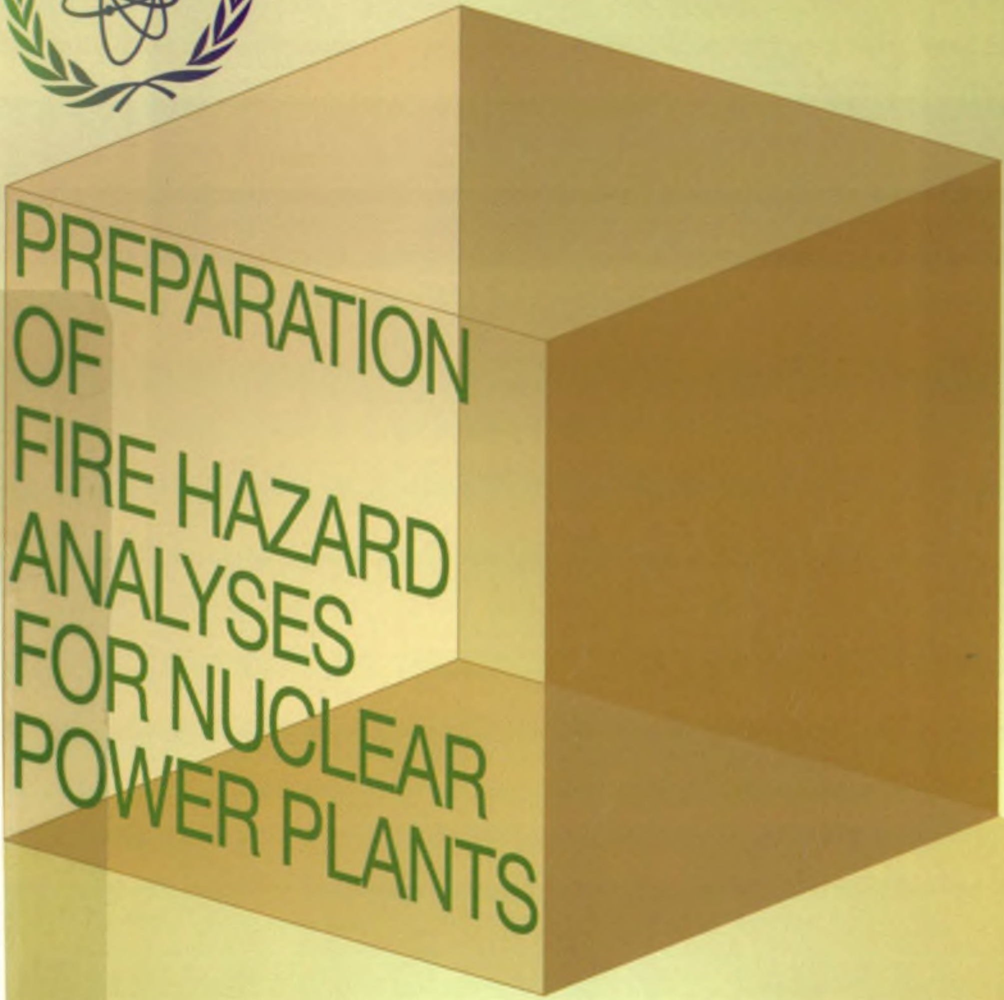
# Safety Reports Series

## No. 8



# PREPARATION OF FIRE HAZARD ANALYSES FOR NUCLEAR POWER PLANTS

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

Printed by the IAEA in Austria
August 1998
STI/PUB/1059

SAFETY REPORTS SERIES No. 8

# PREPARATION OF FIRE HAZARD ANALYSES FOR NUCLEAR POWER PLANTS

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 1998

**VIC Library Cataloguing in Publication Data**

Preparation of fire hazard analyses for nuclear power plants. — Vienna : International Atomic Energy Energy, 1998.
p. ; 24 cm. — (Safety reports series, ISSN 1020–6450 ; no. 8)
STI/PUB/1059
ISBN 92–0–102798–2
Includes bibliographical references.

1. Nuclear power plants—Fire and fire prevention. 2. Fire risk assessment. I. International Atomic Energy Agency. II. Series.

VICL 98–00197

# FOREWORD

In 1974, the IAEA established a special Nuclear Safety Standards (NUSS) programme under which a number of Codes and Safety Guides have been produced in the areas of governmental organization, siting, design, operation and quality assurance. The NUSS Codes and Guides are a collection of basic and derived requirements for the safety of nuclear power plants with thermal neutron reactors. They have been developed with the broadest possible international consensus.

This broad consensus is one of the reasons for the relatively general wording of the main principles and requirements, which may need further elaboration and guidance for application to specific nuclear power plants. In many areas, national regulations and technical standards are available, but often even these do not answer all questions, and only the practice adopted in applying certain rules fully reflects the outcome of the detailed consideration given to solving individual cases.

In order to present further details on the application and interpretation and on the limitation of individual concepts in the NUSS Codes and Safety Guides, a series of publications that detail good practices has been initiated. It is hoped that many Member States will benefit from the experience presented in these publications.

The present report has been developed with the help of experts from regulatory, operating and engineering organizations, all with practical experience in the field of fire safety of nuclear power plants. The publication provides a framework for preparing a comprehensive fire hazard analysis for a nuclear power plant. It includes a detailed description of the issues to be considered in determining the adequacy of fire protection with respect to plant nuclear safety. It can be used for both new and existing plants. The publication will be useful not only to operators and designers but also to safety assessors.

This Safety Report addresses a specialized topic and it is recommended that reference be made to Safety Guide No. 50-SG-D2 (Rev. 1), Fire Protection in Nuclear Power Plants.

The IAEA is grateful to all the experts who helped in the drafting and reviewing of this publication.

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# 1. INTRODUCTION

## 1.1. BACKGROUND

In 1992, the revised Safety Guide No. 50-SG-D2 (Rev. 1), Fire Protection in Nuclear Power Plants [1], was issued. This Safety Guide was developed as part of the IAEA Nuclear Safety Standards (NUSS) programme. The objective of the Safety Guide was to advise designers, safety assessors and regulators on the concept of fire protection in the design of nuclear power plants and to recommend practical ways of implementing this concept in some detail. The Safety Guide described the necessity for preparing a fire hazard analysis early in the design of a new plant. Annex I of the Guide also provided additional guidance on the information that should be contained in the fire hazard analysis.

This Safety Report has been developed to facilitate the preparation of a comprehensive fire hazard analysis for nuclear power plants. It supplements Safety Guide No. 50-SG-D2 (Rev. 1) by providing detailed information on the preparation of such an analysis.

The practical information provided in this Safety Report is fully applicable to both new and existing plants. It is of particular relevance to operating plants, since fire hazard analyses for new plants are usually developed according to accepted and relatively well established international practice.

## 1.2. OBJECTIVE

This Safety Report discusses the ways of preparing a fire hazard analysis for a nuclear power plant. A comprehensive fire hazard analysis determines the adequacy of the fire protection measures (e.g. administrative controls, operator actions and passive fire protection components) and the fixed fire protection systems to fulfil the requirements of paras 202 and 216 of Safety Guide No. 50-SG-D2 (Rev. 1), to which reference should be made. The Safety Report will be useful to designers of new plants as well as to operators of existing plants when preparing or updating a fire hazard analysis.

## 1.3. SCOPE

This publication on fire safety applies to land based nuclear power plants with thermal neutron reactors of general use, such as light water, heavy water or gas cooled types. It provides an objective structure for preparing a comprehensive fire hazard analysis for a nuclear power plant, and may also be useful in preparing a fire hazard analysis for other nuclear installations, including research reactors.

The primary concern of this Safety Report is to ensure the adequacy of fire protection for the safety systems during all the operational states of the plant (including protection of site personnel, the public and the environment from undue radiation hazards).[1] Those aspects of fire protection that are not directly related to nuclear power plant safety and those that are solely related to the physical protection of plant personnel should be determined on the basis of national practice and regulations.

## 1.4. STRUCTURE

Section 2 gives an overview of the fire hazard analysis by outlining its purpose and scope, summarizing the concept of defence in depth, discussing initial development and the need for periodic updating of the fire hazard analysis, and addressing the quality assurance issues related to the preparation of the document and the need for controlled record keeping.

Section 3 describes the methods to be followed in preparing the analysis. Section 4 identifies all the safety systems within the plant, and covers the large amount of other information that must be accumulated during the data collection phase of the process. Section 5 describes the analysis of fire growth for the postulated fire in each fire compartment. Section 6 covers consequence analysis and the various means of quantifying the effects of postulated fires.

Section 7 discusses how the adequacy of fire protection for the plant is determined, and Section 8 addresses the need to recommend improvements to the existing level of fire protection where deficiencies are identified. Finally, Section 9 describes the iterative nature of the fire hazard analysis process, which is repeated for each fire compartment until it can be documented that plant nuclear safety has been achieved and maintained by the fire protection measures provided.

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[1] Where design features have been specifically provided to ensure nuclear safety in a situation following a design basis accident (e.g. post-accident core cooling, containment of radioactive release and hydrogen recombination), the fire protection measures for these features should also be detailed in the analysis.

# 2. FIRE HAZARD ANALYSIS

## 2.1. PURPOSE

From an initial design standpoint, the fire hazard analysis has six separate purposes, as stated in para. 307 of Safety Guide No. 50-SG-D2 (Rev. 1):

(1) To identify items important to safety, and their location.
(2) To analyse the anticipated fire growth and the consequences of the fire with respect to items important to safety.
(3) To determine the required fire resistance of fire barriers.[2]
(4) To determine the type of fire detection and protection means to be provided.
(5) To identify cases where additional fire separation or fire protection is required, especially for common mode failures, in order to ensure that items important to safety will remain functional during and following a credible fire.
(6) To verify that the intent of para. 216 of Safety Guide No. 50-SG-D2 (Rev. 1) has been met. Paragraph 216 states that: "The safety systems required to shut the reactor down, remove residual heat and contain radioactive material shall be protected against the consequences of fires so that the safety systems are still capable of performing the above safety functions, taking into account the effects of a single failure as required in the Code on Design for these functions".

For existing plants, the purpose of fire hazard analysis is to document that the existing fire protection measures are adequate to ensure safety (as defined in item (6) above). In situations where deficiencies are identified during the analysis, the process requires recommendations to be formulated which, when implemented, will ensure that safety is achieved.

## 2.2. SCOPE

To be effective in ensuring safety for the plant, the fire hazard analysis must consider all areas of the site, including the non-nuclear facilities. This assessment is necessary to ensure that all those fire hazards that potentially threaten nuclear safety have been addressed, and that no areas are inadvertently overlooked. Additional fire

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[2] This should include the fire resistance of building structures.

protection may be needed in some areas to ensure adequate access to those plant areas that contain nuclear safety systems.

The fire safety measures necessary to minimize property damage (independent of safety), to provide personnel protection or to minimize plant down-time that could occur as a result of a fire are outside the scope of this report, which concerns itself solely with plant safety issues.

## 2.3. DEFENCE IN DEPTH CONCEPT

It is essential that the fire protection measures are adequate to ensure safety throughout the life of the plant. This is achieved by defence in depth, the concept of which is described in para. 205 of Safety Guide No. 50-SG-D2 (Rev. 1) [1]. This concept incorporates three principal objectives:

(1) To prevent fires from starting (e.g. by control of ignition sources and minimization of combustible material);

(2) To detect and extinguish quickly those fires that do start, thus limiting the damage;

(3) To prevent the spread of those fires that have not been extinguished, thus minimizing their effect on items important to safety.

## 2.4. PERSONNEL QUALIFICATIONS

It is essential that the fire hazard analysis be prepared by technically qualified engineering personnel. This applies to preparation of the initial document and to periodic updating of the analysis.

The expertise needed to conduct a fire hazard analysis combines knowledge of fire engineering, and plant design and operation. The personnel that perform the analysis should be familiar with the fire safety systems, components and equipment, and their interaction with safety systems. The analyst should be capable of evaluating the fire damage effects on those structures, systems and components that are important to safety. This expertise includes the capability of evaluating fire induced failures of the power, control and instrumentation circuits. Good familiarization with the design of the plant safety systems, and with plant layout, is essential. It is advisable that analysts have experience with application of the methods available for quantifying and analysing fire growth and of the computational methods for predicting the consequences of fires.

To ensure that personnel have appropriate qualifications in all the necessary subjects it is likely that a team approach will be needed in preparing and updating the fire hazard analysis.

## 2.5. INITIAL DEVELOPMENT AND UPDATING

The fire hazard analysis is usually developed early in the design of new plants, updated before initial loading of the reactor fuel, updated periodically[3] and, when relevant, operational or plant modifications are proposed within the scope of the fire hazard analysis. For existing plants it is important that a comprehensive fire hazard analysis be performed at the earliest opportunity. This is essential in order to document that the existing fire safety measures and systems are adequate to ensure safety. Periodic updating of the fire hazard analysis is done throughout the lifetime of the plant (including some of the decommissioning phases). Retention of the documentation compiled for previous fire hazard analyses is very important.

Relevant operational or plant modifications that affect fire safety within the scope of the fire hazard analysis include physical changes in the plant arrangement; increases in the combustible fire load; modifications to or relocation of the systems, components or equipment; modifications to the fire detection or fire extinguishing systems or equipment; modifications to the passive fire protection measures; and changes in the ventilation system.

## 2.6. QUALITY ASSURANCE PROGRAMME

It is important that the existing plant quality assurance programme be implemented for controlling fire safety. Detailed guidance on the quality assurance programme in nuclear power plants is provided in Safety Series No. 50-C/SG-Q, Quality Assurance for Safety in Nuclear Power Plants and Other Nuclear Installations [2], and related Safety Guides. This quality assurance programme is also applied to the preparation (including all the necessary iterations) and control of the fire hazard analysis. In addition, all subsequent revisions and updates to the fire hazard analysis are controlled and recorded to the same level of engineering review and approval that applied to the original document, in accordance with the applicable provisions of the quality assurance programme. This element of control is essential in order to provide reliable documentation that reflects current conditions in each fire compartment and fire cell throughout the plant, and

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[3] Some Member States consider an appropriate period for this review and update to be every 5–10 years, in addition to updates following significant plant modifications.

to ensure that the analysis is maintained as a ‘living document’ throughout the life of the plant.

# 3. METHODS TO BE FOLLOWED IN PREPARING THE FIRE HAZARD ANALYSIS

## 3.1. INTRODUCTION

The primary objective of the fire hazard analysis is to demonstrate that the safety systems required to shut down the reactor, to remove the residual heat and to contain the radioactive material are protected from fire, as described in para. 216 of Safety Guide No. 50-SG-D2 (Rev. 1). Prior to development of the fire hazard analysis it is of great importance to identify the fire protection design philosophy.

Two configurations, fire containment and fire influence, have been identified for use in the fire protection evaluation of redundant safety system equipment that is identified as part of a safety function. These two configurations, described in Sections 3.2 and 3.3, are essential elements, both in the design and application of the fire hazard analysis.

## 3.2. FIRE CONTAINMENT APPROACH

The fire containment approach assumes that redundant items are physically located in different fire compartments which are surrounded by fire barriers capable of withstanding the complete combustion of the contents without allowing the fire to spread outside the fire compartment. In addition, potentially unacceptable interactions between safety related equipment in different fire compartments are assumed to be prevented. A full description of the fire containment approach is given in paras 310 and 311 of Safety Guide No. 50-SG-D2 (Rev. 1).

## 3.3. FIRE INFLUENCE APPROACH

The fire influence approach assumes that redundant items are located in different fire cells within the same fire compartment, and that the potential for a fire to disable these items simultaneously is controlled by measures such as separation by distance, local passive protection and active fire protection. The fire influence approach is described in detail in para. 312 of Safety Guide 50-SG-D2 (Rev. 1).

### 3.4. SUBDIVISION OF BUILDINGS INTO FIRE COMPARTMENTS AND FIRE CELLS

The potential identification of rooms or areas of nuclear power plants as fire containment or fire influence configurations emerges during the fire hazard analysis as the safety equipment is identified and located and as the fire resistant qualities of the elements of construction are assessed. Hence, in the absence of specific knowledge in advance on the design, construction, maintenance and modification history of a particular nuclear power plant it is not possible to declare at the outset whether a fire containment or fire influence approach will be adopted. The extent to which either of these descriptions applies becomes evident during progress of the analysis.

For purposes of evaluation, the plant buildings must be systematically divided into separate areas, e.g. the physical areas defined by the fire rated barriers. These individual fire compartments are then evaluated sequentially. The fire resistance of individual load bearing building structures is also assessed. Where fire rated barriers are not provided or documentation is not available to verify the specific fire ratings of the existing plant barriers, large areas of the plant may have to be considered as a single fire compartment. In such a situation, the plant may be divided along suitable lines such as rooms, functional areas or areas with clearly defined spatial separations. Each fire cell within the larger fire compartment is then evaluated individually.

### 3.5. PROCESS

Preparation of the fire hazard analysis can be divided into six distinct steps that are implemented for each identified fire compartment or fire cell, as described in the following sections: data collection; analysis of fire growth; consequence analysis; evaluation of the adequacy of fire safety; considerations before making improvements in fire safety; and repetition of analysis.

## 4. DATA COLLECTION

### 4.1. INTRODUCTION

The first step in the preparation of a fire hazard analysis is to compile the necessary data. The process of data collection usually begins with a review of the available plant documentation, e.g. the equipment arrangement drawings, the design and construction drawings, the location of the fire rated barriers, the cable routing drawings, the ventilation system arrangement, the fire protection system documentation and other plant procedures. In all cases, this initial information is verified by visual inspection of each fire compartment and fire cell throughout the entire plant. This is essential in order to ensure that the data on which the fire hazard analysis is based represent the actual and current conditions at the plant.

This phase of the process will produce a significant amount of interrelated data. As a result, it may be useful to summarize the information in various tables and drawings, and even to enter the information in database format to facilitate organization, sorting and retrieval. Examples of sample schematic tables useful for organizing data collection and walkdown checks are provided in Annex I.

## 4.2. INVENTORY OF SAFETY SYSTEMS

The primary objectives of the fire hazard analysis are as described in Section 2.1 and include documentation that the general safety design requirements from para. 202 of Safety Guide No. 50-SG-D2 (Rev. 1) [1] can be met. These requirements are consistent with the general design requirements provided in Safety Series No. 50-C-D (Rev. 1), Code on the Safety of Nuclear Power Plants: Design [3]:

(1) Means shall be provided to shut down the reactor safely and to maintain it in the safe shutdown condition in operational states and during and after accident conditions;

(2) Means shall be provided to remove residual heat from the core after reactor shutdown, including accident conditions;

(3) Means shall be provided to reduce the potential for the release of radioactive materials and to ensure that any releases are below prescribed limits in operational states and below acceptable limits during accident conditions.

To achieve these objectives, a necessary first step is to identify the safety systems that are needed in the event of a fire, including the associated protection systems, the safety actuation systems and the safety system support features. This is often known as the 'essential' equipment for safe shutdown and residual heat removal. It is also necessary to identify those systems that are necessary to prevent a release of radioactive materials from, for example, the irradiated fuel handling and dismantling facilities, and the radioactive waste storerooms.

It is important to recognize that the equipment necessary to achieve safe shutdown and residual heat removal may not be as extensive as that required to maintain a reactor at power. Identification of this equipment at the outset will provide a focus for the fire hazard analysis, and can be expected to minimize the extent of the work.

However, the possibility that a fire could itself cause other initiating events or hazards (e.g. a loss of coolant accident) must be recognized in the fire hazard analysis, since this may increase the number of systems needed to achieve nuclear safety. The analysis should demonstrate that a fire will not cause such consequences. If this cannot be achieved, the additional equipment needed to protect against the initiating event or hazard must be included within the scope of the fire hazard analysis.

The systems needed to achieve safety include the reactor protection systems and the residual heat removal systems.

Reactor protection systems include components such as instrumentation for measuring temperature, pressure, neutron flux and coolant mass flow; reactor trip instrumentation and logic equipment; control rod actuation equipment; power supplies; and cabling.

Depending on the reactor type, equipment reconfiguration systems, which are designed to change parameters such as the primary and secondary coolant flow for safety reasons, may be necessary immediately after reactor shutdown. Where this is the case, the systems are included in the fire hazard analysis. This equipment may include instrumentation for measuring the temperature, pressure and coolant mass flow; reconfiguration logic equipment; power and control supplies; and cabling.

Residual heat removal systems may include primary coolant circulation pumps; secondary coolant pumps (e.g. steam generator or boiler feed pumps); residual heat removal pumps; emergency core cooling pumps; safety valves; heat exchangers; power and control supplies; and cabling.

Radiological containment systems, which are designed to prevent radiation exposure to personnel or the release of radioactive materials, may include radioactive waste storerooms and vaults; radiation shield doors and windows; radioactive waste processing plants and incinerators; laundries (for contaminated clothing); contaminated ventilation systems; and power supplies and associated cabling.

The fire hazard analysis also considers the necessary safety system support features and services, e.g. electrical supplies for power, control and instrumentation; cooling water; lubrication; compressed air; and heating, ventilation and air conditioning (HVAC).

Identification of the electrical systems that are required for safety reasons during and after a fire may be complex, because it is necessary to examine the whole of the electrical supply route from the safety system back to the source of supply. Sources of information include safety cases and modification registers; drawings; operating instructions; maintenance manuals; and handbooks. This will lead to the identification of distribution boards and subdistribution boards; switchboards; transformers; rectifiers and battery chargers; batteries; motor generators and uninterruptible power supplies; incoming grid based supplies; on-site supplies from diesel generators or gas turbines; and cable routes between all the above items and the safety system items.

Electrical supplies to the supporting services are also included within the scope of the fire hazard analysis.

The location and routing of electrical cables that serve safety systems and their components may be difficult to establish, but they are an essential part of the fire hazard analysis. Information on cable routing can be obtained from documented systems such as drawings, cable registers and databases, although this may not be available at older plants, or may be unreliable or out of date. In this case it may be necessary to trace some cables that are associated with safety systems.

Cable tracing can be done using a combination of plant data, visual inspection and signal injection techniques. This is a time consuming activity that needs care if errors are to be avoided, particularly where the cable densities are high. The tracing must be sufficiently detailed to establish whether or not the cables that serve the redundant safety systems are present in the same route. Where redundant cables are routed together, a high level of fire protection will be needed, together with compensating measures such as the provision of additional segregated cables or dedicated back-up systems. Where information is insufficient it will be necessary to assume that all the major cable routes (i.e. cable races, risers and spreading rooms) contain cables which serve the redundant safety systems.

In compiling an inventory of the systems needed to achieve safety it will be useful to group the supporting services together with the functions they serve, preferably in a tabulated format. This will assist in analysing the consequences of a fire (see Section 6).

With knowledge of the safety systems and their supporting services it may be possible to identify 'trains' of equipment, i.e. those groupings of equipment and supporting services that make up the redundant safety systems. Where the nuclear power plant has used segregation as a design criterion, trains of equipment may be physically separated in different fire compartments. This will greatly assist the fire hazard analysis.

Following identification of the items important to safety it is necessary to identify the interactions and interdependences between systems and the routing of support services, cabling, etc. Where segregation has not been adopted, allocating equipment to safety trains is a valuable concept, since the analysis will identify those locations where redundant trains are present in the same fire compartment (see Section 6). However, it may be difficult to allocate the individual items of supporting equipment to separate trains where this arrangement was not part of the original design intent. For example, a cooling system may be a common service to a number of safety system items, making it impossible to allocate any single cooling pump to any one item. In electrical systems, the cross-links and multiple feeders at several voltage levels will have the same effect of making allocation of switchgear, distribution boards, etc. to trains either difficult or impractical. Under these circumstances, knowledge of the interaction between plant items becomes essential for analysing the effects of a fire on the safety systems.

## 4.3. INVENTORY OF FIRE COMPARTMENTS

For the purpose of providing a systematic method for evaluation, the plant is divided into a number of distinct fire compartments defined by fire rated boundaries. In some cases it may be necessary to further subdivide these compartments into various fire cells. These distinct compartments and cells are then evaluated individually. The inventory for each fire compartment should include the following information:

(1) The materials of construction and the construction details of the bounding walls, floor, ceiling and other structural elements;
(2) The physical dimensions, layout, arrangement, and compartment geometry and configuration, together with special features such as open equipment hatches;
(3) The interior finish materials, including the wall and floor covering materials;
(4) Details of the ventilation and exhaust system, including the ductwork, fans, automatic interlock arrangements, means of isolation, and interconnections with other fire compartments or adjacent areas;
(5) The drainage system arrangements, including the inlets, interconnections with other fire compartments or areas, and any arrangements for the containment of liquid spills;
(6) A description of the plant equipment within the compartment, together with its location, whether determined to be important to safety or not.

## 4.4. INVENTORY OF COMBUSTIBLE MATERIALS

It is essential that a detailed list be drawn up of all the combustible materials present in each fire compartment; this usually includes solid, liquid and gaseous materials. The inventory should address fixed (permanent) combustible materials, as well as combustibles that may be of a transient (non-permanent) nature such as those associated with routine maintenance activities. For all the materials identified, the information collected should include the quantity, the location, the configuration, the geometry and orientation, the containment, the type of container and the pressure (as applicable).

The inventory includes:

(1) The combustible materials of construction, including the facings of floors, walls and ceilings;
(2) Interior furnishings such as desks, tables, upholstered chairs, paper records and drawing files;
(3) All the machinery and equipment that contain combustibles, including oil filled equipment such as transformers, circuit breakers and motor operated valves;

(4) All the flammable and combustible liquids present, e.g. paint, solvents, hydraulic fluids and oil;
(5) Materials of temporary use such as wood scaffolding, health physics protective clothing, plastic sheeting and combustible packaging materials;
(6) Charcoal filters and high efficiency particulate absorbers;
(7) Insulating materials such as pipe lagging and ventilation duct insulation;
(8) All the electrical cabling that is sheathed in combustible insulation, including the cable type, the cable tray fill density, the fire resistant standard, the orientation of the cables, and the specifics of the cable insulation material;
(9) The flammable gases and oxidizing agents that record the type, quantity, use, containment vessel and pressure;
(10) The combustible materials (e.g. bitumen, styrene or epoxy) used to encapsulate radioactive waste, ion exchange resins, etc.

Where a fire compartment has an outside wall, the potential fire or explosion hazards outside the compartment that could breach the wall will have to be identified.

The chemical and physical properties of all the combustible materials identified in the inventory should be established and quantified, including the stability, reactivity, toxicity, flammability, ease of ignition, radiological potential, and potential for environmental effects.

## 4.5. INVENTORY OF POTENTIAL IGNITION SOURCES

An essential element of the fire hazard analysis is a complete list of the potential ignition sources in each fire compartment. Those from fixed equipment or systems should be identified. In addition, it should be assumed that transient (non-permanent) ignition sources are also possible. The inventory of potential ignition sources includes:

(1) Fixed equipment which, under normal operational conditions, has, or is capable of providing, an ignition source such as open flames, sparks, static electricity and hot surfaces;
(2) Equipment failure which, under abnormal operating conditions, may result in sudden high energy release, failure of safety interlocks, excessive frictional heat, electric arcs or spontaneous combustion;
(3) Construction, maintenance or modification activities such as torch cutting, welding, heat treating or other use of heat and flame sources;
(4) Cigarettes and other smoking materials;
(5) Lightning.

## 4.6. PASSIVE FIRE PROTECTION MEASURES

The fire hazard analysis includes a comprehensive description of the passive fire protection measures applied in each fire compartment. For each passive measure, the information collected needs to identify the fire resistance rating of the barrier, the fire resistance test standard with which the fire barrier complies, and documentation that the openings in the fire rated barriers are protected by the elements and materials that are designed, tested and installed to provide a fire resistance rating suitable for use in the barrier (e.g. fire rated doors and dampers). It is recognized that certain elements of civil construction such as brick and concrete may not have a formal fire resistance rating established by testing. In such cases, the fire resistance may be derived from data available in the literature (e.g. tables published in building regulations, insurers' requirements or fire safety handbooks).

The inventory of passive fire protection measures includes:

(1) Clearly defined spatial separations (between the fire cells when the fire influence approach is considered);
(2) Fire rated barriers, including the floors, walls and ceilings;
(3) Fire barrier closures, including the fire rated doors, fire rated dampers and fire rated seals for the mechanical and electrical penetrations of the barriers;
(4) Locally applied separating elements, including the fire rated cable wraps, fire resistant coatings and thermal radiant energy shields;
(5) Fire cabinets and other enclosures.

A description of the system used to identify those fire barriers or designated spatial boundaries that are important to nuclear safety will ensure that these features are readily apparent to all the engineering, operations and maintenance personnel.

## 4.7. FIRE DETECTION SYSTEMS

The fire hazard analysis includes a description of the fire detection systems installed within each fire compartment. The inventory should cover:

(1) The design basis for each detection system, including identification of standards and codes, area specific design criteria, and documentation that the system has been approved by an independent testing authority or other third party certification; where such documentation is not available or is incomplete, retrospective verification of the adequacy of the system design is necessary;
(2) The type and location of the manual fire alarm systems;

(3) The type and location of the automatic fire detection systems, their mode of operation and the alarms they raise;
(4) Interfaces with the automatic fire extinguishing systems, smoke control and ventilation systems.

## 4.8. FIXED FIRE EXTINGUISHING SYSTEMS

The fire hazard analysis includes a description of the fixed fire extinguishing systems installed in each fire compartment. The inventory covers:

(1) The design basis for each extinguishing system, including identification of standards and codes, area specific design criteria, and documentation that the system has been approved by an independent testing authority or third party certification; where documentation is not available or is incomplete, retrospective verification of the adequacy of system design is necessary;
(2) The water supply system (where relevant), including identification of the water source, quantity, flow rate and pressure at which it is available;
(3) The fixed water based fire extinguishing systems (e.g. the type of system, area of coverage, design density, and manual or automatic actuation); a comparison of the water discharge rate and the available drainage has to be made;
(4) Other fixed fire extinguishing systems, e.g. gas, foam and dry powder, including aspects such as the type of system, area/volume of coverage, design concentration, and manual or automatic actuation;
(5) The explosion suppression systems, where installed.

## 4.9. EMERGENCY LIGHTING

The fire hazard analysis includes a description of the emergency lighting system.

## 4.10. COMMUNICATION SYSTEMS

The fire hazard analysis includes a detailed description of the fixed and mobile communication systems and equipment, e.g. radios and telephones.

## 4.11. MANUAL FIRE FIGHTING ARRANGEMENTS

The fire hazard analysis provides a detailed description of the manual fire fighting arrangements for the site. The inventory of such arrangements includes:

(1) The access routes to each fire compartment, and their general accessibility for manual fire fighting operations;
(2) The water supply, hydrants and rising mains (including their number, location and type) provided for use by fire fighting personnel;
(3) The detailed prefire fire fighting strategies developed for each fire compartment for use by fire fighting personnel[4];
(4) The manual fire fighting capability of the plant (both on-site and off-site response), including the personnel, equipment, training and effective response time;
(5) The portable fire extinguishers provided, including their type, size, quantity and location.

# 5. ANALYSIS OF FIRE GROWTH

## 5.1. INTRODUCTION

To evaluate the consequences of a fire at the plant, the physical effects of fires and the response/behaviour of the equipment have to be investigated. To achieve this it is necessary to study the mechanism of fire ignition and the fire growth rate. This section deals with various aspects that influence fire growth: the fire scenarios; the type and nature of the fire; the heat transfer and fire dynamics, including the ventilation aspects; the physical and chemical properties (related to fire/explosion) and the composition of those materials that may be involved in the fire; the applicable methods; the integrity limits and damage threshold values for those structures, systems and components whose failure may influence the growth of the fire, and the associated separating elements and fire barriers; the operation and/or malfunction of the extinguishing systems; and other aspects, as appropriate.

With respect to the above items, additional details on preparing the basic information needed to assess the fire growth are provided in Sections 5.2 to 5.4.

## 5.2. PHYSICAL AND CHEMICAL PROPERTIES OF THE COMBUSTIBLE MATERIALS

Depending on the approach used to quantify fire growth, different levels of detail of specific combustion data may be necessary. For example, in using simple fire growth methods, fire related physical and chemical properties may be sufficient.

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[4] Additional guidance on the form and content of the prefire fire fighting strategies is provided in Annex II.

However, when using more complex methods of analysis, additional data may be needed such as heat transfer and fluid flow (see Section 6.2). In addition, the information already collated in the data collection phase of the analysis (see Section 4) can be utilized.

### 5.2.1. Values for combustion

The values for combustion include:

(1) The combustion heat (calorific value).

(2) The mass burning rate, its dependence on the oxygen content and the rate of heat release. This aspect should take into account different combustion behaviour on the basis of its geometry, location, orientation and arrangement (e.g. fire propagation along vertical cable installations is much faster than that along horizontal installations), and the influence of the oxygen concentration on the combustion process. For the analysis of fire consequences (Section 6), or at least for the calculation of postulated fires, this aspect may become essential.

### 5.2.2. Limiting values for those parameters that influence the fire effects

The important parameters related to fire growth that may influence the functioning of systems, components and equipment include:

(1) The ignition point of the combustibles. This value is essential for predicting the spread of a fire from the place of ignition to other combustible areas located in the same room.

(2) The physical parameters (e.g. the temperature, pressure and humidity) that determine the point at which safety related components and equipment will be damaged (e.g. electronic devices, cables, valves, motors and measurement devices). The damage threshold values may be obtained from fire testing or manufacturers' data. For cases where the equipment damage threshold values are not known, engineering judgement should be used to supplement whatever data are available. The rationale for such judgement should be documented as part of the fire hazard analysis.

(3) The temperatures at which combustible containers (e.g. oil tanks) could fail. Other fixed combustible sources such as the combustible liquids associated with pumps, not normally considered to be exposed combustibles, should be assumed to be exposed as a result of a leak or a small line break. A conservative spill size appropriate for the amount of combustible liquid in the equipment should be determined.

### 5.2.3. Other aspects

Other aspects include:

(1) Production of combustible gases (e.g. new charcoal for filters);
(2) Behaviour of a specific, special type if the combustible comes into contact with extinguishing agents (e.g. boiling over of bitumen if extinguished with a water spray);
(3) Production of fire by-products that could jeopardize the integrity of systems, components and equipment either immediately or after a time delay (e.g. the corrosive effect of hydrochloric acid produced by the combustion of polyvinyl chloride).

## 5.3. PHYSICAL CHARACTERISTICS OF THE FIRE COMPARTMENTS

To determine fire growth inside the fire compartments and the possibility of a fire spreading to other such compartments, the physical characteristics of the following items are needed: the surrounding floors, walls and ceilings[5]; the inner floors, walls and ceilings; and other heat sinks inside the compartments, e.g. steel gratings, masonry walls, pipes, insulations or steel supports.

Individual identification typically includes the following characteristics: the composition/layers of the individual floors, walls and ceilings, or other elements; the heat capacity, absorptivity and heat transfer of the surrounding and inner floors, walls and ceilings, and other heat sinks; the fire resistance (in minutes) of all the boundary floors, walls and ceilings of the fire compartments, including the relevant standards of construction; the fire resistance of all the structural elements, including the relevant standards of construction; and the fire rated doors, dampers and penetration seals.

## 5.4. POSTULATED FIRE FOR EACH FIRE COMPARTMENT

### 5.4.1. General

The fire to be postulated for each fire compartment is the so called design fire. It is defined as the fire that will have the most significant consequences.

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[5] For the surrounding floors, walls and ceilings it is presupposed that all penetrations (e.g. cables, pipes, ventilation) are properly protected. The penetrations are verified as elements of passive protection measures (Section 4.6). On this basis, and taking into account that the percentage of such penetration is negligible, they need not be considered within the framework of this section.

As defined in Safety Guide 50-SG-D2 (Rev. 1), a fire compartment can comprise one or more rooms or spaces. For this reason, for a specific hazard analysis it may often not be sufficient to refer to the average fire hazard and fire consequences of the compartment. Besides analysis of a global fire in the compartment it is necessary to investigate inside those compartment rooms and spaces that contain considerably higher local fire loads (e.g. the oil tank area in the turbine hall). Such specific areas of high fire hazard potential may need additional measures; these would not be necessary if the analysis were to focus only on the global compartment.

To evaluate specific fire hazards it is useful to quantify the relative hazards by preparing a fire load density list, where the fire loading is expressed in terms of megajoules per unit area. Practices differ between countries on this point; in some cases the floor area is used, while others may use the combined surface area of the floor, walls and ceiling. The fire load density is calculated for each individual room and fire compartment or fire cell.

### 5.4.2. Identification of the boundary conditions

To define a specific fire, all the boundary conditions that may occur in a fire cell or fire compartment need clear identification, e.g.:

(1) The specific protection measures of the fire loads, and their consequences for the design fire (e.g. cable coating);
(2) The maximum possible fire, which is not based on the existing fire load but is dependent on the air intake (ventilation controlled fire);
(3) The maximum oil leakages, taking into account, for example, the drainage systems;
(4) The position of the doors and fire dampers (whether they are normally closed or are closed automatically);
(5) The failures in the passive/active fire protection systems;
(6) The actuation sequence of the active system (time from ignition to detection and detection to actuation, and whether actuation is manual or automatic);
(7) The ignition and spread of fire inside the compartment;
(8) The combination of fires with other events;
(9) The behaviour of burndown aspects, e.g. flame propagation, oxygen influence and mass burning rate;
(10) The separation distances between the fire cells within the fire compartments.

### 5.4.3. Heat, smoke and corrosive effects

As a consequence of a postulated fire, a large amount of smoke is produced that will result in poor visibility, affecting, for example, the manual fire fighting efforts (as part of the fire influence approach), and that can cause both short and long term corrosive effects. In addition, depending on the mass burning rate and the local conditions, the local temperature and the temperature of the connected locations will rise.

Within the fire hazard analysis, the possibilities of smoke propagation to other fire compartments, and its consequences on the accessibility of staircases and emergency routes, as well as a reduction in visibility in other areas, should be investigated and analysed.

For example, an unacceptable consequence is the spreading of smoke to areas such as the main or emergency control room and the local control units, and their necessary access routes where, in the event of a fire, personnel must be present to undertake local safety actions.

### 5.4.4. Fire growth rate

The information received as part of the data collection (see especially Sections 4.2 to 4.5) and from the physical and chemical properties (see Section 5.2) provides the input for quantifying fire growth.

To be able to verify the adequacy of the fire barriers or other separation elements such as the boundaries between the fire compartments or fire cells, the expected fire growth should be defined for each compartment and cell.

Depending on the fire hazard and the existing room configuration, one of the following methods can be applied for quantifying the fire growth rate (these methods are discussed in detail in Section 6.3): conservative subjective evaluation by engineering judgement, hand calculations and computer modelling.

### 5.4.5. Effects of ventilation

It is essential that heat, smoke and the decomposition products from the fire do not have unacceptable effects on other compartments (e.g. on the filters). Smoke and heat spread mainly via ventilation systems or by natural ventilation, supported by the thermal buoyancy of the fire gases. Particular consideration is needed with respect to the ventilation inside compartments, and to the consequences for other compartments.[6] Ventilation has to be considered on the basis of its influence on the fire growth rate. Also, the radiological requirements may create a conflict with those ventilation aspects that are related to fire safety.

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[6] Additional guidance on the evaluation of ventilation effects, where the ventilation system serves more than one fire compartment, is provided in Annex III.

# 6. CONSEQUENCE ANALYSIS

## 6.1. OBJECTIVE

The fire hazard analysis has now reached the point where:

(1) The safety systems have been identified (Section 4.2);
(2) The locations of the safety systems have been identified, the fire hazards and ignition sources catalogued, and the fire protection features of each fire compartment established (Sections 4.3 to 4.11);
(3) The growth of fire in each compartment has been estimated, mainly on the basis of the combustible materials present and the physical characteristics of each compartment (Section 5).

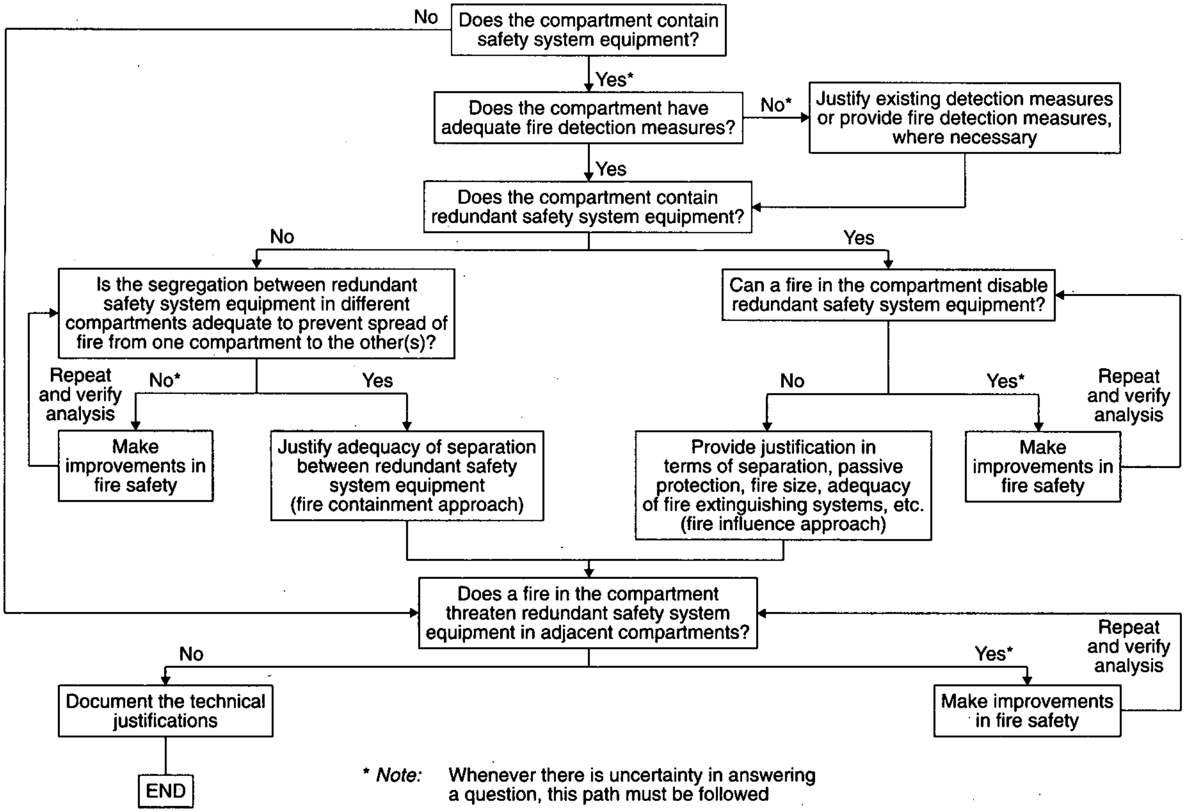
The next step in the process is analysis of the consequences of the fire. The objective is to ensure, for each compartment, that the fire will not threaten the ability to achieve safe shutdown and residual heat removal by simultaneously disabling redundant equipment which is part of the safety system.

## 6.2. DETERMINATION OF THE ADEQUACY OF FIRE PROTECTION

An outline of the principal stages of the consequence analysis process is given in Fig. 1, which illustrates the points that must be addressed in assessing the effects of a fire on the safety systems and associated supporting equipment. The important features of the process are:

(1) All compartments that contain safety system equipment should be provided with a fire detection system , to give early warning of a fire;
(2) Compartments that do not contain redundant safety system equipment are usually justified in terms of their passive fire protection;
(3) Compartments that contain redundant safety system equipment are usually justified in terms of the local passive protection of the fire cells within the compartment, together with separation by distance or the presence of fire extinguishing systems;
(4) The potential spread of a fire from other areas into those compartments that contain redundant safety system equipment needs to be considered in the analysis.

It is important that the conclusions reached for each fire compartment are justified and documented. The conclusions may address the following aspects:



* *Note:* Whenever there is uncertainty in answering a question, this path must be followed

*FIG. 1. Assessment of the fire consequences for a fire compartment.*

(a) The adequacy of the passive fire protection measures, including the adequacy of the fire rated seals for penetrations through walls, floors and ceilings;

(b) The adequacy of the existing plant layout to minimize the fire consequences in adjacent compartments (e.g. subjecting sensitive equipment to excessive temperatures should be avoided);

(c) The adequacy of the fire detection and fixed fire extinguishing systems; deviations from the accepted national standards should be justified at the technical level;

(d) The decision on whether or not to improve fire protection, which should address the options considered, the reasons why the proposed modifications are sufficient to ensure safety, or why it is not necessary or reasonably practicable to implement modifications, as appropriate.

Justification may be made on a qualitative or quantitative basis, but the latter is preferable, where possible.

## 6.3. DETERMINATION OF THE EFFECTS OF A FIRE

Three methods can be used to justify the judgements made in the consequence analysis. The methods are conservative subjective evaluation by engineering judgement, hand calculations and computer modelling. These may be used alone or in combination, depending on the circumstances and the complexity of the compartment.[7] Examples of qualitative and quantitative approaches are described below for passive protection and redundant safety system equipment in the same fire compartment.

(1) In the case of passive fire protection, the objective is to justify the ability of the fire barriers to prevent a fire spreading between redundant safety system equipment. This can be achieved qualitatively by comparing the estimated fire severity and duration in a compartment with the known fire resistance properties of the compartment construction obtained from national standards, the literature, or the relevant fire testing data. Quantitative comparisons can be made by assessing the compartment fire effects against the boundary fire resistance.

(2) The common vulnerability of redundant safety system equipment located in a single fire compartment requires assessment of the consequences of the postulated fire. In cases where the potential for fire growth is low and where there are

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[7] For more detailed guidance on the calculation of fire effects, see the specialized publications listed in the Bibliography.

safe horizontal separation distances without fire load it may be possible to show that the fire is not able to cause damage which would disable redundant safety system equipment. Conversely, where the potential for fire growth is high and/or the horizontal separation distances are not sufficient, damage to all equipment in the compartment is assumed. Conditions between these extremes are more difficult to analyse, and cannot be judged qualitatively with confidence. Under these circumstances, two possible approaches exist:

(a) *Assume that the fire disables all the equipment in the compartment:* This has the advantage of simplicity, but may be too conservative;

(b) *Quantify the effects of the fire by calculation:* Correctly applied, this has the advantage of avoiding excessive conservatism, but the assumptions used should be conservative.

### 6.3.1. Conservative subjective evaluation by engineering judgement

Conservative subjective evaluation is essentially a qualitative process that relies on the application of practical experience and engineering judgement to decide whether the existing fire protection measures (both passive and active) are sufficient to achieve nuclear safety. This type of evaluation could be supported by comparisons with experimental verification; a listing of the equipment within a fire compartment, and its physical separation, where applicable; identification of the separation distances deemed adequate between redundant safety system equipment within a fire compartment; identification of the potential fire growth in the compartment; and a discussion on how the relevant aspects (e.g. fire load, equipment separation and fire protection systems) have been evaluated in judging the adequacy of the elements of the fire compartment.

### 6.3.2. Hand calculations

Hand calculations may be applied to determine the fire duration, the smoke layer depth, radiant heating, etc. by using formulas, graphs, tables or empirical correlations that are generally accepted, e.g. published in the literature. Where this approach is used, it is necessary: (1) to identify the calculation methods used for confirmation of the fire rating of the boundaries of each fire compartment, and to confirm that verification of these calculation methods has been performed; and (2) to identify the fire load/fire resistance graphs/tables used for determining the necessary fire resistance of fire compartment boundaries, and to confirm whether they distinguish between the different types of combustible material (e.g. oil or cables) and also whether they accurately reflect the air exchange/ventilation rate of the fire compartment.

### 6.3.3. Computer modelling

Computer fire modelling has reached the stage where it can be regarded as a fire protection engineering design tool. Practical experience has shown that relatively simple single room models can play a significant role in fire safety design and assessment, particularly for determining the peak temperatures, the maximum rates of temperature rise and the actuation times for fire detection and extinguishing systems. Models may also be useful in situations involving the reactor building containment where the design would otherwise have to rely on engineering judgement or refer to traditional practices. However, use of sophisticated models to predict the growth rate and the spread of a fire should generally be treated with caution because of the uncertainties inherent in the input data required for use of these models.

Computer modelling used to support fire hazard analysis in nuclear power plants usually takes into consideration the significant physical parameters that influence the development of a fire and the distribution of fire products. It is essential that calculations describe both the direct and indirect effects of the fire on the inventory in the vicinity of the fire, as well as the effects of the fire on safety system equipment in areas that are distant from the fire.

The following aspects should be addressed in applying computer models[8]:

(1) Verification that a description of the computer code used is available which presents the main input data, the output data, the model assumptions and the relevant data as described in the databases, and that these parameters are acceptable; it is important that the limitations of the model are known and recognized;

(2) Verification that validation studies or comparisons with experimental data are available and acceptable;

(3) Verification that the computer models include sufficiently detailed parameter studies on the mass burning rate, which is the most important value for calculations but at the same time the most difficult value to obtain;

(4) Verification that sufficient calculations have been made to show the extent to which the results are dependent on the choice of input data.

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[8] It is essential that the computer models are not applied as 'black boxes', and that the analysts using these models have specific knowledge and experience on the subject.

## 6.4. DIRECT, INDIRECT AND SECONDARY EFFECTS OF A FIRE

In the fire hazard analysis, fire is assessed as a single independent hazard in order to determine its effect on the ability to achieve reactor shutdown, to provide for residual heat removal and to contain radioactive materials. It is assumed that such a hazard does not occur simultaneously with other hazards or initiating events. It should also be recognized that the fire may have unintentional/undesirable effects on other plant systems, and that these may be of safety significance and possibly not obvious. For example, the operation of a fire extinguishing system will involve the release of an extinguishing agent such as water, gas, foam or powder to the local environment. Although necessary to extinguish the fire, these releases may themselves have side effects, which need to be taken into account.

The relationship between these effects is presented in Annex IV, which illustrates that both fires and the systems installed to protect against fires are capable of causing plant damage or of being a hazard to personnel. This highlights the need to avoid the spurious operation of fire protection systems which, in addition to the possibility of causing damage, reduces the confidence of plant operators in the systems and causes unnecessary expenditure on resetting and cleanup.

### 6.4.1. Secondary effects of a fire

In a fire compartment or fire cell that contains safety equipment of a given train, together with a train of another piece of redundant equipment that belongs to a different safety system, it may appear that a fire would not adversely affect a safety function. However, a secondary effect may result in the loss of redundant equipment. Some examples are:

(1) The loss of a redundant safety device in another compartment, caused by damage to cabling that is directly involved in the fire (see Annex V);

(2) The closing of fire dampers or ventilation shutdown in an area involved in a fire could result in excessive heat buildup elsewhere, resulting in the loss of redundant safety functions;

(3) The fire detectors in an area outside the fire compartment may be actuated by smoke, resulting in automatic actuation of the fire extinguishing systems or other fire protection measures that affect the redundant safety devices.

### 6.4.2. Secondary effects of a fixed fire extinguishing system

Some examples of the undesirable effects that could result from the installation and actuation of a fixed fire extinguising system are:

(1) Actuation of a water spray or sprinkler system could result in water damage to electrical control cubicles elsewhere in the fire compartment, leading to failure of a redundant safety system;

(2) Accumulation of gases that are heavier than air, e.g. $CO_2$, in the lower levels of a building may present a life hazard to personnel;

(3) Deposition of dry powder extinguishing media may cause delayed corrosion or other damage to electrical equipment.

These effects, which are not anticipated in the design and have occasionally occurred in the past, need to be considered in the fire hazard analysis.

## 6.5. OTHER EFFECTS OF A FIRE OUTSIDE THE FIRE COMPARTMENT

If it is not possible to make an acceptable case against a fire causing loss of containment, the safety system inventory will have to be extended to include additional systems that guard against such an event, and the fire hazard analysis revised accordingly. A complete analysis of the consequences of a fire may not be possible if the original safety system list is not complete. The equipment most likely to be involved is the cabling between equipment items, since precise identification of the cable routes is known to be difficult. An example of this is given in Annex VI for a compartment that contains cabling to two different safety systems which are not functionally redundant but where the effects of a fire could result in the failure of functionally redundant equipment. This re-emphasizes the need to begin the fire hazard analysis with the fullest possible information on the safety systems and the interconnections between equipment (e.g. cabling), and their interactions with supporting services (cooling, lubrication, etc.).

A further consequence of fires and operation of the fire extinguishing systems is the possibility that they may initiate other events which threaten nuclear safety or result in other hazards; this possibility should be recognized in the fire hazard analysis. A particular example is the potential for a fire to cause a breach in the reactor primary containment. Equipment vulnerable to this event should be included in the inventory of safety systems (Section 4.2) and be explicitly considered in the consequence analysis. This is necessary because loss of containment (a loss of coolant accident in a PWR or primary circuit depressurization in a GCR) would make demands on additional systems and equipment that are not needed to achieve safety against a fire alone.

# 7. EVALUATION OF THE ADEQUACY OF FIRE SAFETY

When the consequences of the postulated fire in a given compartment have been analysed, the next step is to evaluate the adequacy of the fire safety measures and systems for that compartment. This evaluation is shown in Fig. 1 in the form of questions on the spread of the fire between redundant safety system equipment.

The adequacy of fire protection to ensure plant nuclear safety is assessed taking into account the relevant factors of the analysis presented in earlier sections: the fire resistance of the load bearing building structures and fire barriers; the location of the redundant safety system equipment; the type and quantity of the combustible materials present; the ignition sources; the fire growth and spread; the presence of fire detection measures; and the fixed fire extinguishing systems (manual/automatic) and manual fire fighting equipment, and their applicability to the postulated fire.

The outcome of this evaluation process is a reasoned judgement as to whether the existing fire safety measures and systems are acceptable. It is important that such judgement is technically justified and documented. This approach allows independent assessors of the work, e.g. regulatory bodies, to understand how the judgement was reached and promotes confidence that a logical and thorough approach was used throughout the analysis.

# 8. CONSIDERATIONS BEFORE MAKING IMPROVEMENTS IN FIRE SAFETY

If the outcome of the fire analysis for a compartment is unfavourable, it is necessary to consider how the fire safety of the nuclear safety systems can be improved. In many cases, this will lead to recommendations for the upgrading of the fire barriers, the fire detection measures and the fixed fire extinguishing systems. However, in other cases, hardware improvements alone may not be able to achieve the required degree of fire safety. Before recommending hardware improvements, the following aspects have to be taken into consideration:

(1) Are there other plant systems, not so far included in the fire hazard analysis, that are capable of achieving the safety functions threatened by a fire in the compartment? If so, inclusion of these systems in the fire hazard analysis may remove the need to improve fire protection by demonstrating that the required safety function can be achieved by other means. However, this approach may prolong the fire hazard analysis process.

(2) It is appropriate to install new, independent safety systems located elsewhere that will not be affected by a fire in the compartment under consideration? In

some compartments it may be very difficult to specify those improvements in fire protection hardware that will achieve the necessary level of safety. This is particularly relevant to the cable routes, where the precise location and relative spacing of important cables may not be known. Given these circumstances it may be more effective to install additional independent safety system equipment that is capable of full service use, or to improve fire protection to a practicable level and install backup equipment that is only intended for infrequent use in the event of the main system failing because of a fire.

In developing specific recommendations for improving fire safety it is important to take the circumstances of the fire compartment, and the equipment within it, into consideration:

(a) Will the proposed system be reliable, in terms of both spurious operation and failure to operate on demand?
(b) Will discharge of the fire extinguishing system cause damage if it operates spuriously?
(c) Is there sufficient drainage to deal with the water discharged from the sprinkler/spray systems?
(d) Is the floor adequately sealed to prevent moisture penetration to the rooms below?
(e) Are interfaces with the HVAC systems required?
(f) Will the fire protection improvements, especially new fire barriers, hinder access for maintenance?
(g) Will it be possible or practical to maintain the fire protection systems themselves?

Failure to take such matters into account can lead to a degradation in nuclear safety, installation difficulties, time delays and additional costs.

## 9. REPETITION OF ANALYSIS

When those improvements in fire safety that are necessary to resolve deficiencies have been identified, they are fed back into the analysis (iterative process) in order to document that the effects of the fire in the compartment concerned will be acceptable when the improvements are taken into consideration. This applies to all types of improvement: reduction in combustible load; inclusion of additional existing plant systems in the analysis; installation of new safety systems; and installation of fire protection measures (passive or active).

The impact on fire safety of future modifications to the plant is assessed by repeating the fire hazard analysis for the compartments concerned and by making further improvements in fire safety, as necessary.

## Annex I

## SAMPLE DATA COLLECTION TABLES

This Annex provides schematic examples of the tables that may be useful in organizing and summarizing data for preparing a fire hazard analysis.

Tables I–1 to I–15 contain material extracted from guidelines developed by the United States Department of Energy [4]. Table I–16 is taken from Safety Guide 50-SG-D2 (Rev. 1) [1]. Table I–17 was compiled by H. Bittner of Siemens AG, Germany.

TABLE I–1. FIRE COMPARTMENT AND FIRE CELL DATA

Fire compartment: ..................................................

Fire cell: ..................................................

Reference drawing: ..................................................

Building: ..................................................

Elevation:

TABLE I–2. CONSTRUCTION BOUNDARIES

| Boundary | Fire barrier | | Fire barrier rating (min) | Construction material | Approximate thickness (cm) | Covering | Verified (as built) |
|---|---|---|---|---|---|---|---|
| | Yes | No | | | | | |
| Wall 1 | | | | | | | |
| Wall 2 | | | | | | | |
| Wall 3 | | | | | | | |
| Wall 4 | | | | | | | |
| Wall 5 | | | | | | | |
| Wall 6 | | | | | | | |
| Wall 7 | | | | | | | |
| Wall 8 | | | | | | | |
| Ceiling | | | | | | | |
| Floor | | | | | | | |

COMMENTS:

TABLE I–3. MAJOR EQUIPMENT AND COMPONENTS

*(a) Safe shutdown related*

Compartment No. ____________

Cell No. ____________

| Item | Equipment No. | Equipment title | Equipment type |
|---|---|---|---|
| 1. | | | |
| 2. | | | |
| 3. | | | |
| 4. | | | |
| 5. | | | |
| 6. | | | |
| 7. | | | |
| 8. | | | |
| 9. | | | |
| 10. | | | |
| 11. | | | |
| 12. | | | |
| 13. | | | |
| 14. | | | |
| 15. | | | |
| 16. | | | |
| 17. | | | |
| 18. | | | |
| 19. | | | |
| 20. | | | |

COMMENTS:

TABLE I–3. (cont.)

*(b) Non-shutdown related (large or significant equipment and components)*

Compartment No. ____________
Cell No. ____________

| Item | Equipment No. | Equipment title | Equipment type |
|---|---|---|---|
| 1. | | | |
| 2. | | | |
| 3. | | | |
| 4. | | | |
| 5. | | | |
| 6. | | | |
| 7. | | | |
| 8. | | | |
| 9. | | | |
| 10. | | | |
| 11. | | | |
| 12. | | | |
| 13. | | | |
| 14. | | | |
| 15. | | | |
| 16. | | | |
| 17. | | | |
| 18. | | | |
| 19. | | | |
| 20. | | | |

COMMENTS:

## TABLE I–4. DOORS

Compartment No. ____________
Cell No. ____________

| Door No. | Reference drawing | Fire door |  | Rating (min) | Material type | Door closer |  | Conditions (A/M/U) | Fit (A/M/U) | Position (O/BO/C/LC) | Operation (A/M/U) |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Yes | No |  |  | Yes | No |  |  |  |  |
| 1. |  |  |  |  |  |  |  |  |  |  |  |
| 2. |  |  |  |  |  |  |  |  |  |  |  |
| 3. |  |  |  |  |  |  |  |  |  |  |  |
| 4. |  |  |  |  |  |  |  |  |  |  |  |
| 5. |  |  |  |  |  |  |  |  |  |  |  |
| 6. |  |  |  |  |  |  |  |  |  |  |  |
| 7. |  |  |  |  |  |  |  |  |  |  |  |
| 8. |  |  |  |  |  |  |  |  |  |  |  |

COMMENTS:

*Note*: A = acceptable; M = marginal; U = unacceptable; O = open; BO = blocked, open; C = closed; and LC = locked, closed.

## TABLE I–5. PENETRATIONS

### *(a) Walls*

Compartment No. ______________
Cell No. ______________

| Location (wall No.) | Fire barrier | | Rating (min) | Penetration No. | Penetration type (see *Note 1*) | Approximate penetration size (cm × cm) | Seal material | Condition (A/M/U) (see *Note 2*) | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | Yes | No | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

COMMENTS:

*Note 1*: Enter type, e.g cable, cable tray, conduit and duct.
*Note 2*: A = acceptable; M = marginal; and U = unacceptable.

TABLE I–5. (cont.)

*(b) Ceilings*

Compartment No. ____________

Cell No. ____________

| Location (ceiling No.) | Fire barrier | | Rating (min) | Penetration No. | Penetration type (see *Note 1*) | Approximate penetration size (cm × cm) | Seal material | Condition (A/M/U) (see *Note 2*) | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | Yes | No | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

COMMENTS:

*Note 1*: Enter type, e.g cable, cable tray, conduit and duct.

*Note 2*: A = acceptable; M = marginal; and U = unacceptable.

TABLE I–5. (cont.)

*(c) Floors*

Compartment No. ____________

Cell No. ____________

| Location (floor No.) | Fire barrier | | Rating (min) | Penetration No. | Penetration type (see *Note 1*) | Approximate penetration size (cm × cm) | Seal material | Condition (A/M/U) (see *Note 2*) | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | Yes | No | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

COMMENTS:

*Note 1*: Enter type, e.g cable, cable tray, conduit and duct.

*Note 2*: A = acceptable; M = marginal; and U = unacceptable.

## TABLE I–6. STRUCTURAL MATERIALS

Compartment No. ____________
Cell No. ____________

| Item | Type | Exposed | | Fireproofing | | Comments |
|---|---|---|---|---|---|---|
| | | Yes | No | Yes | No | |
| Beams | Steel | | | | | |
| | Other | | | | | |
| Columns | Steel | | | | | |
| | Other | | | | | |

COMMENTS:

## TABLE I–7. COMBUSTIBLE MATERIALS

| Type | Fixed quantity | Transient quantity |
|---|---|---|
| Cable insulation | | |
| Lubrication oil (or lubricant) | | |
| Wood | | |
| Plastic | | |
| Plastic floor covering | | |
| Paper | | |
| Grease | | |
| Gases (list) | | |
| Other | | |

COMMENTS:

## TABLE I–8. FIRE SUPPRESSION SYSTEMS

Compartment No. ____________
Cell No. ____________

| Fire suppression | | | Type of fixture (see *Note 1*) | Location (reference drawing No.) | Condition (A/M/U) (see *Note 2*) |
|---|---|---|---|---|---|
| Type | Yes | No | | | |
| Sprinkler | | | | | |
| Deluge | | | | | |
| Halon | | | | | |
| $CO_2$ | | | | | |
| Other | | | | | |

COMMENTS:

*Note 1:* Enter type, e.g. closed head (fusible link) sprinkler, open head sprinkler and nozzle.
*Note 2:* A = acceptable; M = marginal; and U = unacceptable.

## TABLE I–9. FIRE DETECTION SYSTEMS

| Fire detection | | | No. of detectors | Location (reference drawing No.) | Condition (A/M/U) | Alarm | |
|---|---|---|---|---|---|---|---|
| Type | Yes | No | | | | Local room | Control room |
| Smoke | | | | | | | |
| Heat | | | | | | | |
| Linear thermal | | | | | | | |
| Pneumatic | | | | | | | |
| Other | | | | | | | |

COMMENTS:

*Note:* A = acceptable; M = marginal; and U = unacceptable.

## TABLE I–10. FIRE HOSE STATIONS AND WATER CANNONS

### *(a) Fire hose stations*

Compartment No. ____________

Cell No. ____________

| Area | Hose station | | No. of stations | Location (reference drawing No.) | Accessible | | Operable | | Hose condition (A/U) | Nozzle condition (A/U) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Yes | No | | | Yes | No | Yes | No | | |
| Inside | | | | | | | | | | |
| Adjacent | | | | | | | | | | |

COMMENTS:

*Note:* A = acceptable; and U = unacceptable.

### *(b) Water cannons*

| Area | Water cannon | | No. of cannons | Location (reference drawing No.) | Accessible | | Condition (A/U) |
|---|---|---|---|---|---|---|---|
| | Yes | No | | | Yes | No | |
| Inside | | | | | | | |
| Adjacent | | | | | | | |

COMMENTS:

*Note:* A = acceptable; and U = unacceptable.

## TABLE I–11. PORTABLE FIRE EXTINGUISHERS

| Area | Portable fire extinguishers | | No. of extinguishers | Type | Location (reference drawing No.) | Accessible | | Condition (A/U) | Detector type correct for application? | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Yes | No | | | | Yes | No | | Yes | No |
| Inside | | | | | | | | | | |
| Adjacent | | | | | | | | | | |

COMMENTS:

*Note:* A = acceptable; and U = unacceptable.

## TABLE I–12. DRAINAGE

Compartment No. ______________

Cell No. ______________

| Floor drains | | Do floor drains appear to be in a working condition? | | Drain pits | | Drain located in pit | | Equipment curbs | | Curb height (cm) | Dykes around tanks | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | | Yes | No |
| | | | | | | | | | | | | |

COMMENTS:

## TABLE I–13. VENTILATION

Ventilation system(s) serving compartment/cell: ______________

______________

| Air supply | | Air supply automatically shut down | | Exhaust air | | Exhaust air automatically shut down | | Fixed smoke removal system | | Fire dampers in ducts at fire barriers | | Air transfer | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No |
| | | | | | | | | | | | | | |

COMMENTS:

## TABLE I–14. EMERGENCY LIGHTING

Compartment No. ____________

Cell No. ____________

| Area | Emergency lighting | | No. of fixtures | Type of fixtures | | | Do lights work? | | Are lights suitable for the environment? | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Yes | No | | Battery pack | Hard wired | Other (identify) | Yes | No | Yes | No |
| Cell | | | | | | | | | | |
| Access route | | | | | | | | | | |

COMMENTS:

## TABLE I–15. EMERGENCY COMMUNICATIONS

| Area | Telephones/ two way public address system | | Operational | | Portable radio | | Operational | | Communication available with control room and fire command centre | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No |
| Cell | | | | | | | | | | |
| Adjacent cell | | | | | | | | | | |

COMMENTS:

TABLE I–16. FIRE LOADING SCHEDULE [1]

| Hazard | Cables | | Oil | | Other | | Total | | Potential ignition sources | Detector/extinguisher |
|---|---|---|---|---|---|---|---|---|---|---|
| Room enclosure | MJ/m$^2$ | MJ | MJ/m$^2$ | MJ | MJ/m$^2$ | MJ | MJ/m$^2$ | MJ | | |
| Pump room | | | 200 | 8 000 | | | 200 | 8000 | Pump motor | Smoke detector; manual extinguishing |
| Sub change room | | | | | 20 | 400 | 20 | 400 | See *Note 1* | Smoke detector; manual extinguishing |
| Stairway | | | | | | | | | See *Note 1* | Smoke detector; manual extinguishing (see *Note 2)* |
| Cable riser | 1750 | 25 000 | | | | | 1750 | 25 000 | See *Note 1* | Smoke detector; auto-sprinkler (water) |
| Diesel generator room | 30 | 6 000 | 2500 | 60 000 | | | 2530 | 66 000 | Diesel generator; switchgear; pump/motor | Smoke, infrared and thermal detectors; auto-sprinkler (water); manual foam |
| Main switchgear room | 500 | 26 000 | | | | | 500 | 26 000 | Switchgear | Smoke detectors; carbon dioxide; total flooding |
| Essential switchgear | 350 | 18 000 | | | | | 350 | 18 000 | Switchgear | Smoke detectors; carbon dioxide; total flooding |

*Note 1*: There should be no ignition sources present in these areas; however, fire detection and extinguishing are provided to allow for transient or other unspecified causes of ignition. *Note 2:* Smoke detection and manual extinguishing (e.g. portable extinguishers) are provided for unspecified transient combustibles.

TABLE I–17. DATABASE SCHEDULE FOR ASSIGNMENT OF SAFETY RELATED COMPONENTS TO DEDICATED COMPARTMENTS

| Room | Component code No. | Component type | Redundancy/ train | Comment |
|---|---|---|---|---|
| 1116 | TF41S002 | After-cooler valve | 1 | TF injection → flooding |
| | TF41S006 | After-cooler valve | 1 | |
| | TH40B002 | After-cooler | 0 | |
| | TH40D001 | After-cooler pump | 1 | |
| | TH40D002 | Seal water booster pump | 1 | |
| | TH40S001 | Valve, flooding tank suction line | 1 | |
| | TH40S002 | Valve, flooding tank suction line | 1 | |
| | TH40S007 | Cooler valve | 1 | |
| | TH40S008 | Cooler valve | 1 | |
| | TH40S009 | Cooler valve | 1 | |
| | TV05S013 | Valve, after-cooler sampling line | 2 | For the TH system, closing function only |
| | TV05S014 | Valve, after-cooler sampling line | 3 | For the TH system, closing function only |
| 1118 | TH01S001 | Sump isolation valve | 3 | Closing function only |
| | TH04S001 | Sump isolation valve | 1 | Closing function only |
| 1119 | TF11S002 | After-cooler valve | 3 | |
| | TF11S006 | After-cooler valve | 3 | |
| | TH10B002 | After-cooler | 0 | |
| | TH10D001 | After-cooler pump | 3 | |
| | TH10D002 | Seal water booster pump | 0 | Small independent emergency pump |
| | TH10S001 | Valve, flooding tank suction line | 3 | |
| | TH10S002 | Valve, flooding tank suction line | 3 | |
| | TH10S007 | Cooler valve | 3 | |
| | TH10S008 | Cooler valve | 3 | |
| | TH10S009 | Cooler valve | 3 | |
| | TV05S007 | Valve, after-cooler sampling line | 2 | For the TH system, closing function only |
| | TV05S008 | Valve, after-cooler sampling line | 3 | For the TH system, closing function only |
| 1121 | TF21S002 | After-cooler valve | 2 | |
| | TF21S006 | After-cooler valve | 2 | |
| | TH20B002 | After-cooler | 0 | TF injection → flooding |
| | TH20D001 | After-cooler pump | 2 | |
| | TH20D002 | Seal water booster pump | 0 | |
| | TH20S001 | Valve, flooding tank suction line | 2 | |
| | TH20S002 | Valve, flooding tank suction line | 2 | |
| | TH20S007 | Cooler valve | 2 | |
| | TH20S008 | Cooler valve | 2 | |
| | TH20S009 | Cooler valve | 2 | |
| | TH20SO10 | Valve at coolant purification line | 2 | Closing function only |

## Annex II

## PREFIRE FIRE FIGHTING STRATEGY

This Annex provides the format, organization, content and level of detail that should be included in the prefire fire fighting strategy for each fire compartment or fire cell in a nuclear power plant.

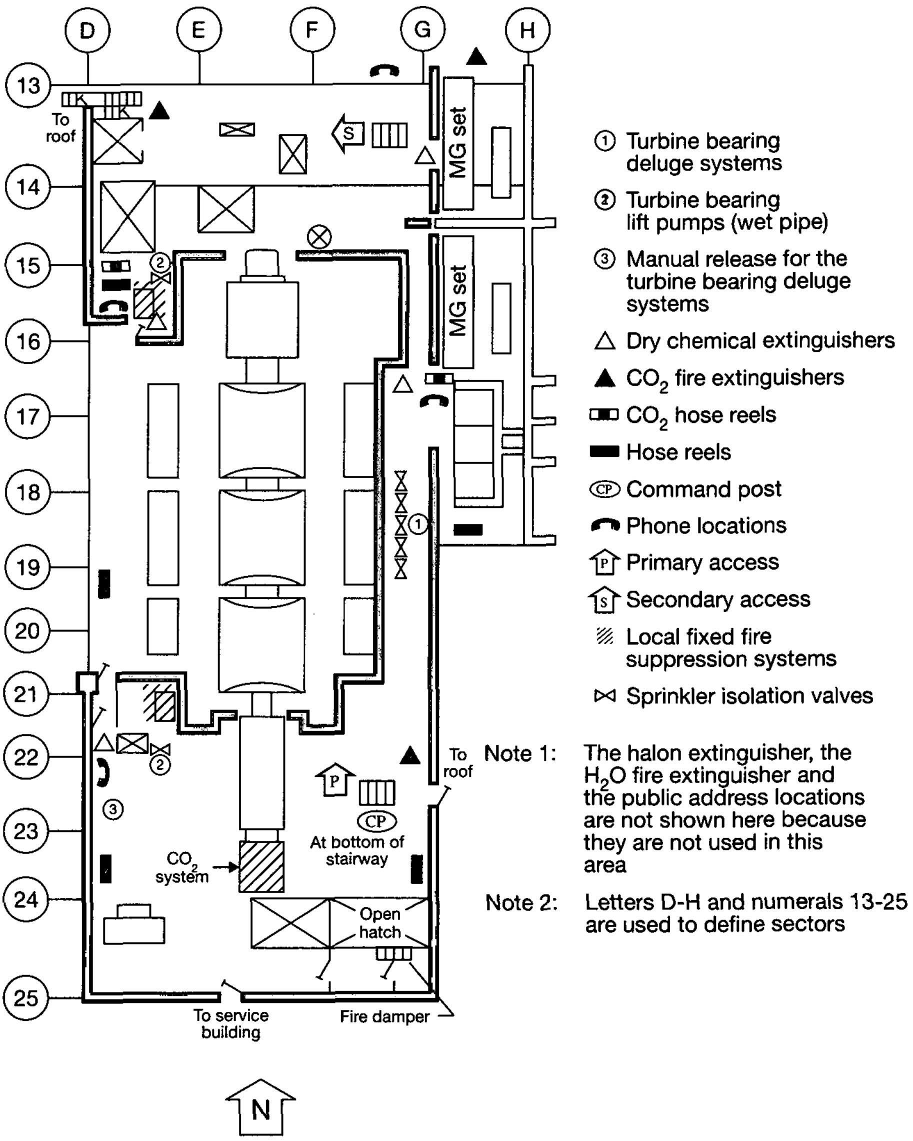
*Summary of fire preplan* *Page 1*

| | |
|---|---|
| *(1) Special instructions*<br>In the event of a gaseous extinguishing system actuating, see item (1) of this Annex. | *(2) Location*<br>Unit 1 turbine building (elevation of 639 ft)<br>Main turbine floor (outside the turbine shield wall)<br>Fire area No. |
| *(3) Access*<br>*Primary:* Stairway to the southeast of unit 1 turbine building (elevation of 639 ft from 595 ft)<br>*Secondary:* Stairway to the northwest of unit 1 main generator (MG) sets (elevation of 639 ft from 595 ft) | *(4) Hazards*<br>*Fire:* Lubricating oil; HVAC duct insulation<br>*Electrical:* See item (4(b)) of this Annex<br>*Other:* Radioactive equipment; respiratory $CO_2$ |
| *(5) Fire protection equipment*<br>Two local wet pipe sprinkler systems<br>Five water system hose reels<br>Two $CO_2$ 1 inch hose reels (200 ft)<br>Three 15# $CO_2$ portable extinguishers<br>Four 20# dry powder (Purple K) extinguishers<br>One water curtain (deluge) | *(6) Guidelines for fire attack*<br>Command post at the bottom of the stairway (elevation of 615 ft) close to the stator water cooler<br>Provide support for the sprinkler system<br>Self-contained breathing apparatus<br>Attack with a portable extinguisher, followed by a 1½ inch hose line<br>Search the area for victims<br>Ventilate and overhaul<br>Provide surveillance for inoperative extinguishing systems |
| *(7) Ventilation*<br>*Fixed:* Operation of HVAC by the control room, as needed<br>*Manual:* Not applicable<br>*Caution:* The fire dampers may not close in the presence of air flow and the fixed ventilation system may need to be tripped to ensure closure of the fire dampers | *(8) Exposures*<br>None |
| *(9) Communications*<br>Two fixed telephones | *(10) Construction*<br>All boundaries are made of concrete |
| *(11) Safety systems*<br>None in this compartment | |

*Note*: 1 ft = 3.048 × $10^1$ m; 1 inch = 2.54 × $10^1$ mm.

Fire area ____________________

Elevation ____________________



Note 1: The halon extinguisher, the $H_2O$ fire extinguisher and the public address locations are not shown here because they are not used in this area

Note 2: Letters D-H and numerals 13-25 are used to define sectors

## FIRE PREPLAN

### (1) Special instructions

(1) Dispatch the fire brigade to the scene with self-contained breathing apparatus
(2) Notify radiation protection to respond to the scene with $O_2/CO_2$ monitoring equipment and to perform a survey
(3) Perform search and rescue activities, if required
(4) Take measures, if necessary, to prevent the discharge from extending into other areas
(5) Ventilate the room to a safe area, if required
(6) Monitor the $O_2/CO_2$ levels until they are normal
(7) Maintain a fire watch in the area until the system is restored to service
(8) Search all the adjacent low lying areas, if necessary

### (2) Location

Unit 1 turbine building
Elevation of 639 ft
Main turbine floor
Fire area No.

### (3) Access

(a) *Primary:* Via the stairway at an elevation of 639 ft; entry is made from the hydrogen seal oil area of unit 1 on the mezzanine floor

(b) *Secondary*: Via the stairway at an elevation of 639 ft; entry is made from the MG set oil cooler area of units 1 and 2 on the mezzanine floor

### (4) Hazards

(a) *Fire:*

| *Material* | *Class* |
|---|---|
| (i) Lubricating oil | B |
| (ii) HVAC duct insulation | A |

(b) *Electrical:*

| *No.* | *Description* | *Circuit breaker* | *Power supply* |
|---|---|---|---|
| 1-5620B | Turbine bearing lift pump 'B' | D2 | MCC 19-3 |
| 1-5620A | Turbine bearing lift pump 'A' | C2 | MCC 19-3 |
| 1/2A | Turbine building crane | 155C | 480 V Switchgear 15 |
| 1/2B | Turbine building crane | 155C | 480 V Switchgear 15 |
| 943-1B | Computer UPS Panel 943-1B | 176C | 480 V Switchgear 17 |
| 1-5802 | Turbine building freight elevator | A2 | MCC 17-2 |
| | Computer UPS 250 V DC Batteries unit 1, unstacking | | Blue building |
| | Transformer | | Switchyard fuses |
| 1-5620D | Turbine building lift pump 'D' | A2 | MCC-19-3 |
| 1-5620E | Turbine building lift pump 'E' | B4 | MCC-19-3 |
| 1-5620C | Turbine building lift pump 'C' | E2 | MCC-19-3 |

(c) *Hazardous substances:* None

(d) *Physical hazards:* Radioactive equipment
Respiratory hazard, $CO_2$ system

(e) *Life safety:* None

### (5) Fire protection equipment

(a) *Detection:* None

(b) *Automatic extinguishing:* One water curtain (deluge); and two wet pipe sprinkler systems (local)

(c) *Hose reels:* Five water system hose reels; and two $CO_2$ 1 inch hose reels (200 ft)

(d) *Portable extinguishers:* Three 15# $CO_2$ portable extinguishers; and four 20# dry powder (Purple K) extinguishers

## (6) Guidelines for fire attack

(a) Establish a command post at the bottom of the stairway (elevation of 615 ft) close to the stator water cooler

(b) Provide support for the automatic extinguishing system

(c) If the extinguishing system fails to actuate, manually actuate the system at the east wall

(d) Ensure that self-contained breathing apparatus is used by all personnel

(e) Use portable extinguishers for the initial attack, backed up by a 1½ inch hose line

(f) Search the entire area for possible victims

(g) Ventilate the area: utilize the fixed ventilation system (see item (7) of this Annex), or place portable smoke ejectors at the personnel doors

(h) Overhaul the entire fire area; check for extension

(i) Position one person with a portable radio at the sprinkler system control valve at the east wall

(j) Provide a fire watch until the fire extinguishing and detection systems are returned to service

## (7) Ventilation

(a) *Fixed:* Operation of HVAC by the control room, as needed

(b) *Manual:* Not applicable

*Caution:* The fire dampers may not close in the presence of air flow and the fixed ventilation systems may need to be tripped to ensure closure of the fire dampers

## (8) Exposures

None

## (9) Communications

(a) *Portable radios:* May be used in this area

(b) *Public address system:* None

(c) *Telephone:* Two fixed units

## (10) Construction

(a) *Floor:* Concrete on exposed steel

(b) *Walls:* North, south, east and west: concrete

(c) *Ceiling:* Concrete on exposed steel

## (11) Safety systems

None in this compartment

# Annex III

## EFFECT OF THE VENTILATION SYSTEMS

It should be established whether the ventilation ducts for a fire compartment run outside or inside the compartments (Fig. III–1). If they run outside (Type B), the effects of closing the fire dampers need no further investigation. If the ventilation ducts run inside the compartments (Type A), closing the fire dampers will result in an interruption of the ventilation in other related compartments. In such cases it should be demonstrated (e.g. by means of calculations) that the resulting rise in temperature in the affected rooms does not affect plant nuclear safety.

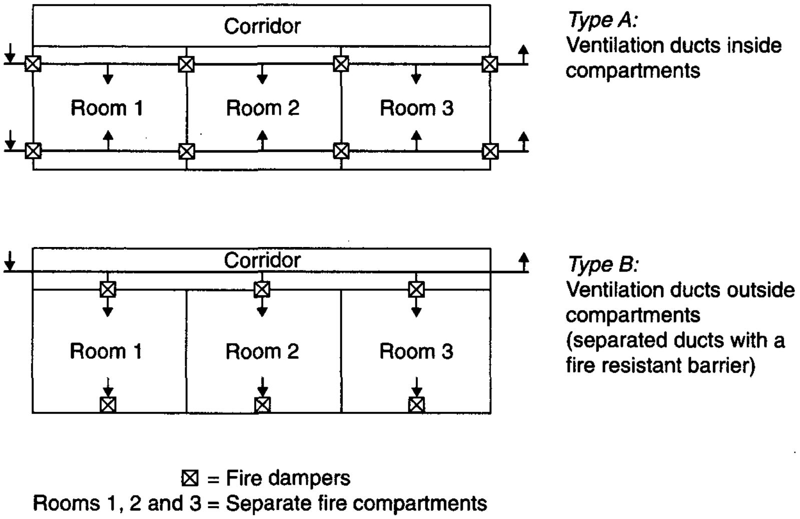


*FIG. III–1. Ventilation duct arrangement in the fire compartments.*

# Annex IV

## DIRECT, INDIRECT AND SECONDARY EFFECTS OF THE FIRE AND FIXED FIRE EXTINGUISHING SYSTEMS

This Annex provides examples of various direct and indirect effects of the fire and fixed fire extinguishing systems. Both effects may or may not be immediately observable. Some examples are provided in Fig. IV–1 for each of the above mentioned categories.

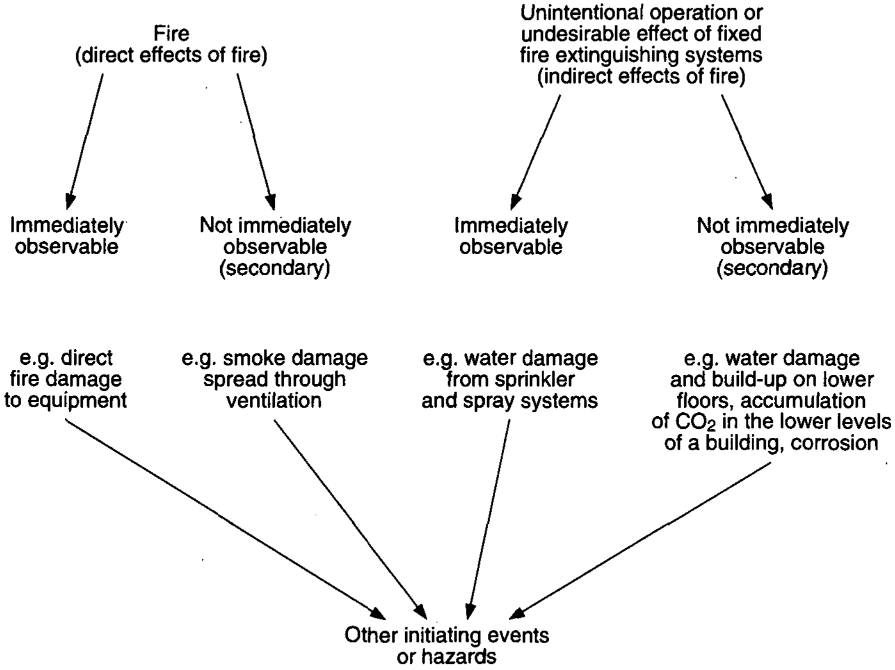


*FIG. IV–1. Various effects of fire and operation of the fire extinguishing systems.*

# Annex V

## OTHER EFFECTS OF A FIRE

Consider the situation described in Fig. V–1 [5]. It is possible that a single fire compartment contains electric cabling related to two different safety systems which are not redundant, e.g. train A cabling for the ventilation fans and train B cabling for the residual heat removal (RHR) pumps.

A preliminary review suggests that a fire in this area would damage the cabling for the RHR pump (train B) and the ventilation fans (train A). Since the equipment served by these cables is not redundant, plant safety appears to be maintained. However, if the cabling is traced back to the safety power supply source, additional safety systems and/or components can be supplied through common switchgear.

A fire in this compartment may result in loss of operation of the RHR pump (train B); also, a fire must be assumed to cause some damage to the cabling for the ventilation fans (train A). In addition, a short circuit may result in an increase in current that is sufficient to trip the circuit breakers for the ventilation fans (switches $S_4$ , $S_5$ and $S_6$). However, it is possible that the increase in short circuit current for each separate cable is not sufficient to trip the individual breakers for the ventilation

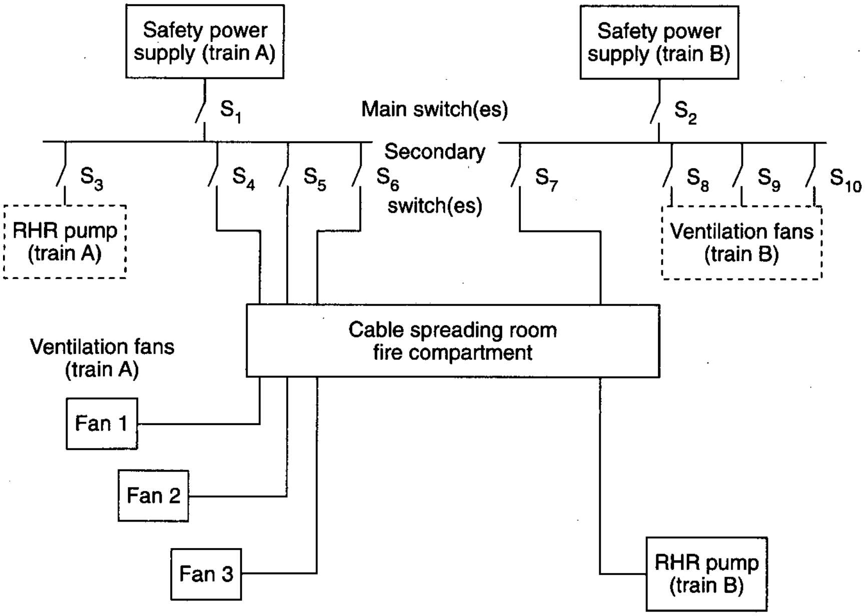


*FIG. V–1. Electrical power supply system to illustrate the indirect effects of a fire [5].*

fans. Instead, the combined effect of the increased short circuit currents may cause tripping of the main switch for the safety power supply (train A). The result is that all the systems and components supplied by this power supply, including the RHR pump (train A), would be affected.

It is important that the fire hazard analysis considers not only the direct effect of a fire within each fire compartment, with respect to the impact on redundant safety systems, but also the indirect impact of a fire as a result of the short circuit overcurrent protection designed into the electrical system power supplies.

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

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Quality Assurance for Safety in Nuclear Power Plants and Other Nuclear Installations, Safety Series No. 50-C/SG-Q, IAEA, Vienna (1996).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Code on the Safety of Nuclear Power Plants: Design, Safety Series No. 50-C-D (Rev. 1), IAEA, Vienna (1988).

[4] UNITED STATES DEPARTMENT OF ENERGY, Reactor Core Protection Evaluation Methodology for Fires at Soviet Designed RBMK and VVER Nuclear Power Plants, Rep. DOE/NE 0113, DOE, Washington, DC (1996).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Evaluation of Fire Hazard Analyses for Nuclear Power Plants, Safety Series No. 50-P-9, IAEA, Vienna (1995).

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AMERICAN SOCIETY FOR TESTING AND MATERIALS, Applications of Fire Science to Fire Engineering (Proc. Symp. Denver, 1984) (MARMATHY, T.Z., Ed.), ASTM, Philadelphia, PA (1985).

*This is a collection of technical papers on a variety of related topics, including fire growth in compartment lines with combustible materials, scaling correlations for flashover, effects of a fire on exposed structural steel elements, computer modelling of structural steel fire endurance, flame spread measurement and small scale experiments of smoke production in fires.*

BERRY, D.L., Analysis of fire barriers within nuclear power plants, Nucl. Technol. **53** (1981) 204–216.

*This describes a methodology for assessing the fire resistance of barriers under the conditions in nuclear power plants where ventilation is controlled. The underlying assumptions are described and a practical, graphic technique of barrier assessment is presented, together with examples of its use.*

CHAMBERLAIN, D., Heat Release Rate Properties of Wood Based Materials, NBSIR 82-2597, National Institute for Science and Technology, Washington, DC (1983).

*This is a useful source of information on the heat release rates of various types of lumber and other wood based products, including the effects of fire retardant treatments and moisture content.*

DRYSDALE, D., An Introduction to Fire Dynamics, Wiley, New York (1985).

*This is a recognized reference work on the fundamentals of fire science and covers heat premixed and diffusion flames, burning of liquid, solid and gaseous fuels, the spread of fire, pre- and post-flashover compartment fires, and the production and movement of smoke. The work includes useful reference data and correlations between theory and experiments.*

Fire Safety in Nuclear Power Plants (Proc. SMIRT-10, Post-Conference Seminar No. 6, Anaheim, CA, 1989), Nucl. Eng. Des. **125** 3 (1991) 289–422 (Extended and updated selected papers).

*This provides a description of the experiments carried out on the burning behaviour of cable fires and large scale hydrocarbon fires under different ventilation conditions, as well as use of simulation techniques as an analytical tool for fire hazard analyses.*

Fire Safety in Nuclear Power Plants, Special Issue for SMIRT-11, Seminar No. 6, Fire Sci. Technol., Suppl., **13** (1993).

*This is a collection of different presentations on fire experiments with different fire loads for nuclear power plants (large and small scale tests), and on the experience gained with fire modelling using different fire simulation codes (zone models, system codes and field models) within the framework of large scale plant fire experiments.*

FRIEDMAN, R., Survey of Computer Models for Fire and Smoke, 2nd edn, Factory Mutual Research Corporation, Norwood, MA (1991).

*This contains the results of a survey prepared for the FORUM for International Cooperation on Fire Research. It describes the 62 different computer models from 11 different countries that are available for use in fire safety engineering. The models are of the zone and field type and cover subjects such as the fire endurance of structural steel, building evacuation, the actuation times for sprinklers and heat detectors, and fire growth and smoke spread. Descriptions of each model include specific technical references, availability and cost, hardware and memory requirements, and computer language, as well as the program capabilities.*

GESELLSCHAFT FÜR ANLAGEN- UND REAKTORSICHERHEIT, Fire Safety in Nuclear Power Plants and Industrial Installations, SMIRT-13, Seminar No. 6, GRS, Cologne (in preparation).

*This reports on the experience gained with fire simulation codes as a tool for fire safety assessment, in particular the fire hazard analysis, as well as new fire experiments for nuclear power plants.*

GUYMER, P., PARRY, G.W., “Use of probabilistic methods in fire hazard analysis”, Fire Protection and Fire Fighting in Nuclear Installations (Proc. Symp. Vienna, 1989), IAEA, Vienna (1989) 485–504.

*This is a useful source of information on point estimate frequencies for a fire in various locations within nuclear power plants, and the unavailability of fire safety features such as fire detectors and extinguishing systems.*

KARWAT, H., CEC Standard Problem: Prediction of Effects Caused by a Cable Fire Experiment within the HDR Experiment, Commission of the European Communities, Luxembourg (May 1993).

*This gives a description and the results of a benchmark exercise using different fire simulation models for a large scale cable test fire (commissioned by the Kernforschungszentrum Karlsruhe) in the containment of a decommissioned steam reactor facility (HDR).*

KERNFORSCHUNGSZENTRUM KARLSRUHE, Behaviour of Oil Fires in a Closed Subsystem With Ventilation Connected and Variable Door Openings, Auswertebericht Versuchsgruppe E41.5-10, Technischer Fachbericht PHDR 130-94, KFK, Karlsruhe (May 1994).

*This describes a series of hydrocarbon pool test fires (commissioned by KFK) in the containment of a decommissioned steam reactor facility (HDR), including different fires under varying bounding conditions (intensity, ventilation, etc.). Pre- and blind post-test calculations were performed to assess the fire simulation models.*

KERNFORSCHUNGSZENTRUM KARLSRUHE, Behaviour of Room Chains in the Case of a Large Oil Pool Fire in a Closed Containment, Auswertebericht Versuchsgruppe E41.1-4, Technischer Fachbericht PHDR 103-91, KFK, Karlsruhe (1991).

*This describes a series of hydrocarbon pool test fires (commissioned by KFK) in the containment of a decommissioned steam reactor facility (HDR), including different fires of varying intensity. In addition, pre- and post-test calculations were performed using different fire simulation models (zone models, system codes).*

KERNFORSCHUNGSZENTRUM KARLSRUHE, Examination of a Cable Fire in Connected Rooms of a Closed Containment, Auswertebericht Versuchsgruppe E42, Technischer Fachbericht PHDR 123-94, KFK, Karlsruhe (Apr. 1994).

*This describes a series of cable test fires (commissioned by KFK) in the containment of a decommissioned steam reactor facility (HDR), including different fires of varying intensity. Pre- and blind post-test calculations were performed to verify the fire simulation models.*

KERNFORSCHUNGSZENTRUM KARLSRUHE, Fire Safety of Nuclear Power Plants (Proc. SMIRT-12 Seminar, Heidelberg, 1993), HDR Safety Program SP4, Work Report PHDR 40.070/94, KFK, Karlsruhe (May 1994).

*This gives the results of large scale hydrocarbon and cable fire experiments carried out in a decommissioned superheated steam reactor facility (HDR), and assessment (including a* *benchmark exercise) of the fire simulation codes used in pre- and post-test calculations for the HDR fire experiments.*

KERNFORSCHUNGSZENTRUM KARLSRUHE, First Assessment of the Simulation Models and Codes Applied to the HDR Fire Experiments, PHDR Work Report No. 5.093/86, GRS-A-1639, KFK, Karlsruhe (1989).

*This gives the results of an assessment made of various fire simulation models (zone models and lumped parameter codes) applied to large scale test fires (commissioned by KFK) in the containment of a decommissioned steam reactor facility (HDR).*

LEE, B.T., Heat Release Rate Characteristics of Some Combustible Fuel Sources in Nuclear Power Plants, NBSIR 85-3195, National Institute for Science and Technology, Washington, DC (1985).

*This provides basic information on the actual heat of combustion and the rate of heat release of a range of fuels likely to be encountered in nuclear power plants, including oils of various grades, several types of electrical cable insulation (including PVC insulated cables), timber material and combustible refuse.*

MOWRER, F.W., Methods of Quantitative Fire Hazard Analysis, Document No. TR-100443, Society of Fire Protection Engineers for the Electric Power Research Institute, Quincy, MA (1992).

*These simplified fire hazard analysis methods were developed as part of the FIVE (Fire Induced Vulnerability Evaluation) risk based methodology for nuclear power plants. The fire hazard analyses permit fire protection personnel to evaluate the potential for exposure fires that would cause critical damage to essential safe shutdown equipment, resulting in compartments where no significant fire hazard exists being screened from further analysis. The fire hazard models described start with mass and energy conservation equations, and use well accepted empirical or semi-empirical correlations for momentum transfer.*

NELSON, H.E., FPETOOL: Fire Protection Engineering Tools for Hazard Evaluation, NISTIR 4380, National Institute of Standards and Technology, Washington, DC (1990).

*This is a collection of 'computerized' hand calculations that covers the buoyant gas head, ceiling jet and plume temperatures, the plume filling rate, the fire severity, the smoke and mass flow, the upper layer temperature, the radiant ignition of nearby fuels and the ventilation limits to combustion. The computer models ASETBX and FIRE SIMULATOR are also provided, including use of the software, and the equations and assumptions on which the software is based.*

NOWLEN, S.P., Heat and Mass Release for Some Transient Fuel Source Fires: A Test Report, NUREG/CR-4680, SAND86-0312, Sandia National Laboratories, Albuquerque, NM (1986).

*This contains the findings of a series of fire characterization tests carried out for the United States Nuclear Regulatory Commission to simulate the small to moderate transient (non-permanent) accumulation of those combustible materials that may be found in nuclear power plants. Data are provided for the heat release rate properties, the plume temperatures and the combustion heat. The fuel packages tested include materials such as cardboard boxes, waste paper, computer paper, small quantities of acetone, polyethylene wash bottles and cotton cloths.*

The SFPE Handbook of Fire Protection Engineering (DI NENNO, P.J., Ed.), 2nd edn, National Fire Protection Association, Quincy, MA (1988).

*This is a major reference work on all aspects of fire safety engineering, including combustion of solid, liquid and gaseous fuels, heat transfer, smoke transport and venting, thermochemistry, toxicity and the behaviour of people under fire conditions. It provides a large amount of tabulated data and covers hazard analysis calculations, design calculations for extinguishing systems and structural members, smoke control and fire risk calculations.*

# DEFINITIONS

*The definitions below are intended for use in the NUSS programme and may not necessarily conform to definitions adopted elsewhere for international use.*

**combustion**. Exothermic reaction of a substance with an oxidizer, generally accompanied by flames, glowing or emission of smoke, or a combination thereof.

**explosion.** An abrupt oxidation or decomposition reaction producing an increase in temperature or in pressure, or in both, simultaneously.

**fire**. (1) A process of combustion characterized by the emission of heat accompanied by smoke or flame, or both. (2) Rapid combustion spreading in an uncontrolled manner in time and space.

**fire barrier.** Walls, floor, ceiling or devices for closing passages such as doors, hatches, penetrations and ventilation systems that are used to limit the consequences of a fire. A fire barrier is characterized by a fire resistance rating.

**fire cell.** A subdivision of a fire compartment in which fire separation between items important to safety is provided by fire protection features (such as limitation of combustible materials, spatial separation, fixed fire extinguishing systems, fireproof[1] coatings or other features) so that consequential damage to the other separated systems is not expected.

*This definition is significant when using the fire influence approach wherein redundant divisions of safety systems or other items important to safety may not necessarily be separated by fire barriers, but the effect of a fire is limited by a combination of distance to other items important to safety, protection features such as an active extinguishing system (e.g. water sprinkler), or passive features such as structural elements (e.g. fire stops and fireproof coatings). This combination shall be so designed that the fire will not spread and the items to be protected will not be affected by the fire. It should be demonstrated by the fire hazard analysis or by tests that the influence approach provides the intended protection. (This text is taken from para. 312 of Safety Guide 50-SG-D2 (Rev. 1).)*

**fire compartment.** A building or part of a building comprising one or more rooms or spaces, constructed to prevent the spread of fire to or from the remainder of the building for a given period of time. A fire compartment is completely surrounded by a fire barrier.

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[1] Within the context of this report, the term 'fireproof' is synonymous with 'fire retardant'.

*This definition is significant when using the fire containment approach, which assumes that all combustibles within a fire compartment can be consumed during a fire. After such a fire, the undamaged portions of the plant shall meet the requirements of para. 216 of Safety Guide 50-SG-D2 (Rev. 1). To ensure that these requirements are met, thorough safety analyses and fire hazard analyses shall be performed. Great care shall be taken to identify within each fire compartment all equipment that performs required safety functions. In addition, potentially unacceptable interactions between safety related equipment in different fire compartments shall be prevented. (This text is taken from para. 310 of Safety Guide 50-SG-D2 (Rev. 1).)*

**fire damper.** A device that is designed, by automatic operation, to prevent the passage of fire through a duct, under given conditions.

**fire load.** The sum of the calorific energies that could be released by the complete combustion of all the combustible materials in a space, including the facings of the walls, partitions, floors and ceilings.

**fire resistance.** The ability of an element of building construction, component or structure to fulfil, for a stated period of time, the required load bearing function, integrity and/or thermal insulation, and/or other expected duty specified in a standard fire resistance test.

**fire retardant.** The quality of a substance for suppressing, reducing or delaying markedly the combustion of certain materials.

**fire stop**. The physical barrier designed to restrict the spread of fire in cavities within and between building construction elements.

**fire watch**. An individual trained in the use of relevant fire fighting equipment and techniques who has the sole duty of surveying a specified plant area in which a fire may occur, for a defined period of time.

**non-combustible material.** A material that, in the form in which it is used and under the conditions anticipated, will not ignite, support combustion, and burn or release flammable vapour when subject to fire or heat.

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No. 7, June 1998

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ISSN 1020–6450