

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.

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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 programme¹ 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

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 events² [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 material³ 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 loads⁴ 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.

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 spurious⁵ 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 cell⁷ (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: