occupied plant areas such as the main control room. For those fire IPEEEs which modelled fire brigade response, drill times were taken to be equivalent to the time to detect, respond, and extinguish the fire. However, drill times typically only record the time for the fire brigade to respond to the scene of the fire after activation of a fire alarm. Therefore, the time to extinguishment may be underestimated. This time underestimation may be especially critical in those plant areas where substantial smoke build-up is possible prior to arrival of the fire brigade. Also, the fire IPEEEs did not consider delay in fire brigade response due to inter-area smoke propagation.

V–3. METHODOLOGY UTILIZED IN THE NPP KRŠKO FIRE PSA TO MODEL THE PROBABILITY OF MANUAL FIRE SUPPRESSION

A thorough walk-through of NPP Krško and review of its fire brigade practices was performed to determine the probability of manual suppression in a given time frame for all critical plant areas. The COMPBRN fire propagation code [V-4] was utilized to predict the time to ignition or damage of critical cables and components. The COMPBRN models estimated fire-induced equipment or cable damage times which were used in conjunction with the time to suppression of fires to obtain the probability that a given fire will damage critical safety equipment before it can be suppressed.

The plant walk-through was employed to assess plant fire fighting capabilities and to note access routes for extinguishing fires in critical plant locations. Information was gathered regarding installed automatic fire suppression systems; manual fire fighting equipment (hose reels and portable extinguishers); fire detectors and alarm provisions; limitations to access (locked doors, security restrictions); distances from external points of access to probable fire locations; and room size and geometry as they relate to access and the level of smoke obscuration. Interview of plant fire department personnel, a comprehensive tour of the fire department facilities, and review of drill records were performed to assess fire department response time, distances to fire locations, training, and equipment provisions.

Information gathered was used to determine the time to reach the discrete fire phases of established burning (flame close to 25 cm high) to suppression. These phases include the following:

(1) Established burning to detection;
(2) Detection to alarm;
(3) Fire brigade response to the building entrance;
(4) Arrival at the room of origin;
(5) Finding the fire;
(6) Extinguishing agent application;
(7) Extinguishment or substantial control of the fire.

Maximum, minimum, and what is considered to be the expected best estimate or median times, are determined for each of these phases. Tables V–1 through V–4 provide examples of these estimates of cumulative times from established burning to the end of each phase from the NPP Krško fire PSA. Also provided, in Tables V–1 through V–4, is information on the type of detection; the type of automatic suppression; and notes on assessment of human detection, manual suppression accessibility, and manual fire fighting equipment available.

The degree of confidence in the estimated times varies, depending on the building features and the phase under consideration. For Phase 1, the confidence in the time estimates is considered good where automatic detectors are provided. For human detection, there is less confidence in the time estimate. For Phase 2, the level of confidence is considered good to excellent for automatic detection and fair for human detection.

An estimate of the time for the response of the smoke detectors was determined using data from a model developed at the National Institute of Standards and Technology called DETACT (DETector ACTivation). It is a routine included in a collection of models/routines called FPETOOL. The input for the model is the time heat release rate growth parameters. The output is the heat release rate necessary for detector activation and the time of activation. The response time index is normally a measurement of the delay of the device in responding to a flow of hot gas due to its mass, material, and configuration. To account for the time for the smoke to penetrate underlying obstructions (e.g., cable trays), a higher response time index can be utilized. In modelling the smoke detector response, a first order approximation of the response of the smoke detector was made by assuming that a temperature rise of some 15^{o}C for a response device with a response time index of 10 approximates a condition at which the smoke detector would respond. The program does not account for the travel time from the generation of the smoke at the point of combustion to the detector. Since smoke detectors at NPP Krško are located relatively close to the fixed combustible fire sources for all critical fire areas, this is a negligible factor. The time to alarm is based on the requirements for alarm systems in the National Fire Protection Association standards for alarm transmission.

For Phase 3, the level of confidence is considered good to excellent. Based upon drill times, from time of notification to arrival at the entry door of the plant for the on-site fire brigade is two and one-half minutes. In addition, the off-site fire brigade is notified to assist on-site fire fighters. The distance between the off-site support fire station and the Krško plant is approximately three miles. Based on drills, it would take four minutes for nine fire fighters of this station to reach the Krško plant. This assumes that all fire fighters are within the station and ready to move upon the emission of an alarm.

The level of confidence for Phase 4 is considered good. It is assumed that a trained local operator has already found the room of origin and assessed the fire condition and is waiting to lead the fire fighters to this room. Time required to arrive at the fire room has a strong dependence on the distance between the fire room and the building entrance. For distances up to 45 metres, the time required to arrive at the fire room is at least two minutes and at most some six minutes. For distances between 45 and 75 metres, these minimum and maximum times are in the order of six to 15 minutes, respectively. For the auxiliary building, entry into the radiation control area requires the issuance of a TLD to fire fighters prior to entry. This delay, based upon drill times, ranges from one minute to a maximum of three minutes.

Time to locate the fire (Phase 5) depends on several factors; the size of the area in which the fire originates, the size of the fire, the amount of equipment within the fire area, and the level of smoke obscuration. In general, it should be easier to locate the fire within a large room which contains a limited amount of equipment, than within a small room with more equipment. A computer model (ASET) was used to estimate fire size and the depth and temperature of smoke in the room. This information was utilized in predicting conditions within the room at the time of fire detection, upon fire brigade arrival at the room, and for estimating the time to find and extinguish/suppress the fire. Room geometry and heat release rates are inputs for this computer model. It was found that the level of smoke obscuration outside the room of fire origin is minimal with the exception of some control building areas.

Finally, the level of confidence for Phase 6 and Phase 7 is considered good. The estimate of the time to agent application is based on the location of manual suppression equipment relative to the incident area. As the hose stations are located at regular intervals throughout the plant and fire extinguishers are readily available in all areas, the time to agent application is minimal. The same time was used for all scenarios within each area, as it is assumed a portion of the fire brigade will be laying lines or retrieving fire extinguishers while other members are locating the fire. Therefore, additional time for this phase is built into the previous phase. The fixed combustible fires modelled are relatively large with regard to heat release rate, but are relatively small in area. Based on the fact a fixed location fire can be easily extinguished by well-trained personnel, times used for this phase are again minimal. Although the time to extinguishment is reported, once agent application begins, the effect of the fire is going to be greatly diminished as the cooling/smothering affect of the agent will quickly reduce the heat release rate associated with the fire.

V–4. RESULTS OF THE FIRE BRIGADE RESPONSE TIME ANALYSIS

Tables V–I to V–IV provide examples of the results of the analysis for the fire brigade manual fire fighting response to postulated fire incidents at NPP Krško. The tables present minimum, average, and maximum times for each phase. The variability between the minimum and maximum response times is diminished from similar analyses done for other plants [V–1, V–5, V–6] due to the following; (a) the fire brigade is located at the plant instead of several miles away, (b) hose stations for suppression activities are located conveniently throughout the plant, and (c) most areas analysed are covered by an automatic fire alarm system with area smoke detection provided in the ceiling.

TABLE V–I. KRŠKO MANUAL FIRE SUPPRESSION AUXILIARY BUILDING BASEMENT (AB–3)

AUTOMATIC DETECTION: None

AUTOMATIC SUPPRESSION: None

HUMAN DETECTION: Delayed

MANUAL SUPPRESSION: Four hose stations provided in the area

EQUIPMENT AVAILABLE: Portable extinguishers, three 5kg carbon dioxide and five 9kg dry chemical fire extinguishers

Event/Phase Description		Cumulative Time (Minutes)		
		Minimum Minutes	Maximum Minutes	Average Minutes
1.	Detection	5.5	8.5	6.5
2.	Alarm	5.5	9.0	6.5
3.	Fire Brigade Building Response	7.5	13.0	9.0
4.	Arrival at the Room of Origin*	10.5	22.0	14.0
5.	Finding the Fire	11.0	23.0	14.5
6.	Agent Application	11.5	24.0	15.0
7.	Extinguishment	12.5	26.0	16.0

NOTES:

* An additional slight delay in fire brigade response has been assessed to account for access into the radiologically controlled area and TLD issuance.

TABLE V–II. KRŠKO MANUAL FIRE SUPPRESSION UPPER CABLE SPREADING ROOM (CB–2)

AUTOMATIC DETECTION:	Area-wide smoke detectors
AUTOMATIC SUPPRESSION:	Wetpipe sprinkler system
HUMAN DETECTION:	Delayed
MANUAL SUPPRESSION:	Three hose stations, two in the Southeast stairwell and one in the turbine building heater bay mezzanine
EQUIPMENT AVAILABLE:	Portable extinguishers located in stairwell

		Cumulative Time (Minutes)		
	Event/Phase Description	Minimum Minutes	Maximum Minutes	Average Minutes
1.	Detection	1.0	5.0	2.0
2.	Alarm	1.0	5.5	2.0
3.	Fire Brigade Building Response	3.0	9.5	4.5
4.	Arrival at the Room of Origin*	7.0	17.5	10.5
5.	Finding the Fire	7.5	18.5	11.0
6.	Agent Application	8.0	19.5	11.5
7.	Extinguishment	9.0	21.5	12.5

NOTES:

* A two-minute delay in arrival at the room of origin was assessed due to the potential for smoke transport into the emergency switchgear rooms and consequent multiple alarms in the control room and on-site fire brigade station.

TABLE V–III. KRŠKO MANUAL FIRE SUPPRESSION ESSENTIAL SERVICE WATER BUILDING (SW)

AUTOMATIC DETECTION: Area-wide smoke detectors

AUTOMATIC SUPPRESSION: Wetpipe sprinkler system in diesel-driven fire pump room

HUMAN DETECTION: Delayed

MANUAL SUPPRESSION: Hose station on east wall

EQUIPMENT AVAILABLE: Portable extinguishers, two units, 5 kg carbon dioxide

		Cumulative Time (Minutes)		
	Event/Phase Description	Minimum Minutes	Maximum Minutes	Average Minutes
1.	Detection	1.0	5.0	2.0
2.	Alarm	1.0	5.5	2.0
3.	Fire Brigade Building Response	3.0	9.5	4.5
4.	Arrival at the Room of Origin	4.0	11.5	6.0
5.	Finding the Fire	4.5	12.5	6.5
6.	Agent Application	5.0	13.5	7.0
7.	Extinguishment	6.0	15.5	8.0

NOTES:

TABLE V–IV. KRŠKO MANUAL FIRE SUPPRESSION COMPONENT COOLING BUILDING (CC)

AUTOMATIC DETECTION:	Area-wide smoke detectors
AUTOMATIC SUPPRESSION:	None
HUMAN DETECTION:	Delayed
MANUAL SUPPRESSION:	Two hose stations, one on each level
EQUIPMENT AVAILABLE:	Portable extinguishers, six units, 9 kg dry chemical and one unit, 5 kg carbon dioxide

		Cumulative Time (Minutes)		
	Event/Phase Description	Minimum Minutes	Maximum Minutes	Average Minutes
1.	Detection	1.0	5.0	2.0
2.	Alarm	1.0	5.5	2.0
3.	Fire Brigade Building Response	3.0	9.5	4.5
4.	Arrival at the Room of Origin	4.0	11.5	6.0
5.	Finding the Fire	4.5	13.5	7.5
6.	Agent Application	5.0	14.5	8.0
7.	Extinguishment	6.0	16.5	9.0

NOTES:

V–5. CONCLUSION

A method for modelling fire brigade response which was initially developed in Reference V–1 has been adapted for the Krško Level 1 Fire PSA. Modelling of fire brigade response was subdivided into the following phases:

(1) Established burning to detection.
(2) Detection to alarm.
(3) Fire brigade response to the building entrance.
(4) Arrival at the room of origin.
(5) Finding the fire.
(6) Agent application.
(7) Extinguishment or substantial control of the fire.

Interview of plant fire department personnel, a comprehensive tour of the fire department facilities, and a review of drill records were performed to assess fire department response time, distances to fire locations, training, and equipment provisions.

Results of this analysis have been compared to and found to be consistent with United States fire data [V–7]. Crediting fire brigade response and suppression before critical damage occurs on a consistent plant-wide basis has allowed for removal of unnecessary conservatisms in the analysis and avoidance of potential skewing of fire area importance (if manual fire suppression is credited in only limited plant areas).

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