IAEA SAFETY STANDARDS SERIES

Protection against Internal Fires and Explosions in the Design of Nuclear Power Plants

SAFETY GUIDE

No. NS-G-1.7

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PROTECTION AGAINST INTERNAL FIRES AND EXPLOSIONS IN THE DESIGN OF 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".

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FOREWORD

by Mohamed ElBaradei
Director General

One of the statutory functions of the IAEA is to establish or adopt standards of safety for the protection of health, life and property in the development and application of nuclear energy for peaceful purposes, and to provide for the application of these standards to its own operations as well as to assisted operations and, at the request of the parties, to operations under any bilateral or multilateral arrangement, or, at the request of a State, to any of that State's activities in the field of nuclear energy.

The following bodies oversee the development of safety standards: the Commission on Safety Standards (CSS); the Nuclear Safety Standards Committee (NUSSC); the Radiation Safety Standards Committee (RASSC); the Transport Safety Standards Committee (TRANSSC); and the Waste Safety Standards Committee (WASSC). Member States are widely represented on these committees.

In order to ensure the broadest international consensus, safety standards are also submitted to all Member States for comment before approval by the IAEA Board of Governors (for Safety Fundamentals and Safety Requirements) or, on behalf of the Director General, by the Publications Committee (for Safety Guides).

The IAEA's safety standards are not legally binding on Member States but may be adopted by them, at their own discretion, for use in national regulations in respect of their own activities. The standards are binding on the IAEA in relation to its own operations and on States in relation to operations assisted by the IAEA. Any State wishing to enter into an agreement with the IAEA for its assistance in connection with the siting, design, construction, commissioning, operation or decommissioning of a nuclear facility or any other activities will be required to follow those parts of the safety standards that pertain to the activities to be covered by the agreement. However, it should be recalled that the final decisions and legal responsibilities in any licensing procedures rest with the States.

Although the safety standards establish an essential basis for safety, the incorporation of more detailed requirements, in accordance with national practice, may also be necessary. Moreover, there will generally be special aspects that need to be assessed on a case by case basis.

The physical protection of fissile and radioactive materials and of nuclear power plants as a whole is mentioned where appropriate but is not treated in detail; obligations of States in this respect should be addressed on the basis of the relevant instruments and publications developed under the auspices of the IAEA. Non-radiological aspects of industrial safety and environmental protection are also not explicitly considered; it is recognized that States should fulfil their international undertakings and obligations in relation to these.

The requirements and recommendations set forth in the IAEA safety standards might not be fully satisfied by some facilities built to earlier standards. Decisions on the way in which the safety standards are applied to such facilities will be taken by individual States.

The attention of States is drawn to the fact that the safety standards of the IAEA, while not legally binding, are developed with the aim of ensuring that the peaceful uses of nuclear energy and of radioactive materials are undertaken in a manner that enables States to meet their obligations under generally accepted principles of international law and rules such as those relating to environmental protection. According to one such general principle, the territory of a State must not be used in such a way as to cause damage in another State. States thus have an obligation of diligence and standard of care.

Civil nuclear activities conducted within the jurisdiction of States are, as any other activities, subject to obligations to which States may subscribe under international conventions, in addition to generally accepted principles of international law. States are expected to adopt within their national legal systems such legislation (including regulations) and other standards and measures as may be necessary to fulfil all of their international obligations effectively.

EDITORIAL NOTE

An appendix, when included, is considered to form an integral part of the standard and to have the same status as the main text. Annexes, footnotes and bibliographies, if included, are used to provide additional information or practical examples that might be helpful to the user.

The safety standards use the form 'shall' in making statements about requirements, responsibilities and obligations. Use of the form 'should' denotes recommendations of a desired option.

The English version of the text is the authoritative version.

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. This Safety Guide supplements the requirements established in Safety of Nuclear Power Plants: Design [1]. It supersedes Safety Series No. 50-SG-D2 (Rev. 1), Fire Protection in Nuclear Power Plants: A Safety Guide, issued in 1992. This Safety Guide contributes to the fire protection programme[1] for a nuclear power plant. Operational aspects of fire protection, including organization, training, manual fire fighting arrangements and maintenance, are covered in Ref. [2]. Other IAEA publications are also relevant to the fire protection programme (see Refs [3–7]).

OBJECTIVE

1.2. The objective of this Safety Guide is to provide recommendations and guidance to regulatory bodies, nuclear power plant designers and licensees on design concepts for protection against internal fires and explosions in nuclear power plants.

SCOPE

1.3. This Safety Guide applies primarily to land based stationary nuclear power plants with water cooled reactors designed for electricity generation or for other heat production applications (such as district heating or desalination). It is recognized that for other reactor types, including innovative developments in future systems, some parts of this Safety Guide may not be applicable or may need some judgement in their interpretation.

1.4. This Safety Guide covers the design features necessary to protect items important to the nuclear safety of plants against internal fires and explosions. It does not cover conventional aspects of fire protection or the safety of plant

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[1] A 'fire protection programme' is an integrated effort involving equipment, procedures and personnel necessary to conduct all fire protection activities. It includes system and facility design and analysis; fire prevention, detection, annunciation, confinement and extinguishing; administrative controls; fire brigade organization; training; inspection, maintenance and testing; and quality assurance.

personnel, or the protection of property. Fires affecting the site and originating from nearby forest fires or spills of flammable liquid from a refuelling vehicle or a crashing aircraft or other similar events are dealt with in Ref. [8].

1.5. This Safety Guide is restricted to protection against explosions due to releases of flammable liquids and gases from plant systems. It does not cover protection against explosions inside plant systems; these should be protected against by the design of the systems themselves.

1.6. National regulations or standards for fire protection may require approaches that differ from the recommendations given in this Safety Guide. A compromise may in this case have to be found on the basis of engineering judgement.

STRUCTURE

1.7. Section 2 outlines the general concepts of protection against internal fires and explosions in nuclear power plants. Section 3 describes the approach to building design for fire protection of plants. Sections 4 and 5 describe considerations in and provide recommendations for fire prevention, detection and extinguishing. Section 6 deals with the mitigation of secondary fire effects. Section 7 covers safety classification and quality assurance. Seven appendices give further guidance.

2. GENERAL CONCEPTS

GENERAL

2.1. Structures, systems and components important to safety are required to be designed and located, consistent with other safety requirements, so as to minimize the likelihood and effects of internal fires and explosions caused by external or internal events[2] [1]. The capability for shutdown, removal of

[2] Fires and explosions originated by external sources are outside the scope of this Safety Guide. They are considered in Ref. [8].

residual heat, confinement of radioactive material and monitoring of the state of the plant is required to be maintained [1]. These requirements should be met by the suitable incorporation of redundant parts, diverse systems, physical separation and design for fail-safe operation such that the following objectives are achieved (para. 5.10 of Ref. [1]):

(1) To prevent fires from starting;
(2) To detect and extinguish quickly those fires that do start, thus limiting the damage done;
(3) To prevent the spread of those fires which have not been extinguished, thus minimizing their effects on systems performing essential safety functions.

2.2. For protection against explosions, the following steps should be taken, in order of priority:

(a) Prevent explosions from occurring;
(b) Minimize the risk of an explosion, if an explosive atmosphere cannot be avoided;
(c) Implement design provisions necessary to limit the consequences of an explosion.

Item (c) should only be necessary in exceptional cases, in which items (a) and (b) cannot be achieved.

2.3. Objective (1) in para. 2.1 requires that the design of the plant be such that the probability of a fire starting is minimized. Objective (2), which requires the early detection of fires and their extinguishing by a combination of automatic and/or manual fire fighting techniques, relies on active techniques. Objective (3) relies primarily on the use of fire barriers and physical or spatial separation.

2.4. To meet the requirements stated in para. 2.1, reactor designs incorporate redundant safety systems so that no postulated initiating event, such as a fire or explosion, could prevent safety systems from performing their required safety functions. As the degree of redundancy or diversity decreases, the need to protect each safety system from the effects of fire and explosions increases. In the case of fire, this would generally be accompanied by improved passive protection and physical separation or greater use of systems for fire detection and extinguishing.

2.5. Fire protection should be developed on a deterministic basis, with the following assumptions:

(a) A fire is postulated wherever fixed or transient combustible material[3] is located.
(b) Only one fire is postulated to occur at any one time; consequential fire spread should be considered part of this single event, if necessary.
(c) The fire is postulated whatever the normal operating status of the plant, whether at power or during shutdown.

Consideration should be given to combinations of fire and other postulated initiating events that are likely to occur independently of the fire (paras 2.20–2.24).

2.6. A fire hazard analysis should be carried out to demonstrate that the overall safety objectives of para. 2.1 are met. Guidance on the scope of a fire hazard analysis is given in Section 3, paras 3.20–3.27.

FIRE PREVENTION

2.7. Fire loads[4] in nuclear power plants should be kept to the minimum by the use, as far as practicable, of suitable non-combustible materials; otherwise, fire retardant materials should be used.

2.8. The number of ignition sources should be minimized in the design.

2.9. The design and construction of each plant system should, as far as practicable, ensure that its failure does not cause a fire.

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[3] In this Safety Guide, 'fire' means (a) a process of combustion characterized by the emission of heat accompanied by smoke or flame or both, or (b) a process of rapid combustion spreading in an uncontrolled manner in time and space. 'Explosion' means an abrupt oxidation or decomposition reaction resulting in an increase in temperature or in pressure, or in both simultaneously. 'Combustion' is the exothermic reaction of a substance with an oxidizer, generally accompanied by flames, glowing or the emission of smoke, or a combination of these. The term 'combustible material' is used as a general term to cover solid, liquid and gaseous materials that can undergo combustion. The term 'flammable' is used where appropriate for liquids and gases that can undergo combustion. No distinction is made between 'flammable' and 'highly flammable' liquids and gases.

[4] The 'fire load' is 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 ceiling.

2.10. Items important to safety whose malfunction or failure could result in unacceptable releases of radioactive material should be protected from natural phenomena that could give rise to a fire, such as lightning [8].

2.11. Design measures should be implemented to provide for the proper storage of transient combustible materials that arise during operation, either away from items important to safety or otherwise protected. Reference [2] covers operational aspects of fire protection.

DETECTION AND EXTINGUISHING OF FIRES

2.12. Fire detection and fire fighting systems should be provided, with the necessary systems being defined by the fire hazard analysis (paras 3.20–3.27). The systems should be designed to provide a timely alarm in the event of fire, and/or its speedy extinguishing. This will minimize the adverse effects on items important to safety and to personnel.

2.13. Fire fighting systems are required to be automatically initiated where necessary, and systems are required to be designed and located so as to ensure that their rupture or spurious[5] operation does not significantly impair the capability of structures, systems and components important to safety, and does not simultaneously affect redundant safety groups, thereby rendering ineffective the measures taken to meet the 'single failure'[6] criterion (para. 5.12 of Ref. [1]).

2.14. Fire fighting systems should be designed and located to ensure that neither their intentional nor their spurious operation jeopardizes protection against criticality events.

2.15. Consideration should be given in the design to the potential for errors in the operation of extinguishing systems. Consideration should also be given to the effects of discharges from systems in locations adjacent to fire compartments (para 3.9) and from adjacent fire cells (para. 3.17).

[5] The term 'spurious' is used to encompass all unwanted and unintended (false or inadvertent) operations of fire detection and extinguishing systems.

[6] A single failure is a failure that results in the loss of capability of a component to perform its intended safety function(s), and any consequential failure(s) which result from it.

2.16. Suitable emergency lighting and communications equipment should be provided to support the operation of manual fire fighting activities.

CONFINEMENT OF FIRES AND MITIGATION OF THE EFFECTS OF FIRES

2.17. To follow the recommendations of para. 2.1, the concept of sufficient segregation of redundant parts of safety systems should be adopted. This ensures that a fire affecting one division of a safety system would not prevent the execution of the safety function by another division. This should be achieved by locating each redundant division of a safety system in its own fire compartment or at least in its own fire cell[7] (paras 3.8–3.19). The number of penetrations between fire compartments should be minimized.

2.18. The effects of postulated fires should be analysed for all areas containing safety systems and all other locations that constitute a fire hazard to safety systems. In the analysis, the functional failure of all safety systems within the fire compartment, or fire cell, in which the fire is postulated should be assumed, unless they are protected by a qualified fire barrier designed to, or able to, withstand the consequences of the fire. Exceptions should be justified.

2.19. Fire detection systems, fire extinguishing systems and support systems such as ventilation and drainage systems should, as far as practicable, be independent of their counterparts in other fire compartments. The purpose of this is to maintain the operability of such systems in adjacent fire compartments (paras 6.5–6.10).

COMBINATIONS OF EVENTS

2.20. A random combination of events may represent an extremely unlikely scenario that should be shown in the probabilistic safety analysis to be sufficiently rare as to be able to be discounted, rather than being taken as a postulated accident (paras I.14–I.18 in Appendix I of Ref. [1]).

[7] This approach has resulted in the adoption of two, three or four way segregation depending on the design concept applied in the State concerned.

2.21. In the design of fire protection systems and equipment, some combinations of fire and other postulated initiating events likely to occur independently of a fire should be taken into account, by the method given in paras I.14–I.18 of Appendix I of Ref. [1], and appropriate provisions should be made. For example, concerning the combination of a loss of coolant accident and an independent fire, the post-event recovery period should be taken into account while the near term period, including the occurrence of the event and the startup of mitigation systems, may be excluded.

2.22. A postulated initiating event should not lead to a fire with consequences for safety systems. Possible causes of fires, such as severe seismic events or the disintegration of a turbine, should be addressed in the fire hazard analysis, and special design provisions (e.g. use of cable wraps, detection systems and suppression systems) should be made as necessary. In the fire hazard analysis, special attention should be paid to hot equipment and/or to the potential failure of circuits conveying flammable liquids and gases.

2.23. Fire protection systems and equipment that need to maintain a functional capability (their integrity and/or their functional capability and/or their operability) despite the effects of the postulated initiating event should be identified, adequately designed and qualified.

2.24. Fire protection systems that do not need to maintain a functional capability following a postulated initiating event should be designed and qualified so as not to fail in a way that threatens nuclear safety.

FIRES OF EXTERNAL ORIGIN

2.25. Regardless of the origin of the fire under consideration (i.e. whether of internal or external origin), the design concept described and recommendations made in this Safety Guide should be followed.

2.26. It should be confirmed that fires of external origin (and consequential smoke and heat propagation) do not modify the basic assumptions as stated in this Safety Guide (e.g. the occurrence of one fire at a time) or prevent field operators, fire teams or an external fire brigade from performing their tasks.

2.27. The plant should be designed to prevent the effects of fires of external origin from hindering the performance of necessary safety functions. For example, the ventilation system should be designed to prevent smoke and heat from external fires from entering buildings containing items important to safety.

2.28. Recommendations and guidance on design considerations for fires of external origin are provided in Ref. [8].

PROTECTION AGAINST EXPLOSION HAZARDS

2.29. Explosion hazards should be eliminated by design, as far as practicable. Priority should be given to design measures that prevent or limit the formation of explosive atmospheres.

2.30. Flammable gases and liquids and combustible materials that could produce or contribute to explosive mixtures should be excluded from fire compartments and fire cells and also from areas adjacent to them or connected to them by ventilation systems. When this is not practicable, quantities of such materials should be strictly limited, adequate storage facilities should be provided and reactive substances, oxidizers and combustible materials should be segregated from each other. Cylinders of compressed flammable gases should be securely stored in dedicated compounds that are located away from main plant buildings and provide appropriate protection from local environmental conditions. Consideration should be given to the provision of automatic systems for the detection of fire and flammable gases and of automatic fire extinguishing systems to prevent a fire induced explosion from affecting items important to safety in other buildings.

2.31. Explosion hazards should be identified for fire compartments and fire cells, and for other locations that constitute a significant explosion hazard to these areas. Chemical explosions (explosions of gas mixtures, including explosions of oil filled transformers), explosions induced by fire exposure and physical explosions (rapid air expansion through high energy arcing) should be considered. Consequential effects of postulated initiating events (e.g. the rupture of pipes conveying flammable gases) should be taken into account in the identification of explosion hazards.

2.32. Physical explosion hazards, such as those created by high voltage electric arcing, should be minimized by the appropriate selection of electrical components (e.g. breakers) and by system design, to limit the probability, magnitude and duration of potential electric arcs.

2.33. If an explosive atmosphere cannot be avoided, appropriate design or operating provisions should be implemented to minimize the risks: the limitation of the volumes of explosive gases, the elimination of ignition sources, adequate ventilation rates, the appropriate choice of electrical equipment designed for use in an explosive atmosphere, inerting, explosion venting (e.g. blow-out panels or other pressure relief devices) and separation from items important to safety. Equipment that needs to maintain its functionality following a postulated initiating event should be identified and adequately designed and qualified.

2.34. The risk of explosions induced by fire exposure such as boiling liquid expanding vapour explosions (BLEVEs) should be minimized by means of separation between potential fire exposures and potentially explosive liquids and gases, or by active measures such as fixed water based fire suppression systems designed to provide cooling and vapour dispersion. Consideration should be given to the blast overpressure and missiles generated by BLEVEs, and to the potential for the ignition of flammable gases at a location distant from the point of release, which could result in the explosion of a gas cloud.

2.35. Explosion hazards that cannot be eliminated should be identified and design provisions to limit the consequences of an explosion (overpressure, missile generation or fire) should be implemented. The consequential effects of postulated explosions on safety systems should be assessed against the objectives of para. 2.1. Access and rescue routes for operating personnel (in the main control room and supplementary control room) should also be assessed. Special design provisions should be made if necessary.

3. THE APPROACH TO DESIGN FOR BUILDINGS

GENERAL

3.1. Section 3 describes the design activities necessary to ensure that the goals for fire safety described in Section 2 have been satisfactorily incorporated into the plant design.

PLANT LAYOUT AND CONSTRUCTION

3.2. Early in the design phase, the plant buildings should be subdivided into fire compartments and fire cells. The purpose is to segregate items important to safety from high fire loads and to segregate redundant safety systems from each other. The aim of segregation is to reduce the risk of fires spreading, to minimize secondary effects (Section 6) and to prevent common cause failures. The use of fire compartments is discussed in paras 3.8–3.14; the use of fire cells is discussed in paras 3.15–3.19. Appendix I illustrates their use.

3.3. Building structures should be suitably fire resistant. The fire stability rating (load bearing capacity) of the structural elements of a building that are located within a fire compartment or that form the compartment boundaries should not be less than the fire resistance rating of the fire compartment itself.

3.4. Non-combustible or fire retardant and heat resistant materials are required to be used as far as practicable throughout the plant and in particular in locations such as in the reactor containment and the control room (Ref. [1], para. 5.13).

3.5. From the start of the design phase, an inventory should be maintained of combustible materials and their locations in the plant. The inventory should be kept updated over the lifetime of the plant. This inventory is a key input to the fire hazard analysis (para. 3.20).

3.6. The plant layout should be such that combustible materials (solids, liquids and gases) are not in proximity to items important to safety, as far as practicable.

3.7. The plant layout should provide for adequate access and rescue routes (Appendix II).

SUBDIVISION OF BUILDINGS INTO FIRE COMPARTMENTS: THE FIRE CONTAINMENT APPROACH

3.8. Redundant items important to safety should be located in separate fire compartments, in order to implement the concept of segregation as described in Section 2 and to separate them from high fire loads and other fire hazards. This preferred method is referred to as the fire containment approach.

3.9. A fire compartment is a building or part of a building that is completely surrounded by fire resisting barriers: all walls, the floor and the ceiling. The fire resistance rating of the barriers should be sufficiently high that total combustion of the fire load in the compartment can occur (i.e. total burnout) without breaching the fire barriers.

3.10. Confinement of the fire within the fire compartment is intended to prevent the spread of fire and its effects (e.g. smoke and heat) from one fire compartment to another, and thus to prevent the failure of redundant items important to safety.

3.11. The separation provided by fire barriers should not be compromised by the temperature or pressure effects of fires on common building elements such as building services or ventilation systems.

3.12. Since any penetration of a barrier can reduce its overall effectiveness and reliability, such penetrations should be minimized. Any devices for closing passages, such as doors, ductwork, hatches, and pipe and cable entryway seals, that form part of a fire barrier and a fire compartment boundary should have a fire resistance at least equal to the fire resistance necessary for the fire barrier itself.

3.13. The fire containment approach does not require the provision of fire extinguishing systems to meet the requirements stated in para. 2.1. Nevertheless, such provisions should be installed where there is a high fire load, as determined by the fire hazard analysis, in order to arrest a fire as soon as possible.

3.14. The fire resistance rating of the barriers that form the boundaries of a fire compartment should be established in the fire hazard analysis. A minimum resistance rating of one hour should be adopted. National regulations may require higher values for the minimum resistance rating of fire compartment boundaries. Information on fire barriers and penetrations is provided in Appendix III.

USE OF FIRE CELLS: THE FIRE INFLUENCE APPROACH

3.15. Conflicts between requirements for fire protection and other plant requirements may prevent the adoption of the fire containment approach throughout the design of a nuclear power plant. For example:

— In areas such as the reactor containment and in control rooms of certain designs, where redundant divisions of safety systems may be located close to each other in the same fire compartment;
— In areas where the use of structures to form fire barriers could unduly interfere with normal plant functions such as plant maintenance, access to equipment and in-service inspection.

3.16. In situations such as those described in para. 3.15, for which individual fire compartments cannot be utilized to separate items important to safety, protection can be provided by locating the items in separate fire cells. This is known as the ‘fire influence approach’.

3.17. Fire cells are separate areas in which redundant items important to safety are located. Since fire cells may not be completely surrounded by fire barriers, spreading of fire between cells should be prevented by other protection measures. These measures include:

— The limitation of combustible materials;
— The separation of equipment by distance, without intervening combustible materials;
— The provision of local passive fire protection[8] such as fire shields or cable wraps;
— The provision of fire extinguishing systems.

Combinations of active and passive measures may be used to achieve a satisfactory level of protection; for example, the use of fire barriers together with an extinguishing system.

3.18. The fire hazard analysis should demonstrate that protection measures are sufficient to prevent the failure of redundant items important to safety that are located in separate fire cells in the same fire compartment.

3.19. Where separation by distance alone is claimed as the protection between fire cells within a fire compartment, the fire hazard analysis should demonstrate that neither radioactive nor convective heat transfer effects would jeopardize the claimed separation.

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[8] ‘Passive fire protection’ means a fire protection feature that, by its presence, controls the spread of fire or limits the damage caused by a fire.

ANALYSIS OF FIRE HAZARDS

3.20. A fire hazard analysis of a plant is required to be carried out to demonstrate that the overall safety objectives of para. 2.1 are met. In particular, the fire hazard analysis is required to determine the necessary rating of fire barriers and the capability of fire detection and extinguishing systems (Ref. [1], para 5.11).

3.21. The fire hazard analysis should be carried out early in the design phase, should be updated before initial loading of the reactor fuel and should be kept up to date during operation.

3.22. The analysis should be based on the assumptions outlined in para. 2.5.

3.23. For multiunit plants, simultaneous unrelated fires in more than one unit need not be considered in the design of fire protection systems, but the possibility of a fire spreading from one unit to other units should be taken into account in the fire hazard analysis.

3.24. Fire hazard analysis has the following purposes:

(a) To identify items important to safety and to establish the locations of individual components in fire compartments.
(b) To analyse the anticipated growth of a fire and the consequences of a fire with respect to items important to safety. Assumptions and limitations applicable to the methods of analysis should be clearly stated.
(c) To determine the necessary fire resistance of fire barriers. In particular, the fire hazard analysis should be used to determine the necessary fire resistance of the boundaries of the fire compartments (the fire containment approach).
(d) To determine the passive and active fire protection measures necessary to achieve safety against fire.
(e) To identify cases in which additional fire separation or fire protection is necessary, especially for common cause failures, so as to ensure that safety systems would remain functional during and following a credible fire. In particular, fire hazard analysis should be used to determine the extent of the passive and active protection measures necessary to separate the fire cells (the fire influence approach).

3.25. Secondary effects of fires and extinguishing systems should be evaluated in a fire hazard analysis in order to ensure that these secondary effects would not have an adverse effect on nuclear safety.

3.26. Detailed guidance on the preparation of a fire hazard analysis is given in Ref. [7]. Detailed guidance on the evaluation of a fire hazard analysis is given in Ref. [4].

3.27. Probabilistic safety assessment (PSA) may be carried out as a complement to the deterministic approach. PSA has been used in many power plants to identify and rank the risks of fire. PSA may be used in the design phase to support decision making in the deterministic design of plant layout and fire protection systems. The use of PSA is discussed in Ref. [6].

SECONDARY EFFECTS OF FIRES AND EXTINGUISHING SYSTEMS

3.28. In this Safety Guide, the primary effects of fire are taken to be the direct fire damage to safety systems within a fire compartment or fire cell. Effects associated with the spread of smoke and heat beyond the fire compartment or fire cell are considered secondary effects. Secondary effects are outlined here and discussed further in Section 6.

3.29. The impact of secondary effects on safety will depend on whether the fire containment approach or the fire influence approach has been adopted as the basis for the location under analysis. If the fire compartments have been correctly designed, the spreading of secondary effects between them would be prevented by the surrounding fire barriers, but within a fire compartment it may be possible for secondary effects to spread between fire cells. Examples of secondary effects are as follows:

- — Excessive dilution of neutron liquid poisons by water spray and the impact of this on the effectiveness of the secondary shutdown system.
- — Impact of water spray on the criticality of enriched fuel in storage.
- — Dispersal of radioactive material due to impingement of water spray, which may lead to the contamination of other areas and drainage systems.
- — Unavailability of a fire extinguishing system subsequent to its discharge (proper or spurious).
- — Spurious actuation of another fire protection system in the absence of a fire demand upon it, with subsequent significant deleterious effects and unavailability of the fire protection system. In water based systems this

can be caused by a pressure pulse in the pipework originating from the actuation of the first system.

— Deleterious effects from heat, smoke, water spray, steam from evaporating water sprays, flooding from deluge or sprinkler systems and corrosion by foam solutions of items important to safety.
— The presence of corrosive products of combustion from burning of electrical cable insulation. These products may be transported into areas remote from the original fire where, in the presence of atmospheric moisture, they can cause general corrosion of equipment and structures or electrical failures many hours or days after the initial fire incident.
— Failures of electrical switching devices as a result of the insulation (i.e. breaking) or corrosion of electrical contacts caused by dry chemical extinguishing agents.
— As a sudden drop in temperature or a pressure impact due to the discharge of a carbon dioxide extinguishing system causing malfunction of sensitive electronic equipment.
— As a sudden drop in temperature due to the impingement of water discharges onto hot metal parts.
— Intrusion of water into electrical systems, causing failures due to short circuits or earth circuits.
— Open electrical circuits, short circuits, earth faults and arcing, and additional energy input due to the failure of equipment and piping.
— Mechanical damage due to the deformation and collapse of structures, possibly aggravated by (secondary) explosions which can cause the generation of missiles [9]; additional loading on items important to safety and the release of fluids at high temperature.
— Smoke logging and buildup of heat, preventing staff from carrying out essential duties in an effective manner (e.g. in a control room).
— Blockage of access and escape routes.

4. DESIGN MEASURES FOR FIRE PREVENTION

GENERAL

4.1. In common with most other types of industrial plant, nuclear power plants contain a range of combustible materials, as part of the structure, equipment, cabling or miscellaneous items in storage. Since fire can be assumed to occur in any plant area where combustible materials are present, design measures for fire prevention should be applied to all the fixed and transient fire loads. Such measures include minimization of fixed fire loads, prevention of accumulation of transient combustible materials and control or (preferably) elimination of sources of ignition.

4.2. The design of fire prevention measures should commence in the early stages of the design process. All such measures should be fully implemented before nuclear fuel arrives on the site.

4.3. Fire prevention at operating plants is covered in Ref. [2].

CONTROL OF COMBUSTIBLE MATERIALS BY DESIGN

4.4. In order to reduce the fire load and minimize the fire hazard, the following aspects should be considered in plant design:

- The use of non-combustible construction materials (e.g. structural materials, insulation, cladding, coatings and floor materials) and plant fixtures as far as practicable.
- The use of air filters and filter frames of non-combustible or low combustible construction.
- The use of a protected pipe or double pipe design for lubricating oil lines.
- The use of hydraulic control fluid of low flammability for the control system of steam turbines and other equipment.
- The selection of dry type transformers for interior applications.
- The siting of large oil filled transformers in external areas where a fire would not cause undue hazards.
- The use of non-combustible materials in electrical equipment such as switches and circuit breakers, and in control and instrumentation cubicles.
- The separation of switchgear boards from each other and from other equipment by means of fire barriers or fire compartments.
- The use of fire retardant cabling. A more detailed discussion of cable fire hazards is given in Appendix IV.
- The separation of areas containing high fire loads of electrical cables from other equipment by means of fire barriers or fire compartments.
- The use of non-combustible scaffolding and staging materials.

4.5. Precautions should be taken to prevent thermal insulating materials from absorbing flammable liquids (e.g. oil). Suitable protective coverings or drip guards should be provided.

4.6. Electrical systems should be designed neither to cause a fire nor, as far as practicable, to support a fire.

4.7. Cables should be laid on trays made of steel, installed in steel conduits or placed in other structurally acceptable and non-combustible cable supports. The distances between power cables or cable trays should be sufficient to prevent the cables from heating up to unacceptably high temperatures. The electrical protection system should be designed so that the cables will not overheat under normal loads or transient short circuit conditions [10, 11]. Care should be taken to ensure that cables serving items important to safety are not routed over designated storage areas or other such areas of high fire hazard.

4.8. Storage allowances for flammable liquids and gases inside plant buildings should be minimized. Storage areas for bulk supplies of any flammable or combustible materials should be located in areas or buildings that do not contain items important to safety.

4.9. Systems containing flammable liquids or gases should be designed with a high degree of integrity in order to prevent leaks. They should be protected from vibration and other destructive effects. Safety devices, such as flow limiting, excess flow and/or automatic shut-off devices, and bunding and/or dyking devices, should be provided to limit potential spills in the event of a failure.

CONTROL OF EXPLOSION HAZARDS

4.10. Hydrogen supply cylinders or special containers for hydrogen and their distribution manifolds should be placed in well ventilated external locations separated from the plant area containing items important to safety. If placed indoors, the equipment should be positioned on an outside wall and separated from areas containing items important to safety. Interior storage locations should be provided with a ventilation system designed to maintain the hydrogen concentration to values significantly below the lower flammable limit in the event of a leak of gas. Hydrogen detection equipment should be provided to give an alarm at suitably low gas concentration levels.

4.11. Where turbogenerators are cooled using hydrogen, monitoring equipment should be provided to indicate the pressure and purity of the hydrogen within the cooling system. Provision should be made to purge hydrogen filled components and related systems of pipes and ducts with an inert gas such as carbon dioxide or nitrogen before filling or when draining.

4.12. At nuclear power plants where there is a potential hazard due to hydrogen in plant operations, provisions should be made to control the hazard by the use of hydrogen monitors, recombiners, adequate ventilation, controlled hydrogen burning systems, equipment designed for use in an explosive atmosphere or other appropriate means. Where inerting is used, fire hazards arising during maintenance and refuelling should be considered, and care should be taken to ensure that gas mixtures remain within the limits of non-flammability.

4.13. The provisions of paras 4.10–4.12 should be applied, as appropriate, to the storage and use of any other bulk flammable gases used in plant operation. This should include cylinders containing gases such as acetylene, propane, butane and liquefied petroleum gas that are used in maintenance and repair work.

4.14. Each electrical battery room that contains batteries which may generate hydrogen during operation should be provided with a separate ventilation exhaust arranged to discharge directly to the outside of the building so that the hydrogen concentration is kept at a safe level below the lower flammability limit. The layout of the room and the design of the ventilation system should be such as to prevent local accumulations of hydrogen with or without an operational ventilation system. The room should be provided with a hydrogen detection system and ventilation system sensors arranged to provide alarms in the control room to indicate hydrogen levels approaching the lower flammability limit and any failure of the ventilation system. If fire dampers are installed on ventilation systems serving battery rooms, the effects of their closure on the buildup of hydrogen should be considered. Consideration should be given to the use of recombinant batteries to replace lead acid cells. Recombinant batteries generate less hydrogen, but it should not be assumed that this will eliminate the risk of hydrogen production.

ADDITIONAL CONSIDERATIONS FOR THE CONTROL OF COMBUSTIBLE MATERIALS

4.15. Significant leakage of flammable liquids or gases from fixed installations should be detected promptly so that corrective action can be promptly taken. Leakage can be detected by the use of fixed flammable gas detectors, suitably qualified level alarms or pressure alarms, or by other suitable automatic or manual means.

4.16. In areas of the plant where flammable liquids may be present in large amounts, means of confining emissions due to ruptures, leaks or spills should be provided. Flammable liquid tanks, storage areas or reservoirs should be surrounded by non-combustible walls or dykes that should have sufficient volume to hold the entire contents of the tanks or reservoir plus the anticipated quantity of fire fighting foam or water. Where practicable, pressurized oil pipes should be enclosed by continuous, concentric steel guards or be placed in concrete troughs to prevent the spread of oil in the event of pipe rupture. Where drains are provided, they should be designed to remove any spilled material to a safe location, limiting any environmental release, and to prevent the spread of fire.

4.17. Suitable fire rated storage cabinets should be provided to house any small quantities of flammable liquids necessary to support plant operations.

LIGHTNING PROTECTION

4.18. Buildings or areas containing items important to safety should be equipped with lightning protection systems. Specific guidance is provided in Ref. [11].

CONTROL OF IGNITION SOURCES

4.19. Potential ignition sources arising from plant systems and equipment should be controlled. Systems and equipment should be made safe through design so as not to provide any ignition source, separated from combustible materials, isolated or enclosed. Electrical equipment should be selected and classified for occupancy conditions. Equipment for dispensing flammable liquids or gases should be properly earthed. Hot pipework near combustible materials that cannot be moved elsewhere should be shielded and/or insulated.

4.20. The control of ignition sources during plant operation is covered in Ref. [2].

MULTIUNIT NUCLEAR POWER PLANTS

4.21. In the construction or operation of a multiunit power plant, steps should be taken to ensure that a fire in a unit under construction or in operation would not have any safety consequences for a neighbouring operating unit. Temporary fire separations should be used if necessary to protect the operating units.

4.22. The main control rooms should be adequately separated from possible sites of fire. Consideration should be given to the possibility of fires involving facilities shared between units (para. 5.57 of Ref. [1]).

5. PROVISIONS FOR FIRE DETECTION AND EXTINGUISHING

GENERAL

5.1. In order to protect items important to safety, a nuclear power plant should have a sustained capability for the early detection and effective control of fires. The control of fire is achieved through a combination of fixed fire suppression and extinguishing systems and a manual fire fighting capability. To ensure an adequate level of protection for fire compartments and fire cells, the following elements should be considered in the design of the plant:

(a) Where detection or extinguishing systems are credited as active elements of a fire cell or fire compartment, arrangements for their design, procurement, installation, verification and periodic testing should be sufficiently stringent to ensure their permanent availability. A fire extinguishing system should be included in the assessment against the single failure criterion for the safety function it protects. The application of the single failure criterion is described in paras 5.34–5.39 of Ref. [1].
(b) Where detection systems or fixed fire extinguishing systems are relied upon as protection against a potential fire following a postulated initiating event (e.g. an earthquake), they should be designed to resist the effects of this postulated initiating event.
(c) The normal or the spurious operation of fire extinguishing systems should not impair safety functions.

5.2. All the systems for fire detection and annunciation should be available by the time the nuclear fuel arrives on the site, and sufficient fire extinguishing equipment should be available to protect the fuel from the effects of fire while in storage and in transit. All fire extinguishing systems should be fully operational before the initial fuel loading of the reactor.

5.3. The designed reliability of fire detection and extinguishing systems should be consistent with their role in providing defence in depth and with the recommendations given in Ref. [10].

5.4. The design of fire detection and extinguishing systems should provide for easy access for inspection, maintenance and testing (Section 7 of Ref. [2]).

5.5. The need to minimize spurious alarms and discharges of extinguishant should be taken into account in the design of fire detection and extinguishing systems.

FIRE DETECTION AND ALARM SYSTEMS

5.6. Each fire compartment and fire cell should be equipped with a fire detection and alarm system (Appendix V gives further guidance on fire detection systems).

5.7. The nature of the fire alarm system, its layout, the necessary response time and the characteristics of its detectors should be determined in the fire hazard analysis.

5.8. The detection system should provide detailed annunciation in the control room about the location of the fire (i.e. at the fire cell level) by means of audible and visual alarms. Local audible and visual alarms, as appropriate, should also be provided in plant areas that are normally occupied. Fire alarms should be distinctive and should not be capable of being confused with any other alarms in the plant.

5.9. All detection and alarm systems should be energized at all times and should be provided with non-interruptible emergency power supplies, including fire resistant supply cables where necessary, to ensure functionality in the event of a loss of normal power. (Guidance on emergency power supplies is provided in Refs [10, 11].)

5.10. Individual detectors should be sited so that the flow of air due to ventilation or pressure differences necessitated for contamination control will not cause smoke or heat energy to flow away from the detectors and thus unduly delay actuation of the detector alarm. Fire detectors should also be placed in such a way as to avoid spurious signals due to air currents generated by the operation of the ventilation system. This should be verified by in situ testing.

5.11. In the selection and installation of fire detection equipment, account should be taken of the environment in which the equipment will function (e.g. in terms of radiation fields, humidity, temperature and air flow). If the environment does not allow detectors to be placed in the immediate area to be protected (e.g. owing to increased radiation levels or high temperatures), alternative methods should be considered, such as the sampling of the gaseous atmosphere from the protected area for analysis by remote detectors with automatic operation.

5.12. There should be annunciation of the actuation of any automatic extinguishing system.

5.13. When items such as fire pumps, water spray systems, ventilation equipment and fire dampers are controlled by fire detection systems, and where spurious operation would be detrimental to the plant, operation should be controlled by two diverse means of detection operating in series. The design should allow the operation of the system to be stopped if the actuation is found to be spurious.

5.14. Wiring for fire detection systems, alarm systems or actuation systems should be:

- Protected from the effects of fire by a suitable choice of cable type, by proper routing, by a looped configuration or by other means;
- Protected from mechanical damage;
- Constantly monitored for integrity and functionality.

FIXED PROVISIONS FOR FIRE EXTINGUISHING

General considerations

5.15. Nuclear power plants should be provided with fixed fire extinguishing equipment. This should include provisions for manual fire fighting, such as fire hydrants and fire standpipes.

5.16. The fire hazard analysis should determine the need to provide automatic extinguishing systems such as sprinklers, spray systems, foam, water mist or gaseous systems, or dry chemical systems. The design criteria for fire extinguishing systems should be based on the findings of the fire hazard analysis, so as to ensure that the design is appropriate for each fire hazard that is being protected against.

5.17. In the selection of the type of extinguishing system to be installed, consideration should be given to the necessary response time, the suppression characteristics (e.g. thermal shock) and the consequences of operation of the system for people and for items important to safety (e.g. on reaching criticality conditions during water or foam flooding of nuclear fuel storage areas), as established by the fire hazard analysis.

5.18. In general, water systems should be preferred in areas containing high fire loads, where there is a possibility of deep seated fires and where cooling is necessary. Automatic sprinklers or water spray systems should be used in cable spreading rooms and storage areas, and to protect equipment containing large quantities of oil, such as turbogenerators and oil cooled transformers. Water mist systems are more complex but have the advantage of discharging smaller quantities of water to achieve control. They can be used in various applications but should be individually designed within the bounds of their tested configurations. Gaseous extinguishing systems are usually used in locations containing control cabinets and other electrical equipment susceptible to water damage.

5.19. For prompt operation and availability at the time of a fire emergency, automatic extinguishing systems are preferred. Provision should be made for the manual initiation of automatic systems (except in the case of fusible link or frangible bulb type sprinkler systems). Provision should also be made for manual shut-off of automatic systems, to permit the termination of spurious discharges or the control of water runoff.

5.20. The exclusive use of manually operated extinguishing systems should only be acceptable if the evaluation in the fire hazard analysis demonstrates that the anticipated delay in manual actuation would not result in unacceptable damage.

5.21. Any fixed extinguishing system that is solely manually actuated should be designed to withstand fires for a period of time set to be sufficient to allow for the manual initiation.

5.22. All parts, except for the detection devices themselves, of any electrical activation system or electrical supplies for fire extinguishing systems should be protected from fire or should be located outside the fire compartments protected by the systems. Failure of the electrical supply should give rise to an alarm.

5.23. A formal maintenance, testing and inspection programme should be established in order to provide assurance that fire protection systems and components function correctly and meet the design requirements. Recommendations and guidance on these activities are provided in Ref. [2].

Water based extinguishing systems

5.24. Water based extinguishing systems should be permanently connected to a reliable and adequate supply of fire fighting water (para. 5.40).

5.25. Water based automatic fire extinguishing systems include automatic sprinkler, water spray, deluge, foam and water mist systems. The characteristics of these systems are outlined in Appendix VI. Subject to the findings of a fire hazard analysis, automatic water sprinkler (or spray) protection should be provided at all locations where one of the following factors applies:

— A high fire load is present.
— A potential for rapid spread of fire exists.
— A fire could compromise redundant safety systems.
— An unacceptable hazard for fire fighters could be created.
— An uncontrolled fire would make access for fire fighting difficult.

5.26. If the fire hazard analysis indicates that water alone may not be suitable for successfully coping with the hazard, such as for applications to flammable liquids, consideration should be given to systems using fire fighting foam as the extinguishing medium.

5.27. In addition to the expected fire exposure as determined in the fire hazard analysis, various factors should be addressed in the design of water sprinkler systems. These include: the spacings and locations of sprinkler heads; the selection of either a closed head or an open head system; the temperature rating and thermal response time of the sprinkler head or actuator; and the water discharge rate necessary for a fire to be extinguished. Further discussion of these factors is provided in Appendix VI.

5.28. The component parts of water spray and sprinkler systems should be constructed from compatible materials in order to avoid galvanic corrosion.

Fire hydrant, standpipe and hose systems

5.29. Reactor buildings should be provided with a de-energized fire standpipe and hose system (dry risers). The fire hydrant system for the reactor building should have provisions for local or remote actuation.

5.30. The distribution loop for fire hydrants should provide exterior coverage of the building. Internal standpipes with a sufficient number of fire hoses of sufficient length, and with connections and accessories adequate for the hazard, should be provided to cover all interior areas of the plant.

5.31. Each hydrant hose and standpipe riser should have connections that are compatible with on-site and off-site fire fighting equipment.

5.32. Suitable accessories such as fire hoses, adapters, foam mixing devices and nozzles should be provided at strategically located points throughout the plant, as identified in the fire hazard analysis. The accessories should be compatible with those of external fire services.

5.33. Each branch line to a separate building should be provided with no fewer than two independent hydrant points. Each branch line should be provided with an indicating shut-off valve.

Water supply system for fire extinguishing equipment

5.34. The main loop of the water supply system for the fire extinguishing equipment should be designed to supply the anticipated demand for water (para. 5.39). The distribution of water to the fire extinguishing equipment should be through a main loop such that water can reach each connection from two directions (Fig. 1).

5.35. Valves should be provided to isolate parts of the main loop for the water (Fig. 1). Local visual indications of whether the valves are open or closed should be provided. Valves in the main loop should be so arranged that closure of a single valve should not cause the complete loss of capability of the fire extinguishing system in any given fire compartment in contradiction to the recommendations of the fire hazard analysis. The loop valves for the fire fighting water should be located sufficiently far from the hazard against which they are protecting as to remain unaffected by a fire in that area.

5.36. The water system for the fire extinguishing system should be used only for fire fighting. This water system should not be connected into the piping of the service water or sanitary water systems except as a source of backup supplies of fire fighting water or to perform a safety function to mitigate an accident condition. Such connections should be provided with an isolating valve that is locked in the closed position or should be provided with position monitoring during normal operation.

5.37. The fire fighting water main loop may serve more than one reactor at a multiunit site, and common water supplies may be utilized for such installations.

5.38. At sites where a pumping capability is necessary to provide the amount of water needed, fire pumps should be redundant and separated in the fire context in order to ensure adequate functionality in the event of equipment failure. Fire pumps should have independent controls, automatic start and manual shut-off, diverse power supplies provided by the plant's emergency power supply system and independent prime movers [11]. Alarms indicating pump running, power failure or failure of the fire pumps should be provided in the control room. In areas subject to freezing temperatures, a low temperature alarm should also be provided.

5.39. The water supply system for the fire extinguishing system should be designed on the basis of the highest expected flow rate at the necessary pressure for the minimum period of time required. This flow rate, derived from the fire hazard analysis, should be based on the largest water demand for any fixed fire extinguishing system plus an adequate allowance for manual fire fighting. In the design of the water supply system for the fire extinguishing system, the recommendations on the minimum pressure at the highest outlet in the plant should be taken into account. Any need to prevent freezing under low temperature climatic conditions should be taken into account. Consideration

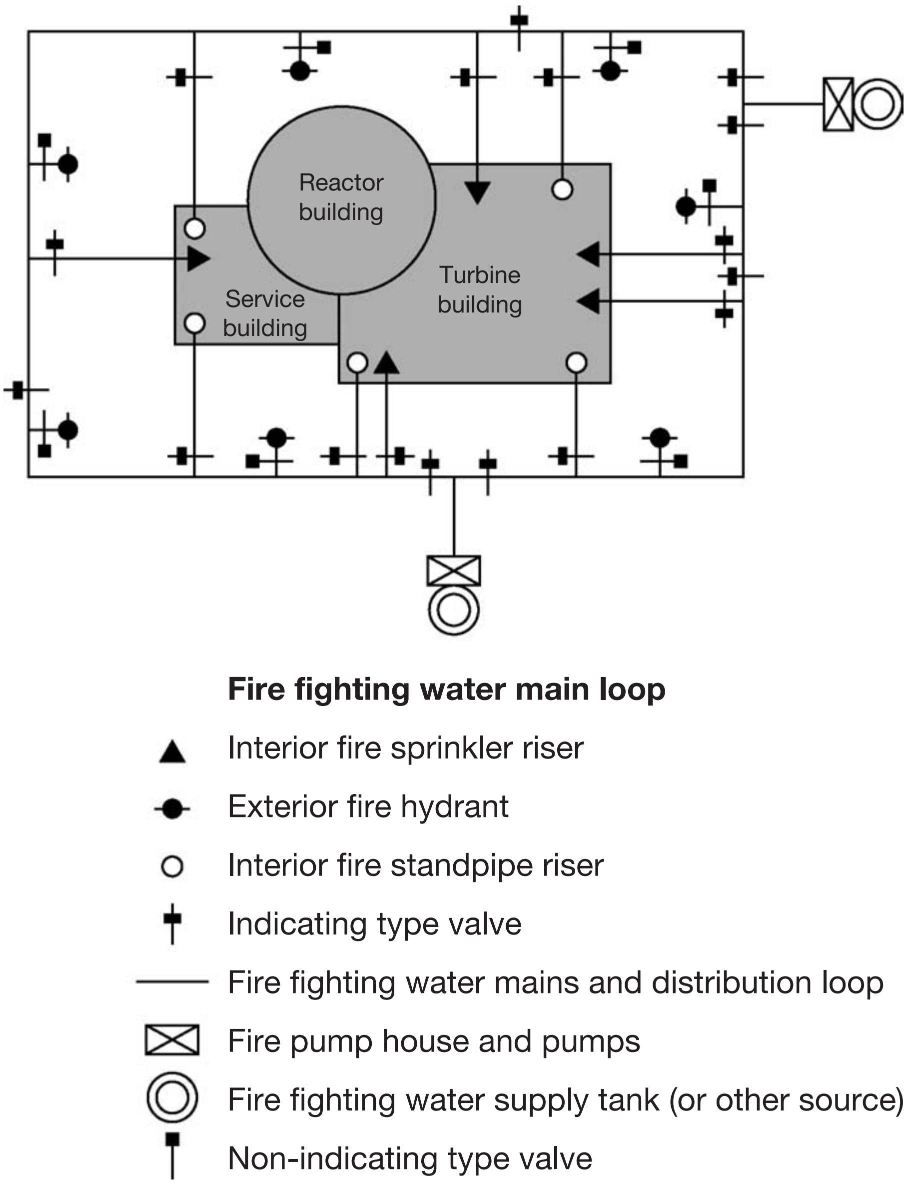

FIG. 1. A possible layout of the supply system for water for the fire extinguishing system.

should be given to the provision of trace heating or other measures to prevent the freezing of vulnerable pipework.

5.40. Two separate reliable water sources should be provided. If only one water source is provided, then it should be sufficiently large (e.g. a lake, pond or river) and at least two independent intakes should be provided. If only water tanks are provided, two tanks, each capable of providing the entire demand for water for the system, should be installed. The main plant water supply capacity should be sufficient to allow refilling of either tank within a sufficiently short period of time. Tanks should be capable of being interconnected so that pumps can take suction from either tank or both tanks. Each tank should be capable of being isolated in the event of a leak. Tanks should be fitted with fire pump connections.

5.41. When a common water supply is provided for fire protection and for the ultimate heat sink[9], the following conditions should also be satisfied:

- The capacity needed to meet the recommendations for the water supply for the fire protection system should be a dedicated part of the total water inventory.
- Failure or operation of the fire protection system should not violate the intended functions of any water supply for the ultimate heat sink, or vice versa.

5.42. The water supply for sprinkler systems may necessitate chemical treatment and additional filtration to ensure that no blockage of the sprinklers occurs from the effects of debris, biological fouling or corrosion products.

5.43. Provision should be made for the inspection of water suppression equipment such as filters, end connections and sprinkler heads. Water flows should be regularly tested by discharge to provide confidence in the continued ability of the system to perform its intended functions throughout the lifetime of the plant. Precautions should be taken to prevent any possible water damage to electrical equipment during testing (para. 3.29).

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[9] The ultimate heat sink is a medium to which the residual heat can always be transferred, even if all other means of heat removal have been lost or are insufficient. This medium is usually a body of water or the atmosphere.

Gaseous extinguishing systems

5.44. Carbon dioxide and halogenated hydrocarbons were the original gaseous fire suppression agents. Halon is no longer available and should not be used owing to its ozone depleting potential. Carbon dioxide continues to be available, as do other gases that are not ozone depleting, such as argon and argon–nitrogen mixtures and chlorofluorocarbons. Owing to the potential for causing a severe hazard to personnel, carbon dioxide systems should never be used to protect areas that are normally occupied.

5.45. Considerations for gaseous fire extinguishing systems are as follows:

(a) In determining the need for gaseous extinguishing systems, consideration should be given to the type of fire, possible chemical reactions with other materials, the effects on charcoal filters, and the toxic and corrosive characteristics of the products of thermal decomposition and of the agents themselves.
(b) Gaseous extinguishants do not have a large cooling effect on a fire. They should not be used where cooling is needed, for example to extinguish deep seated fires such as those in areas containing a high fire load of electrical cable material. When gaseous agents are used to extinguish surface oil fires, consideration should be given to the possibility of re-ignition if the concentration of extinguishant falls below the minimum necessary level before the fuel has cooled.
(c) Gaseous extinguishing systems should be used only in areas where the gas concentration needed to extinguish the fire can be maintained for the necessary period of time.
(d) The design of gaseous extinguishing systems should be such as to avoid overpressures that would result in structural damage or damage to equipment.
(e) The design of gaseous extinguishing systems should ensure that nozzles are sited to avoid fanning the flames of the fire on the initial discharge of the system.
(f) Carbon dioxide extinguishing systems and any other gaseous system with the potential for causing a hazard to personnel should be provided with early warning alarms for prompt evacuation of personnel from the affected area before the system discharges.

5.46. Suitable safety precautions should be taken to protect persons who enter a location where the atmosphere may have become hazardous owing to the inadvertent leakage or discharge of carbon dioxide or any other hazardous gas from an extinguishing system. Such precautions should include:

— Provision of devices to prevent automatic discharge of the system while personnel are, or may be, within the protected space;
— Provision for manual operation of the system from outside the protected space;
— Continued operation of the fire detection and alarm system until the atmosphere has been returned to normal (this can help to avoid premature re-entry with the fire still ignited and can protect personnel from toxic gases);
— Provision of a continuous alarm following the discharge of a gas within the entrances to protected enclosures until the atmosphere has been returned to normal.

5.47. Precautions should be taken to prevent leakage of carbon dioxide or any other hazardous extinguishing gas in dangerous concentrations to adjacent areas that may be occupied by personnel.

5.48. Means should be provided to ventilate the protected enclosure after the discharge of the gaseous protection system. Forced ventilation is often needed to ensure that an atmosphere hazardous to personnel is dissipated and not moved to other areas.

5.49. Consideration should be given to the consequences of the local cooling of items important to safety if such effects are expected to occur during and after the operation of gaseous systems.

5.50. Further guidance on gaseous extinguishing systems is provided in Appendix VII.

Dry powder and chemical extinguishing systems

5.51. Dry powder and chemical fire suppression systems consist of a stored quantity of powder or chemical suppression agent, a source of compressed gas propellant, an associated distribution network, discharge nozzles and provisions for detection and/or actuation. The systems can be either manually operated at the hazard, or remotely or automatically actuated by a detection system. These systems are usually used to protect against flammable liquid fires and certain fires involving electrical equipment. These extinguishing agents should not be used on sensitive electrical equipment since they generally leave a corrosive residue.

5.52. The type of powder or chemical agent selected should be compatible with the combustible material and/or the hazard. Special powders should be used to fight metal fires.

5.53. Careful consideration should be given to the use of dry powder systems in possibly contaminated areas, since decontamination following their discharge may be rendered more difficult owing to residues of contaminated powder. The consequential clogging of filters should also be taken into account.

5.54. The possible adverse effects of using dry powders in conjunction with other extinguishing systems such as foam should be considered; some combinations should not be used.

5.55. Since dry powders do not provide cooling or an inerting atmosphere and only minimally secure the hazard, precautions should be taken to prevent or to reduce the possibility of re-ignition of a fire.

5.56. Dry powder systems are difficult to maintain. Precautions should be taken to ensure that the powder does not compact in its storage container and that the nozzles do not become blocked during discharge.

PORTABLE AND MOBILE FIRE EXTINGUISHING SYSTEMS

5.57. Portable and mobile fire extinguishers of a type and size suitable for the hazards being guarded against should be provided for use in manual fire fighting by plant personnel.

5.58. The entire plant should be equipped with a sufficient number of portable and mobile extinguishers of the appropriate types as well as spares or facilities for recharging. All fire extinguisher locations should be clearly indicated.

5.59. Fire extinguishers should be placed close to the locations of fire hoses and along the escape and access routes for fire compartments.

5.60. Consideration should be given to the possible adverse consequences of the use of extinguishers, such as cleanup problems after use of dry powder extinguishers.

5.61. In plant areas with potential hazards due to flammable liquids, foam concentrate for fire fighting and portable equipment that are suitable for the hazard should be readily available.

5.62. Portable and mobile extinguishers filled with water or foam solution and other extinguishing agents with a neutron moderating capability should not be used in locations where nuclear fuel is stored, handled or passes in transit unless an assessment of the criticality hazard has demonstrated that it is safe to do so.

PROVISIONS FOR MANUAL FIRE FIGHTING

5.63. Manual fire fighting forms an important part of the defence in depth strategy for fire fighting. The extent of reliance on on-site and off-site fire brigades should be established at the design stage. The location of the site and the response time of any off-site fire brigade will affect the necessary level of provision for manual fire fighting. Manual fire fighting capabilities are discussed in Ref. [2].

5.64. The design of the plant should allow for access by fire teams and fire brigades using heavy vehicles.

5.65. Suitable emergency lighting should be provided for all fire compartments.

5.66. A fixed wired emergency communication system with a reliable power supply should be installed at preselected stations [12].

5.67. Alternative communication equipment such as two way radios should be provided in the control room and at selected locations throughout the plant. In addition, portable two way radios should be provided for the fire fighting team. Prior to the first fuel loading, testing should be carried out to demonstrate that the frequencies and transmitter powers used will not cause spurious operation of the protection system and control devices.

5.68. Self-contained breathing apparatus, including spare cylinders and a facility for recharging, should be provided at appropriate locations for the use of the emergency response team.

5.69. Arrangements for plant equipment and for storage in the plant should be designed to facilitate access for fire fighting, as far as practicable.

5.70. Detailed fire fighting strategies should be developed for locations containing items important to safety.

PROVISIONS FOR SMOKE AND HEAT VENTING

5.71. An assessment should be carried out to determine the need for smoke and heat venting, including the need for a dedicated smoke and heat extraction system, to confine the products of combustion and prevent the spread of smoke, to reduce temperatures and to facilitate manual fire fighting.

5.72. In the design of a smoke and heat extraction system, the following criteria should be taken into account: fire load, smoke propagation behaviour, visibility, toxicity, fire brigade access, the type of fixed fire extinguishing system used and radiological aspects.

5.73. The necessary capability of the smoke and heat extraction system should be determined from assessments of the smoke and heat released from the postulated fire for the fire compartment or fire cell (see Section 5 of Ref. [7]). The following locations should have provisions for smoke and heat venting:

- Areas containing a high fire load due to electrical cables;
- Areas containing a high fire load of flammable liquids;
- Areas containing safety systems that are normally occupied by operating personnel (e.g. the main control room).

6. MITIGATION OF SECONDARY FIRE EFFECTS

GENERAL

6.1. The hazardous secondary effects of fire are the production of smoke (with the consequent possibility of its spread to other areas not affected by the originating fire), heat and flame, which may lead to the further spread of fire, to equipment damage, to functional failures and to possible explosive effects. Examples of secondary effects due to extinguishing systems are given in para. 3.29. A fire hazard analysis should be conducted to assess these effects. Secondary effects from transient fire loads and fires of external origin should also be taken into account in the assessment.

6.2. The main objectives in mitigating the effects of a fire are therefore:

- To confine the flame, heat and smoke in a limited space within the plant to minimize spread of the fire and consequential effects on the surrounding plant;
- To provide safe escape and access routes for personnel;
- To provide access to permit manual fire fighting, manual actuation of fixed extinguishing systems and operation by plant personnel of systems necessary to reach and maintain safe shutdown;
- To provide the means for venting of smoke and heat either during or following a fire, if necessary (see Section 5);
- To control the spread of the extinguishing agents to prevent damage to items important to safety.

LAYOUT OF BUILDINGS

6.3. The layout of buildings and equipment, plant ventilation systems and fixed fire extinguishing systems should be taken into account in considering the mitigation of fire effects.

6.4. Adequate protected escape and access routes for the fire fighting teams or field operators should be provided. The routes should be free from combustible materials. The layout of buildings should be arranged to prevent the propagation of fire and smoke from adjacent fire compartments or cells to the escape or access routes. Further details are given in Appendix II.

VENTILATION SYSTEMS

6.5. In order to meet the objectives of para. 6.2, ventilation systems should neither compromise building compartmentation nor compromise the availability of redundant safety systems. These conditions should be addressed in the fire hazard analysis [7].

6.6. Each fire compartment containing a redundant division of a safety system should have an independent and fully separated ventilation system. Parts of the ventilation system (e.g. connecting ducts, fan rooms and filters) that are situated outside the fire compartment should have the same fire resistance as the compartment or, alternatively, the fire compartment penetration should be isolated by rated fire dampers.

6.7. If a ventilation system serves more than one fire compartment, provision should be made to maintain the segregation between fire compartments. Means should be provided to prevent the spread of fire, heat or smoke to other fire compartments by installing fire dampers at the boundaries of each fire compartment or by installing fire resisting duct work, as appropriate.

6.8. Charcoal filter banks contain a high fire load. These should be taken into consideration in determining recommendations for fire protection. A fire in a filter bank may lead to the release of radioactive materials. Passive and active means of protection should be provided to protect charcoal filter banks from fire. Such measures could include:

— Locating the filter in a fire compartment.
— Monitoring of the air temperature and automatic isolation of the air flow.
— Provision of automatic protection by means of a water sprinkler to cool the outside of the filter vessel.
— Provision of a water spray system inside the charcoal vessel with a manual hose connection. In designing such a system, it should be recognized that if the flow rate of the water is too low, the reaction between overheated charcoal and water can result in the production of hydrogen. To prevent this, a high water flow rate should be used.

6.9. Where combustible filters are used in ventilation systems[10] whose subsequent malfunction or failure could result in unacceptable radioactive releases the following precautions should be taken:

— Filter banks should be separated from other equipment by means of adequate fire barriers.
— Appropriate methods (e.g. upstream and downstream dampers) should be used to protect the filters from the effects of fire.
— Fire detectors, carbon monoxide gas sensors (preferably after the filters) or temperature sensors (before the filters) should be installed inside the ducts before and after the filter bank.

6.10. The intakes for the fresh air supply to the fire compartments should be located away from the exhaust air outlets and smoke vents of other fire

[10] The precautions specified should also be applied to non-combustible filters if they might become contaminated by combustible materials such as oil.

compartments to the extent necessary to prevent the intake of smoke or combustion products and the malfunction of items important to safety.

FIRES AND POTENTIAL RADIOACTIVE RELEASES

6.11. Equipment that could release radioactive substances in the event of a fire should be identified in the fire hazard analysis. This equipment should be housed in separate fire compartments where the designed fire loads, fixed or transient, are minimized.

6.12. Consistent with safety, the design may need to provide for fire venting in fire compartments containing radioactive materials. Although venting can result in the release of radioactive material to the outside environment, it can prevent, directly or through the improvement of conditions for fire fighting, the ultimate release of larger quantities of radioactive material. Two cases should be distinguished:

(1) That in which the possible release can be shown to be well below the acceptable limits defined by the regulatory body.
(2) That in which the amount of radioactive material in the fire compartment can make possible a release exceeding the acceptable limits as defined by the regulatory body. In this case a provision should be made for closing the ventilation or fire dampers.

In each case monitoring of the vented air should be performed.

6.13. Design measures should be taken to keep the amount of radioactive material released as low as reasonably achievable. The design should include provisions for monitoring the condition of filters in order to assist operators in taking operational decisions.

LAYOUT AND SYSTEMS FOR ELECTRICAL EQUIPMENT

6.14. Cabling for redundant safety systems should be run in individual specially protected routes, preferably in separate fire compartments, and no cables should cross between redundant divisions of safety systems. As outlined in para. 3.15, exceptions may be necessary in certain locations such as control rooms, cable spreading rooms and the reactor containment. In such cases, the cables should be protected by means of qualified fire rated barriers (e.g. cable wraps). Fire extinguishing systems or other appropriate means may be used, with justifications made in the fire hazard analysis.

PROTECTION AGAINST EXPLOSIONS INDUCED BY FIRE

6.15. The potential for fire related secondary explosions occurring within or adjacent to a fire compartment should be eliminated, as outlined in paras 2.29–2.35 and paras 4.10–4.14. However, if the potential for such an explosion remains, the combined effects of fire and explosion should be assessed, and means should be provided in the design to ensure that neither nuclear safety functions nor the safety of plant personnel carrying out safety tasks are compromised.

SPECIAL LOCATIONS

6.16. The main control room of a nuclear power plant may contain the equipment of different safety systems in close proximity. Particular care should be taken to ensure that non-combustible material is used in control rooms for all electrical cabinets, the room structure itself, any fixed furnishings, and floor and wall finishes. Redundant equipment used to perform the same safety function should be housed in separate electrical cabinets and should have as much physical separation as the location affords. Where this is not possible, fire barriers should be utilized to provide any necessary separation. Every effort should be made to keep the fire load in control rooms to a minimum.

6.17. In order to ensure their habitability, main control rooms should be protected against the ingress of smoke and hot fire gases and against other secondary effects of fire and of the operation of extinguishing systems.

6.18. The fire protection of the supplementary control room should be similar to that of the main control room. Particular emphasis should be placed on protection from flooding and other effects of the operation of fire extinguishing systems. The supplementary control room should be placed in a fire compartment separate from the one containing the main control room, and its ventilation system should not be a common system shared with the main control room. The separations between the main control room, the supplementary control room and their associated ventilation systems should be such as to meet the intent of para. 2.2 after any postulated initiating event such as a fire or explosion.

6.19. The reactor containment is a fire compartment in which items of equipment for redundant divisions of safety systems may be close to each other. Structural materials within this fire compartment as well as fire stops and fire barriers between safety systems should be non-combustible. Redundant divisions of safety systems should be located as far apart as practicable.

6.20. Reactor coolant pump motors containing a large inventory of flammable lubricating oil should be provided with fire detection systems, fixed fire extinguishing systems (normally under manual control) and oil collection systems. The oil collection systems should be capable of collecting oil and water from all potential leakage points or discharge points and draining them to a vented container or another safe location.

6.21. The turbine building may contain items important to safety. Fire compartmentation is often difficult, and substantial fire loads are present. Large inventories of flammable materials are found in the lubricating, cooling and hydraulic systems of the steam turbine(s) and in the hydrogen atmosphere within the generator(s). Consequently, in addition to fire suppression systems, adequate oil collection systems should be provided for all equipment containing flammable liquids. The use of flammable hydrocarbon based lubricating fluids should be minimized. If flammable liquids have to be used they should be liquids with high flashpoints, consistent with the operational requirements.

7. SAFETY CLASSIFICATION AND QUALITY ASSURANCE

SAFETY CLASSIFICATION

7.1. As required in para. 5.1 of Ref. [1], “All structures, systems and components, including software for instrumentation and control (I&C), that are items important to safety shall be first identified and then classified on the basis of their function and significance with regard to safety. They shall be designed, constructed and maintained such that their quality and reliability are commensurate with this classification.”

7.2. The safety significance of the fire protection systems and components is, according to para. 5.2 of Ref. [1], related to the following factors:

— The safety function(s) to be performed by the item;
— The consequences of failure to perform its (safety) function;
— The probability that the item will be called upon to perform a safety function;
— The time following a postulated initiating event at which, or the period throughout which, it will be called upon to operate.

7.3. Since the contribution of fire protection features to achieving the safety objectives (para. 2.1) is dependent upon the design and layout of the plant as well as the details of the approach to fire protection, the safety classification of the fire protection features should be determined at the design stage. Examples of possible classifications are given in paras 7.4 and 7.5.

7.4. Where the fire containment approach is used, equipment belonging to a safety system is surrounded by fire barriers capable of resisting the total burnout of the contents of the fire compartment. If the failure of the barriers to fulfil their function in the event of a fire could prevent the meeting of the objectives defined in para. 2.1, it may be appropriate to classify the fire barriers as a 'safety related item'.

7.5. Where the fire influence approach is used, safety against the spreading of a fire between redundant safety groups is achieved through the limitation of materials, separation by distance, fire shielding or other local passive protection measures, fire extinguishing systems or a combination of these measures. If the failure of the fire detection or extinguishing systems could prevent the meeting of the objectives defined in para. 2.1, it may be appropriate to classify these systems as a 'safety related system' or a 'safety system' depending on the design and layout of the plant.

7.6. Given the potential consequences of a fire for nuclear safety, special consideration should be given in the design of fire protection systems and equipment to quality assurance, qualification tests and in-service testing.

QUALITY ASSURANCE

7.7. Recommendations on and concepts of quality assurance covering fire protection features should be applied from the inception of plant design, through construction, commissioning, operation and into decommissioning. Requirements and recommendations on quality assurance are provided in Ref. [13].

7.8. The quality assurance programme should provide assurances that:

(a) The design meets all the recommendations for fire protection.
(b) All equipment and materials for fire protection meet the procurement specifications based on the fire protection recommendations and general plant drawings. The fire detection and extinguishing equipment should be qualified as suitable for its intended functions and preferably be of a proven type. Newly developed detection and suppression equipment should be subjected to qualification tests.
(c) Plant equipment and materials for fire detection and extinguishing have been fabricated and installed in accordance with design recommendations, and recommended pre-operational and startup testing programmes on fire extinguishing systems and equipment have been satisfactorily completed.
(d) In the event of a fire during construction, commissioning, operation or decommissioning that affects an item important to safety, an evaluation has been made to ensure that the performance capability of the affected item remains at, or is restored to, the design intent.
(e) Fire prevention procedures have been implemented, equipment and systems for fire detection and extinguishing have been tested and are operable, and plant personnel are properly trained in the operation and use of these systems and equipment.

7.9. Controls to be put into effect in implementing the quality assurance programme should be specified in written procedures.

Appendix I

APPLICATIONS OF THE FIRE CONTAINMENT APPROACH AND THE FIRE INFLUENCE APPROACH

I.1. Figure 2 shows applications of the fire containment approach and the fire influence approach.

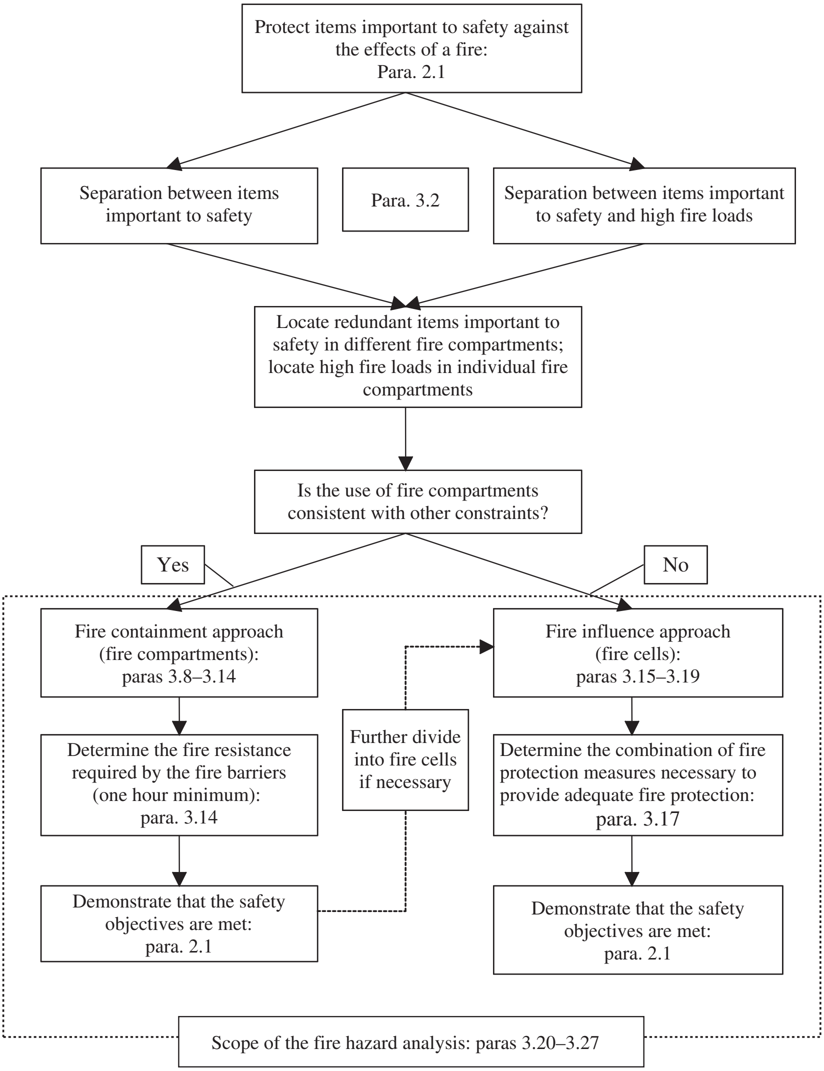

FIG. 2. Applications of the fire containment approach and the fire influence approach.

Appendix II

ACCESS AND RESCUE ROUTES

II.1. Adequate escape and rescue routes for personnel should be provided, with account taken of the requirements of national building codes, fire protection regulations and rules for accident prevention, as well as the recommendations of this Safety Guide. A minimum of two escape routes from every building should be provided. For each route the following general conditions should be met:

(a) Escape and rescue routes should be protected from the effects of fire and smoke. Protected escape and rescue routes comprise staircases and passageways leading to an external exit from the building.
(b) Escape and rescue routes should be kept clear of any stored material.
(c) Fire extinguishers should be placed at appropriate locations along the escape and rescue routes as required by national regulations.
(d) Escape and rescue routes should be clearly and permanently marked and should be easy to recognize. The markings should show the shortest possible safe routes.
(e) The floor level or number should be clearly marked on all staircases.
(f) Emergency lighting should be provided on escape and rescue routes.
(g) Appropriate means for raising the alarm (e.g. fire call points) should be available at all places that have been defined in a risk analysis (which may be the fire hazard analysis), and on all escape routes and building exits.
(h) Escape and rescue routes should have the capability to be ventilated, by either mechanical or other means, to prevent smoke accumulating and to facilitate access.
(i) Staircases that serve as escape and rescue routes should be kept free of all combustible materials. Overpressure ventilation may be necessary in order to keep the staircase free of smoke. It is advisable to make provision for smoke removal from corridors and rooms leading to staircases. For high multistorey staircases, consideration should be given to subdividing the staircase.
(j) Doors leading onto staircases or escape and rescue routes should be of the self-closing and latching type and should open in the direction of escape.
(k) Means should be provided to allow quick evacuation of the reactor containment through airlocks. The measures should be adequate to deal

with the largest number of personnel expected to be present during maintenance periods and outages.

(l) A reliable communication system should be provided for all escape and rescue routes.

Appendix III

FIRE BARRIERS

III.1. The overall purpose of fire barriers in nuclear power plants is to provide a passive boundary around a space (e.g. a fire compartment) with a demonstrated capability to withstand and contain an expected fire without allowing the fire to propagate across to, or otherwise cause direct or indirect damage to, materials or items on the side of the fire barrier not exposed to the fire. The fire barrier is expected to perform this function independently of any fire extinguishing action.

III.2. The fire resistance of fire barriers is characterized by stability, integrity and insulation under fire conditions. The corresponding physical criteria are:

— Mechanical resistance;
— Flame proof capacity and hot or flammable gas proof capacity;
— Thermal insulation, which is considered satisfactory when the temperature of the unexposed face remains below a prescribed value (e.g. 140°C on average and 180°C at any one point).

III.3. The absence of any emission of flammable gases from the face unexposed to the fire should also be verified.

III.4. Passive fire protection systems may be categorized against three performance criteria, depending on their specific function and their potential role in a fire:

— Load bearing capability (stability) — The ability of a specimen of a load bearing element to support its test load, where appropriate, without exceeding specified criteria with regard to either the extent or the rate of deformation or both.
— Integrity — The ability of a specimen of a separating element to contain a fire to specified criteria for collapse, freedom from holes, cracks and fissures, and sustained flaming on the unexposed face.
— Insulation — The ability of a specimen of a separating element to restrict the temperature rise of the unexposed face to below specified levels.

III.5. Within each category, the fire classification of the components is expressed as a 'rating' (minutes or hours) corresponding to the period of time for which the components continue to perform their function or role when subjected to a thermal test programme according to the standards of the International Organization for Standardization (ISO) or other standards.

III.6. The specific functions (load bearing capacity, integrity and insulation) and ratings (e.g. 90 min) of components used as fire barriers (walls, ceilings, floors, doors, dampers, penetration seals and cable wraps) should be specified in the fire hazard analysis.

Appendix IV

PROTECTION AGAINST ELECTRICAL CABLE FIRES

FIRE PROTECTION APPROACH

IV.1. Together with liquid hydrocarbons used as fuel and as lubricating and insulating fluids, the large inventories of organic insulated electrical cable constitute a significant source of combustible material in nuclear power plants. The impact of electrical cable fires on items important to safety should be determined in the fire hazard analysis.

IV.2. Various design approaches have been taken to limit the significant impact of cable fires. Among these approaches are: protecting electrical circuits against overload and short circuit conditions; limiting the total inventory of combustible material in cable installations; reducing the relative combustibility of cable insulation; providing fire protection to limit fire propagation; and providing separation between cables from redundant divisions of safety systems, and between power supply cables and control cables.

CONTROL OF CABLE INVENTORY

IV.3. Controls should be imposed on the quantities of polymer insulated cables installed on cable trays and within cable routes. These controls are necessary to prevent the fire load exceeding the rated resistance of compartment fire barriers and to minimize the rate of spread of fire along cable trays. The controls may include limits on the numbers and sizes of cable trays and/or the loading of insulation upon them, and should correspond to the combustion characteristics of the cables used.

FIRE TESTING

IV.4. While details of qualification tests for fire retardant electrical cables vary according to national standards, large scale flame propagation tests for cables often involve vertical cable samples exposed to a flaming ignition source. Among the important variable factors associated with cable fire tests are:

— The cable inventory as an ignition source,

— Cable layout,
— Resistance to ignition,
— The extent of fire propagation,
— Air flow rate,
— The thermal isolation of the enclosure,
— The toxicity and corrodibility associated with smoke formation.

CABLE FIRE PROTECTION

IV.5. In some circumstances, specific passive protection measures may be necessary to protect electrical cables from fire. Such measures include:

— Cable coatings to reduce the potential for ignition and flame propagation,
— Cable wraps to provide segregation from other fire loads and from other systems,
— Fire stops to limit flame propagation.

Since these measures can lead to overheating of the cable and derating of the current load, these factors should be taken into account in determining the choice of materials to be used.

IV.6. Experience with major electrical cable fires shows that water will promptly extinguish such fires. An automatic water based system (e.g. sprinklers) should be used as the primary extinguishing system for electrical cable fires. Bunches of cables may produce a deep seated fire which is not readily extinguishable by gaseous fire extinguishing agents. If a gaseous system is used for this application, it should be designed with account taken of the possibility of a deep seated fire. Water based systems are generally preferred.

IV.7. Where manual fire fighting is needed to supplement fixed automatic extinguishing systems in locations where there are high concentrations of electrical cables, fire fighters should be given training in the techniques and equipment to be used.

IV.8. This does not mean that fixed water systems should be installed everywhere. Equipment that could be damaged by water should be shielded or relocated away from the fire hazard and the water. Drains should be provided to remove any water used for fire extinguishing, to ensure that the accumulation of water does not incapacitate items important to safety.

IV.9. The potential impact of cable fires can be reduced by providing suitable separation, either by the fire containment approach or by the fire influence approach (Appendix I).

IV.10. In some cases, spatial separation with no intervening combustible materials used, alone or in conjunction with fire safety measures, may provide sufficient separation to preclude damage to redundant items important to safety due to a single credible fire. It is not possible to specify a single minimum distance that would provide adequate safe separation for all circumstances, but rather the adequacy of the separation should be determined by making a careful analysis of particular situations (see Ref. [4] for further guidance on fire hazard analysis).

IV.11. The preferred approach for the separation of redundant divisions of a safety system should be the provision of unpenetrated fire barriers (see Appendix III for a discussion of fire rated barriers and the protection of openings).

Appendix V

FIRE DETECTION SYSTEMS

V.1. This appendix provides further guidance on the factors to be taken into account in the selection of detectors for particular applications.

TYPES OF FIRE DETECTOR

V.2. The main categories of fire detectors are as follows:

(1) Heat detectors, including: (a) frangible bulbs and fusible links, which are generally used as the activating devices in water sprinkler systems; and (b) ceiling mounted point type detectors, linear heat detection cables, temperature probes, and thermocouple and resistance thermometer type detectors, all of which are used in electrically initiated detection systems.
(2) Smoke detectors (or combustion product detectors): the most widely available types are the ionization chamber and the optical type detector. A suction smoke detection system continuously draws atmospheric samples from different locations through tubes that lead to a central smoke detector.
(3) Flame detectors (infrared and ultraviolet detectors): these are used generally for the detection of flames.
(4) Flammable gas detectors: these are used to monitor an area or enclosure where a flammable gas and air mixture could be present.
(5) Early warning 'incipient stage' fire detectors.

DETECTOR FEATURES

V.3. Heat detectors are usually positioned immediately above or around the equipment at risk and are used in applications where the atmospheric conditions might cause spurious alarms in smoke detectors; for example, in areas where there could be oil fumes. Heat detectors are also used to provide an early warning of a temperature rise to a dangerous level in a flammable liquid. A further development in the application of heat detectors is the use of linear heat detection cabling, which can be laid close to the source of the risk (e.g. cable trays) and which will operate if any single point along the length of the cable reaches a certain temperature and can then activate an extinguishing system around this local area alone.

V.4. Smoke detectors will generally detect the onset of fire at an earlier stage than heat detectors and should therefore be preferred for most situations. However, in areas where there may be high levels of ionizing radiation, ionization chamber type detectors should not be used unless they are appropriately qualified for the environment and there is a planned maintenance programme for verifying their continued sensitivity. Care should be taken in the positioning of smoke detectors to ensure that their performance is not adversely affected by ventilation systems.

V.5. Infrared and ultraviolet detectors have the ability to detect flames quickly. They should be utilized in locations such as diesel generator rooms, where the combination of rotating machinery, high heat and flammable liquids can lead to a rapidly growing fire. Care should be taken in the choice of detector to ensure that other infrared or ultraviolet sources (e.g. hot pipes or sunlight) do not cause spurious alarms.

V.6. Flammable gas detectors, suitable for the gases expected to be present, should be installed in locations such as indoor hydrogen storage areas where a flammable gas–air mixture could be expected under normal or accident conditions.

V.7. New types of detector are continually being developed. Some types of detector system are based on air sampling and high sensitivity detection of smoke particles, and are therefore useful for early warning purposes. Other types, which utilize methods of visual comparison, also provide earlier warning than conventional types.

V.8. All detector types can be used as activation devices for fire suppression systems. Owing to their superior reliability, heat detectors are normally used for activating water based extinguishing systems. For areas of high fire hazard where a fast response is necessary, such as stores for flammable liquids, smoke or optical detectors are usually selected. Such detectors are usually also used to activate gaseous systems.

SELECTION OF DETECTOR TYPES AND LOCATION OF DETECTORS

V.9. The selection of the types of fire detector and of the positioning and location of detectors should be made carefully to ensure that the detectors would actuate as expected in response to a fire. Numerous factors affect the response of fire detectors to the growth of a fire, among which are:

- Burning rate,
- Rate of change of the burning rate,
- Characteristics of the burning materials,
- Ceiling height,
- Positions and locations of detectors,
- Locations of walls,
- Positions of any obstructions to gas flow,
- Room ventilation,
- Response characteristics of the detector.

V.10. Analyses should be performed to evaluate the effectiveness of the selected type and locations of the fire detectors.

Appendix VI

AUTOMATIC WATER SPRINKLER AND SPRAY SYSTEMS

VI.1. Water is generally considered to be the most effective agent for extinguishing fires involving ordinary solid combustible materials and flammable liquids. Water sprinklers and water spray systems have been demonstrated to be effective in extinguishing fires involving flammable liquids, including pool fires and pressurized spray fires. Properly designed water spray systems can also be safely applied to live electrical hazards such as transformers.

VI.2. Water sprinkler and water spray systems include all fire protection systems that discharge water for the control and extinguishing of fires. These can be closed head and/or open head systems. In closed head systems, individual sprinkler heads have a fusible or frangible element that prevents the discharge of water until a certain minimum temperature has been reached. In open head systems, water is discharged upon the opening of a valve in the piping system, either manually or automatically.

VI.3. Water mist systems have been developed recently. In these systems the use of either a very high water pressure and impingement nozzles, spiral or vortex nozzles of a special internal design, or two-phase nozzles (e.g. water and pressurized air), generates very small water droplets at the discharge nozzles. Water mist systems have many of the advantages provided by water based systems. Their main benefit is that a relatively low water volume is sufficient to achieve suppression. Owing to the need for higher pressures, water mist systems tend to be more complex. The systems should be installed in accordance with strict pretested arrangements for the plant specific equipment and design.

VI.4. The type and characteristics of the sprinkler heads or discharge nozzles to be used and the arrangement of the system itself should be selected specifically for the particular hazard.

VI.5. In addition to the expected fire exposure as determined in the fire hazard analysis, various factors should be taken into account in the design of water sprinkler and water spray systems. Among these factors are the spacing and locations of sprinkler heads, the temperature rating and the thermal response time of the actuation devices or sprinkler heads, and the water discharge rate necessary for extinguishing a fire.

VI.6. The necessary spacing of the sprinkler heads should be determined on the basis of the discharge characteristics of the individual devices and the expected severity of the fire hazard to be protected against, as determined in the fire hazard analysis. The spacing of sprinkler heads solely on the basis of prescriptive standards would not necessarily result in an adequate level of protection against all fire hazards.

VI.7. The locations of the sprinkler heads should be carefully selected to optimize the response to a fire and the distribution of the water spray, while also minimizing any obstructions to the distribution of water.

VI.8. The temperature ratings of sprinkler heads should be selected so that the normal maximum ambient temperature is suitably below the rated actuation temperature of the head.

VI.9. Where rapid actuation of the sprinkler system is determined in the fire hazard analysis to be necessary, sprinkler heads with a quicker response time should be used, for example a deluge system released by smoke detectors of the fire detection system.

VI.10. The discharge rate or discharge density of water is the critical parameter in determining whether sprinklers would be effective in extinguishing a particular fire. The discharge density from a sprinkler system is a function of the orifice size of the sprinkler head, the volume and pressure of water available from the water supply system, and the size and arrangement of the sprinkler piping system. The expected discharge density can be determined by means of hydraulic calculations. Design discharge densities should be carefully selected to match the expected fire intensity.

VI.11. The discharge of water from sprinkler systems, either in response to an actual fire or from spurious actuation of the sprinkler, can result in the spurious operation of electrical systems that are sensitive to moisture. The potential for, and the consequences of, spurious operation due to the discharge of sprinklers should be evaluated in the fire hazard analysis. Sensitive components of systems important to safety may need special shielding against the intrusion of water.

VI.12. Where water based extinguishing systems are used, means should be provided to confine potentially contaminated water, and adequate drains should be provided with arrangements to prevent any uncontrolled release of radioactive material to the environment.

VI.13. To provide a prompt response to fires, sprinkler systems should preferably be automatically actuated. Manually operated sprinkler systems should be used only in cases where it has been clearly demonstrated in the fire hazard analysis that delayed operation of the sprinkler system in a fire emergency would not compromise plant safety.

Appendix VII

GASEOUS FIRE EXTINGUISHING SYSTEMS

VII.1. Gaseous extinguishing agents are usually termed clean agents as they leave no residue upon actuation. Since they are also non-conductive, their combined characteristics make them suitable for protecting electrical equipment. Several types of gaseous extinguishing systems are available and more are under development. The advantages of clean agent systems are offset by the need for the concentration of the agent to be maintained, the complexity of the systems, their inability to provide cooling and the single use nature of their operation.

VII.2. There are generally two methods of providing protection with gaseous extinguishing agents: (1) local application, where the agent is discharged towards the hazard or a particular piece of equipment; (2) total flooding, where the agent is discharged into a fire compartment or into enclosed equipment such as switchgear. Some extinguishing agents are unsuitable for local application.

VII.3. The total quantity of any gaseous extinguishing agent should be sufficient to extinguish the fire. This is usually accomplished, except for halogenated agents, by means of oxygen dilution. In determining the quantity of agent necessary, account should be taken of the leaktightness of the enclosure, the necessary extinguishing concentration for the particular hazard, the rate of application and the period for which the design concentration is to be maintained.

VII.4. The structural effects of the buildup of pressure within the protected enclosures resulting from the discharge of gaseous extinguishing agents should be evaluated, and provision should be made for safe venting where necessary. Caution is necessary in selecting venting arrangements so as not to transfer the overpressure or environmental conditions into the relieving area.

VII.5. Consideration should be given to the potential for damage due to thermal shock when gaseous extinguishing systems are discharged directly onto equipment. This may occur during local manual applications and during automatic discharges into electrical cabinets.

VII.6. Fire extinguishing agents consisting of halogenated hydrocarbons extinguish fires by inhibiting the chemical reaction. These agents vaporize before or during application and leave no particulate residue. An undesirable aspect of some of these agents (i.e. halons) is the release of volatile bromine, which has a deleterious effect on the earth's ozone layer. Consequently, the use of halons is being phased out.

VII.7. All total flooding applications need a rapid and even distribution of gas throughout the space that is flooded. This is usually achieved within 10–30 s of actuation by the use of special nozzles and an adequate system designed to proprietary specifications. Rapid distribution of gas is particularly important when the gaseous agent is heavier than air, in order to minimize the stratification of gas within the space and its potentially more rapid leakage.

VII.8. For all gaseous suppression systems, an operational test is usually necessary in commissioning, either by means of actual discharge tests or by the use of equivalent methods such as room pressurization.

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