

# IAEA Safety Standards

for protecting people and the environment

## Protection against Internal Hazards in the Design of Nuclear Power Plants

Specific Safety Guide

No. SSG-64



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## IAEA SAFETY STANDARDS

Under the terms of Article III of its Statute, the IAEA is authorized to establish or adopt standards of safety for protection of health and minimization of danger to life and property, and to provide for the application of these standards.

The publications by means of which the IAEA establishes standards are issued in the **IAEA Safety Standards Series**. This series covers nuclear safety, radiation safety, transport safety and waste safety. The publication categories in the series are **Safety Fundamentals**, **Safety Requirements** and **Safety Guides**.

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All users of IAEA safety standards are invited to inform the IAEA of experience in their use (e.g. as a basis for national regulations, for safety reviews and for training courses) for the purpose of ensuring that they continue to meet users' needs. Information may be provided via the IAEA Internet site or by post, as above, or by email to [Official.Mail@iaea.org](mailto:Official.Mail@iaea.org).

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The IAEA provides for the application of the standards and, under the terms of Articles III and VIII.C of its Statute, makes available and fosters the exchange of information relating to peaceful nuclear activities and serves as an intermediary among its Member States for this purpose.

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PROTECTION AGAINST  
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IN THE DESIGN OF  
NUCLEAR POWER PLANTS



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IAEA SAFETY STANDARDS SERIES No. SSG-64

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SPECIFIC SAFETY GUIDE

INTERNATIONAL ATOMIC ENERGY AGENCY  
VIENNA, 2021

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# FOREWORD

**by Rafael Mariano Grossi**  
**Director General**

The IAEA's Statute authorizes it to "establish...standards of safety for protection of health and minimization of danger to life and property". These are standards that the IAEA must apply to its own operations, and that States can apply through their national regulations.

The IAEA started its safety standards programme in 1958 and there have been many developments since. As Director General, I am committed to ensuring that the IAEA maintains and improves upon this integrated, comprehensive and consistent set of up to date, user friendly and fit for purpose safety standards of high quality. Their proper application in the use of nuclear science and technology should offer a high level of protection for people and the environment across the world and provide the confidence necessary to allow for the ongoing use of nuclear technology for the benefit of all.

Safety is a national responsibility underpinned by a number of international conventions. The IAEA safety standards form a basis for these legal instruments and serve as a global reference to help parties meet their obligations. While safety standards are not legally binding on Member States, they are widely applied. They have become an indispensable reference point and a common denominator for the vast majority of Member States that have adopted these standards for use in national regulations to enhance safety in nuclear power generation, research reactors and fuel cycle facilities as well as in nuclear applications in medicine, industry, agriculture and research.

The IAEA safety standards are based on the practical experience of its Member States and produced through international consensus. The involvement of the members of the Safety Standards Committees, the Nuclear Security Guidance Committee and the Commission on Safety Standards is particularly important, and I am grateful to all those who contribute their knowledge and expertise to this endeavour.

The IAEA also uses these safety standards when it assists Member States through its review missions and advisory services. This helps Member States in the application of the standards and enables valuable experience and insight to be shared. Feedback from these missions and services, and lessons identified from events and experience in the use and application of the safety standards, are taken into account during their periodic revision.

I believe the IAEA safety standards and their application make an invaluable contribution to ensuring a high level of safety in the use of nuclear technology. I encourage all Member States to promote and apply these standards, and to work with the IAEA to uphold their quality now and in the future.

# THE IAEA SAFETY STANDARDS

## BACKGROUND

Radioactivity is a natural phenomenon and natural sources of radiation are features of the environment. Radiation and radioactive substances have many beneficial applications, ranging from power generation to uses in medicine, industry and agriculture. The radiation risks to workers and the public and to the environment that may arise from these applications have to be assessed and, if necessary, controlled.

Activities such as the medical uses of radiation, the operation of nuclear installations, the production, transport and use of radioactive material, and the management of radioactive waste must therefore be subject to standards of safety.

Regulating safety is a national responsibility. However, radiation risks may transcend national borders, and international cooperation serves to promote and enhance safety globally by exchanging experience and by improving capabilities to control hazards, to prevent accidents, to respond to emergencies and to mitigate any harmful consequences.

States have an obligation of diligence and duty of care, and are expected to fulfil their national and international undertakings and obligations.

International safety standards provide support for States in meeting their obligations under general principles of international law, such as those relating to environmental protection. International safety standards also promote and assure confidence in safety and facilitate international commerce and trade.

A global nuclear safety regime is in place and is being continuously improved. IAEA safety standards, which support the implementation of binding international instruments and national safety infrastructures, are a cornerstone of this global regime. The IAEA safety standards constitute a useful tool for contracting parties to assess their performance under these international conventions.

## THE IAEA SAFETY STANDARDS

The status of the IAEA safety standards derives from the IAEA's Statute, which authorizes the IAEA to establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned, standards of safety for protection of health and minimization of danger to life and property, and to provide for their application.

With a view to ensuring the protection of people and the environment from harmful effects of ionizing radiation, the IAEA safety standards establish fundamental safety principles, requirements and measures to control the radiation exposure of people and the release of radioactive material to the environment, to restrict the likelihood of events that might lead to a loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation, and to mitigate the consequences of such events if they were to occur. The standards apply to facilities and activities that give rise to radiation risks, including nuclear installations, the use of radiation and radioactive sources, the transport of radioactive material and the management of radioactive waste.

Safety measures and security measures<sup>1</sup> have in common the aim of protecting human life and health and the environment. Safety measures and security measures must be designed and implemented in an integrated manner so that security measures do not compromise safety and safety measures do not compromise security.

The IAEA safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from harmful effects of ionizing radiation. They are issued in the IAEA Safety Standards Series, which has three categories (see Fig. 1).

### **Safety Fundamentals**

Safety Fundamentals present the fundamental safety objective and principles of protection and safety, and provide the basis for the safety requirements.

### **Safety Requirements**

An integrated and consistent set of Safety Requirements establishes the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements are governed by the objective and principles of the Safety Fundamentals. If the requirements are not met, measures must be taken to reach or restore the required level of safety. The format and style of the requirements facilitate their use for the establishment, in a harmonized manner, of a national regulatory framework. Requirements, including numbered ‘overarching’ requirements, are expressed as ‘shall’ statements. Many requirements are not addressed to a specific party, the implication being that the appropriate parties are responsible for fulfilling them.

### **Safety Guides**

Safety Guides provide recommendations and guidance on how to comply with the safety requirements, indicating an international consensus that it

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<sup>1</sup> See also publications issued in the IAEA Nuclear Security Series.

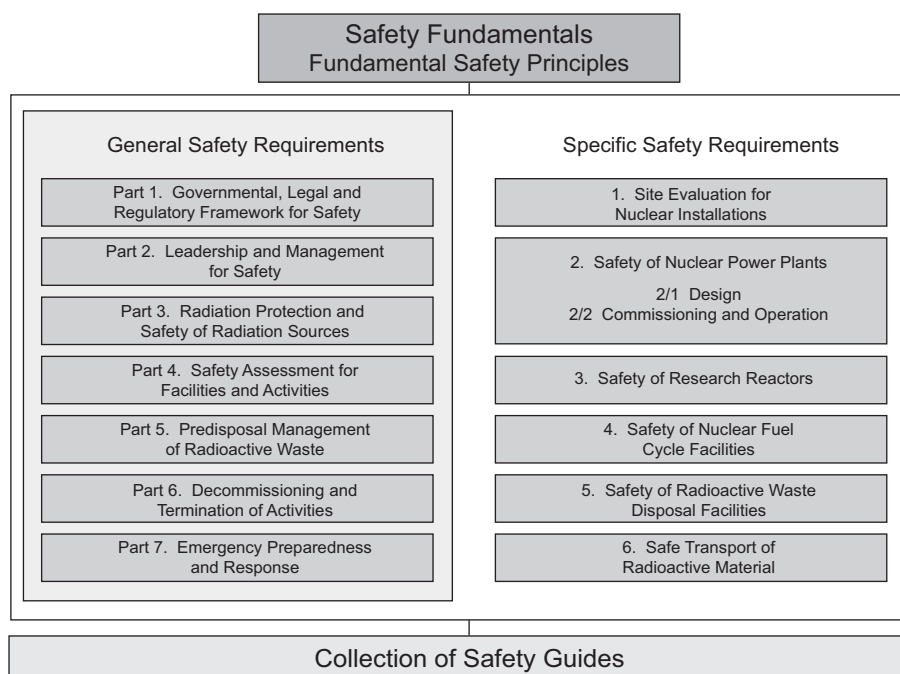


FIG. 1. The long term structure of the IAEA Safety Standards Series.

is necessary to take the measures recommended (or equivalent alternative measures). The Safety Guides present international good practices, and increasingly they reflect best practices, to help users striving to achieve high levels of safety. The recommendations provided in Safety Guides are expressed as ‘should’ statements.

## APPLICATION OF THE IAEA SAFETY STANDARDS

The principal users of safety standards in IAEA Member States are regulatory bodies and other relevant national authorities. The IAEA safety standards are also used by co-sponsoring organizations and by many organizations that design, construct and operate nuclear facilities, as well as organizations involved in the use of radiation and radioactive sources.

The IAEA safety standards are applicable, as relevant, throughout the entire lifetime of all facilities and activities — existing and new — utilized for peaceful purposes and to protective actions to reduce existing radiation risks. They can be

used by States as a reference for their national regulations in respect of facilities and activities.

The IAEA's Statute makes the safety standards binding on the IAEA in relation to its own operations and also on States in relation to IAEA assisted operations.

The IAEA safety standards also form the basis for the IAEA's safety review services, and they are used by the IAEA in support of competence building, including the development of educational curricula and training courses.

International conventions contain requirements similar to those in the IAEA safety standards and make them binding on contracting parties. The IAEA safety standards, supplemented by international conventions, industry standards and detailed national requirements, establish a consistent basis for protecting people and the environment. There will also be some special aspects of safety that need to be assessed at the national level. For example, many of the IAEA safety standards, in particular those addressing aspects of safety in planning or design, are intended to apply primarily to new facilities and activities. The requirements established in the IAEA safety standards might not be fully met at some existing facilities that were built to earlier standards. The way in which IAEA safety standards are to be applied to such facilities is a decision for individual States.

The scientific considerations underlying the IAEA safety standards provide an objective basis for decisions concerning safety; however, decision makers must also make informed judgements and must determine how best to balance the benefits of an action or an activity against the associated radiation risks and any other detrimental impacts to which it gives rise.

## DEVELOPMENT PROCESS FOR THE IAEA SAFETY STANDARDS

The preparation and review of the safety standards involves the IAEA Secretariat and five Safety Standards Committees, for emergency preparedness and response (EPReSC) (as of 2016), nuclear safety (NUSSC), radiation safety (RASSC), the safety of radioactive waste (WASSC) and the safe transport of radioactive material (TRANSSC), and a Commission on Safety Standards (CSS) which oversees the IAEA safety standards programme (see Fig. 2).

All IAEA Member States may nominate experts for the Safety Standards Committees and may provide comments on draft standards. The membership of the Commission on Safety Standards is appointed by the Director General and includes senior governmental officials having responsibility for establishing national standards.

A management system has been established for the processes of planning, developing, reviewing, revising and establishing the IAEA safety standards.

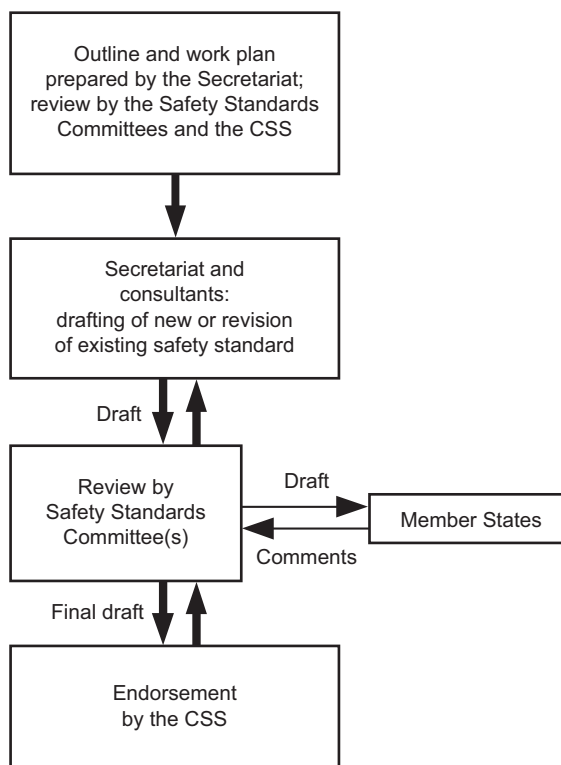


FIG. 2. The process for developing a new safety standard or revising an existing standard.

It articulates the mandate of the IAEA, the vision for the future application of the safety standards, policies and strategies, and corresponding functions and responsibilities.

## INTERACTION WITH OTHER INTERNATIONAL ORGANIZATIONS

The findings of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the recommendations of international expert bodies, notably the International Commission on Radiological Protection (ICRP), are taken into account in developing the IAEA safety standards. Some safety standards are developed in cooperation with other bodies in the United Nations system or other specialized agencies, including the Food and Agriculture Organization of the United Nations, the United Nations Environment Programme, the International Labour Organization, the OECD Nuclear Energy Agency, the Pan American Health Organization and the World Health Organization.

## INTERPRETATION OF THE TEXT

Safety related terms are to be understood as defined in the IAEA Safety Glossary (see <https://www.iaea.org/resources/safety-standards/safety-glossary>). Otherwise, words are used with the spellings and meanings assigned to them in the latest edition of The Concise Oxford Dictionary. For Safety Guides, the English version of the text is the authoritative version.

The background and context of each standard in the IAEA Safety Standards Series and its objective, scope and structure are explained in Section 1, Introduction, of each publication.

Material for which there is no appropriate place in the body text (e.g. material that is subsidiary to or separate from the body text, is included in support of statements in the body text, or describes methods of calculation, procedures or limits and conditions) may be presented in appendices or annexes.

An appendix, if included, is considered to form an integral part of the safety standard. Material in an appendix has the same status as the body text, and the IAEA assumes authorship of it. Annexes and footnotes to the main text, if included, are used to provide practical examples or additional information or explanation. Annexes and footnotes are not integral parts of the main text. Annex material published by the IAEA is not necessarily issued under its authorship; material under other authorship may be presented in annexes to the safety standards. Extraneous material presented in annexes is excerpted and adapted as necessary to be generally useful.

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# 1. INTRODUCTION

## BACKGROUND

1.1. This Safety Guide provides recommendations on how to meet the requirements established in IAEA Safety Standards Series No. SSR-2/1 (Rev. 1), Safety of Nuclear Power Plants: Design [1], in relation to protection against internal hazards in the design of land based stationary nuclear power plants with water cooled reactors.

1.2. This Safety Guide is a revision and merger of IAEA Safety Standards Series No. NS-G-1.11, Protection against Internal Hazards other than Fires and Explosions in the Design of Nuclear Power Plants<sup>1</sup>, and IAEA Safety Standards Series No. NS-G-1.7, Protection against Internal Fires and Explosions in the Design of Nuclear Power Plants<sup>2</sup>, both of which are superseded by this Safety Guide. This revision principally consists of updating the technical content to make it consistent with the requirements established in SSR-2/1 (Rev. 1) [1]. In addition, internal hazards due to electromagnetic fields or electromagnetic interference, and those due to the release of hazardous substances originating from within the site boundary are included in the scope of this Safety Guide.

## OBJECTIVE

1.3. The objective of this Safety Guide is to provide recommendations to regulatory bodies, nuclear power plant designers and licensees on hazard assessment (including for combinations of hazards) and design concepts for protection against internal hazards in nuclear power plants, in order to meet the requirements established in SSR-2/1 (Rev. 1) [1].

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<sup>1</sup> INTERNATIONAL ATOMIC ENERGY AGENCY, Protection against Internal Hazards other than Fires and Explosions in the Design of Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-1.11, IAEA, Vienna (2004).

<sup>2</sup> INTERNATIONAL ATOMIC ENERGY AGENCY, Protection against Internal Fires and Explosions in the Design of Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-1.7, IAEA, Vienna (2004).

## SCOPE

1.4. 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). For innovative developments in future systems, for plant modifications or for other reactor types, some parts of this Safety Guide might not be fully applicable or might need some judgement in their interpretation.

1.5. This Safety Guide covers the design features necessary to protect items (i.e. structures, systems and components (SSCs)) important to safety in nuclear power plants against the effects of internal hazards during all modes of operation. The following internal hazards are reviewed in this Safety Guide: fires, explosions, missiles, pipe breaks, flooding, collapse of structures and falling objects with a focus on heavy load drop, electromagnetic interference and release of hazardous substances originating from within the site boundary.

1.6. This Safety Guide does not cover conventional industrial safety, except where this could affect the safety of the nuclear power plant.

1.7. The recommendations provided in this Safety Guide are targeted primarily at new nuclear power plants. For plants designed with earlier standards, it is expected that in the safety assessments of such designs a comparison will be made with the current standards (for example as part of the periodic safety reassessment for the plant), to determine whether the safe operation of the plant could be further enhanced by means of reasonably practicable safety improvements: see para. 1.3 of SSR-2/1 (Rev. 1) [1].

## STRUCTURE

1.8. Section 2 outlines general considerations for protection against internal hazards in nuclear power plants. Section 3 provides general design recommendations for protection against internal hazards in nuclear power plants. Section 4 provides specific recommendations for protection against fires, explosions, missiles, pipe breaks, flooding, collapses of structures and falling objects with a focus on heavy load drop, electromagnetic interference and release of hazardous substances originating within the site boundary. Appendix I provides guidance on dealing with hazard combinations. Appendix II provides detailed guidance on protection against internal fires.

## 2. GENERAL CONSIDERATIONS

2.1. Requirement 17 of SSR-2/1 (Rev. 1) [1] states:

**“All foreseeable internal hazards and external hazards, including the potential for human induced events directly or indirectly to affect the safety of the nuclear power plant, shall be identified and their effects shall be evaluated. Hazards shall be considered in designing the layout of the plant and in determining the postulated initiating events and generated loadings for use in the design of relevant items important to safety for the plant.”**

2.2. Paragraph 5.16 of SSR-2/1 (Rev. 1) [1] states:

“The design shall take due account of internal hazards such as fire, explosion, flooding, missile generation, collapse of structures and falling objects, pipe whip, jet impact and release of fluid from failed systems or from other installations on the site. Appropriate features for prevention and mitigation shall be provided to ensure that safety is not compromised.”

2.3. Sections 3 and 4 of this Safety Guide provide general design recommendations and specific design recommendations, respectively, to meet Requirement 17 and the requirements established in para. 5.16 of SSR-2/1 (Rev. 1) [1] regarding internal hazards.

2.4. An item important to safety is an item that is part of a safety group and/or whose malfunction or failure could lead to radiation exposure of the site personnel or members of the public [2]. In accordance with this definition, and the definition of design extension conditions in SSR-2/1 (Rev. 1) [1], safety features for design extension conditions are items important to safety. Therefore, safety features for design extension conditions need to be designed or protected against applicable internal hazards. In addition, safety features for design extension conditions could be sources of internal hazards that need to be considered.

2.5. Internal hazards are those hazards to the safety of the nuclear power plant that originate from within the site boundary and are associated with failures of facilities and activities that are under the control of the operating organization. The internal hazards covered in this Safety Guide are listed in para. 1.5.

2.6. The hazards caused by (or occurring at) other facilities on the same site are also considered to be internal hazards.

2.7. Internal hazards can also be generated by external hazards (e.g. an earthquake followed by an internal flood, an earthquake causing a fire).

2.8. Effects induced by internal hazards can also result in cascading effects and induce other internal hazards (e.g. a missile can cause a pipe break and then internal flooding).

2.9. All credible combinations of hazards (see Appendix I) are also considered within the scope of this Safety Guide.

2.10. Internal hazards have the potential to induce initiating events, to cause failures of equipment that is necessary to mitigate the consequences of such events and to adversely affect (directly or indirectly) the barriers for the prevention of the release of radioactive material. Internal hazards could, because of their nature, simultaneously challenge more than one level of defence in depth, and increase, for example, the degree of dependency between the originator of initiating events and the failure of mitigation equipment.

2.11. While it might not be practical or possible to prevent an internal hazard from triggering an anticipated operational occurrence, one of the objectives of layout and design of the nuclear power plant is to ensure, to the extent practicable, that internal hazards do not trigger an accident.

2.12. The aim of considering internal hazards in the design of nuclear power plants is to ensure that the fundamental safety functions (see Requirement 4 of SSR-2/1 (Rev. 1) [1]) are fulfilled in any plant state, and that the plant can be brought to and maintained in a safe state after the occurrence of any credible internal hazard. This implies the following:

- (a) Redundant systems are segregated to the extent possible or adequately separated, and protected as necessary, to prevent the loss of the safety function performed by the systems.
- (b) The design of individual SSCs is such that design basis accidents, or design extension conditions potentially induced by internal hazards, are avoided to the extent practicable.
- (c) The segregation, separation and protection measures implemented are adequate to ensure that the system response described in the analysis of postulated initiating events is not compromised by the effects of the internal hazard.

- (d) The design is such that an internal hazard does not lead to a common cause failure between redundant safety systems designed to control design basis accidents, and between these systems and the safety features necessary in the event of design extension conditions with core melting.
- (e) An internal hazard occurring elsewhere in the plant does not affect the habitability of the main control room. If the main control room is not habitable, access to, and habitability of the supplementary control room are ensured. In addition, and when necessary, access by plant personnel to equipment in order to perform local actions is possible.

2.13. In accordance with the concept of defence in depth, the first level of defence in depth provides protection against internal hazards in general by ensuring the high quality and reliability of SSCs, by environmental qualification of these SSCs, by application of the principles of redundancy and diversity, by physical separation and segregation, and by design of appropriate barriers and other protective means. Therefore, design against the effects of internal hazards is an iterative process, integrating the needs of protection against several internal hazards. Proper surveillance and in-service inspections of SSCs need to be implemented for early detection of the occurrence of an internal hazard (or of signs that can lead to the occurrence of an internal hazard) and implementation of necessary corrective actions to ensure protection against the hazard. Identification of hazards at an early stage in the design is often used as a practical method to identify and eliminate hazards.

### **3. GENERAL DESIGN RECOMMENDATIONS FOR PROTECTION AGAINST INTERNAL HAZARDS**

3.1. Notwithstanding the measures taken to minimize the likelihood of an internal hazard, such hazards are possible. The capability of the nuclear power plant to withstand internal hazards and to mitigate the effects of postulated initiating events caused by them is required to be an integral part of the design of the plant: see para. 5.16 of SSR-2/1 (Rev. 1) [1].

3.2. The design approach proposed in this Safety Guide for the protection of items important to safety and, as applicable, of plant personnel performing actions to protect against internal hazards, is based on the following major steps:

- (a) Identification of internal hazards and credible combinations of hazards, and characterization of the effects of the hazard(s);
- (b) Design for preventing internal hazards or for preventing the adverse effects of internal hazards;
- (c) Design of means for mitigating the adverse effects of internal hazards on items important to safety.

The design approach also includes the assessment of the protection against internal hazards, consistent with the design objectives in para. 2.12, and the verification that these objectives are met for all credible hazards at the plant.

3.3. The design for the protection against internal hazards should take into account design recommendations for safety and design recommendations for security in an integrated manner, such that safety measures and security measures do not compromise each other. Recommendations on nuclear security are provided in Ref. [3].

3.4. Certain postulated internal hazards might be of such magnitude that providing design features to mitigate the effects of these hazards is not practicable (e.g. an uncontrolled drop of the reactor vessel head). In such cases, the focus is on prevention, and an evaluation should be performed to ensure, with a high level of confidence, that such events are extremely unlikely. Even if such events cannot be completely prevented, design measures are still required to be implemented to mitigate the consequences of such events to the extent practicable: see para. 2.8 of SSR-2/1 (Rev. 1) [1].

3.5. 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 internal hazards.

## IDENTIFICATION AND CHARACTERIZATION OF INTERNAL HAZARDS AND HAZARD COMBINATIONS

3.6. In plant design, internal hazards should be identified using a combination of engineering judgement, operating experience and lessons from similar plant designs, and the results of deterministic safety assessments and probabilistic

safety assessments. The identification and the characterization of internal hazards should include a consideration of the initial conditions (e.g. plant shutdown modes), the magnitude and the likelihood of the hazards, the locations of the sources of the hazards, the resulting environmental conditions and the possible impacts on SSCs important to safety or on other SSCs for which failure could lead to a postulated initiating event. The hazard identification and characterization process should be rigorous, well documented and supported by plant walkdowns for verification purposes.

3.7. Possible combinations of internal–internal and internal–external hazards and any consequential effects (e.g. high energy pipe break, pipe whip, jet effect, flooding) are required to be considered in the design of the plant: see para. 5.32 of SSR-2/1 (Rev. 1) [1]. The combinations to be considered will depend on the site characteristics and the general plant design.<sup>3</sup>

3.8. All credible combination of hazards should be considered in the design. The screening out of any combinations should be justified (see Appendix I).

3.9. The identification of hazards includes assumptions about their characteristics. Bounding or conservative assumptions could be made about these characteristics in order to address uncertainties, provided these assumptions are justified.

3.10. Paragraph 5.15A of SSR-2/1 (Rev. 1) [1] states:

“Items important to safety shall be designed and located, with due consideration of other implications for safety, to withstand the effects of hazards or to be protected, in accordance with their importance to safety, against hazards and against common cause failure mechanisms generated by hazards.”

The relevant internal hazards are required to be identified, and the effects and environmental conditions created by these hazards are required to be evaluated and taken into account in the design and layout of the plant: see Requirement 17 of SSR-2/1 (Rev. 1) [1]. This is considered in paras 3.11–3.34, which also apply, as appropriate, to internal hazards resulting from combinations of hazards.

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<sup>3</sup> For example, some combinations of hazards might involve external events that are not plausible in certain locations (e.g. sandstorms, blizzards). Therefore, it is not necessary or even feasible to prescribe a set of combined hazards that would be applicable to all sites.

## PREVENTION OF INTERNAL HAZARDS AND OF THE EFFECTS OF THE HAZARDS

3.11. Some hazards may be screened out either because they are physically impossible (e.g. heavy load drop if there is no lifting equipment) or by a stringent justification, including, at a minimum, very high quality design, manufacturing, construction, in-service inspection and due consideration of feedback from operating experience.

3.12. When hazards cannot be screened out, measures, including administrative ones, should be implemented to reduce the frequency and potential magnitude of the hazards and their effects on SSCs important to safety. This should be mainly achieved by reducing, as far as practicable, the potential sources of hazards (e.g. limiting the use of combustible materials and the presence of ignition sources), supported by surveillance and in-service inspections. It can also be achieved by location and layout (e.g. ensuring the best orientation of fast rotating machines).

## MITIGATION OF THE EFFECTS OF INTERNAL HAZARDS

3.13. For each internal hazard that is considered in the design, measures should be implemented to control and to limit the consequences. These measures will depend on the type of hazard and on the specific technical solutions included in the design. In general, specific measures for the detection of the occurrence of the respective hazard should also be included.

3.14. The design features for protection from the effects of internal hazards are required to be safety classified: see Requirement 22 of SSR-2/1 (Rev. 1) [1]. This safety classification should be conducted in accordance with the recommendations provided in IAEA Safety Standards Series No. SSG-30, Safety Classification of Structures, Systems and Components in Nuclear Power Plants [4]. Protective design features are required to be classified on the basis of their function and their safety significance: see para. 5.34 of SSR-2/1 (Rev. 1) [1].

3.15. Measures to mitigate the consequences of events can be passive, active or procedural. Passive design solutions — without moving parts or an external energy supply — are generally considered preferable to the implementation of active measures or of procedures.

3.16. For active protective features, where applicable, the worst single failure should be assumed.

3.17. The consideration of failure of a passive protective feature is not necessary, provided that it is demonstrated that its failure is very unlikely and that its function would remain unaffected by the postulated hazard (see para. 5.40 of SSR-2/1 (Rev. 1) [1]).

3.18. If it is feasible, the early detection of the occurrence of internal hazards, supported by appropriate actions in response to the detection of the hazard, contributes to the mitigation of the possible consequences.

3.19. Measures for mitigation of the effects of internal hazards should include, as appropriate, redundancy, diversity and physical separation, including segregation of redundant trains. The concept of segregation is applicable at the following levels:

- (a) Plant layout: for example, separating the emergency diesel generators from one another.
- (b) Building layout: for example, mitigating the effects of missile hazards by proper orientation of equipment.
- (c) Rooms and compartments: for example, dividing them into fire compartments or cells.
- (d) SSCs: for example, separating cables of different safety trains from one another.

3.20. The layout and design provisions that protect SSCs important to safety from the effects of internal hazards should be such that the design objectives in para. 2.12 are met.

3.21. The reliability of the means of detecting internal hazards and mitigating their consequences should be consistent with their role in providing defence in depth.

## ASSESSMENT, VERIFICATION AND SUCCESS CRITERIA

3.22. To evaluate the adequacy of the design, qualitative and/or quantitative success criteria should be defined, consistent with the design objectives in para. 2.12.

3.23. An assessment should be made to demonstrate that the internal hazards relevant to the design of the nuclear power plant have been considered, and that provisions for prevention and mitigation have been designed with sufficient safety margins to address the uncertainties in the identification and characterization of internal hazards and their effects, as well as for the avoidance of cliff edge effects. This assessment should be carried out early in the design stage and should be

documented. It should be updated before initial loading of the reactor with nuclear fuel, and kept up to date during plant operation.

3.24. It should be a goal of the design that a single internal hazard does not trigger an accident, unless the hazard can be considered by itself as a postulated accident (e.g. pipe rupture). In particular, the design should ensure with a high level of confidence that a single internal hazard does not result in design extension conditions with core melting. If this cannot be achieved, the designer should demonstrate that the boundary conditions used in the analysis of the corresponding accident are not affected by the loads resulting from the internal hazard.

3.25. The design features protecting the SSCs that are intended to be used under design extension conditions should be designed or verified for the loads, conditions and durations associated with these scenarios (e.g. effects of hydrogen combustion). These design features should be protected against the consequences of an internal hazard that occurs before design extension conditions have been completely mitigated. Best estimate design loads, conditions and durations can be used for the design or the verification of these protective features.

3.26. Deterministic safety analyses, supplemented if applicable by probabilistic analyses, should be performed to demonstrate the adequacy of the design of the protection against internal hazards. The design should be an iterative process accounting for the results of such safety analyses.

3.27. Internal hazards considered in the deterministic safety analyses for a specified location in the nuclear power plant include the following categories:

- (a) Internal hazards that do not trigger, or result from, an anticipated operational occurrence or an accident;
- (b) Internal hazards that could trigger, or result from, an anticipated operational occurrence;
- (c) Internal hazards that could trigger, or result from, a design basis accident;
- (d) Internal hazards that could trigger, or result from, design extension conditions without significant fuel degradation;
- (e) Internal hazards that could result from design extension conditions with core melting.

3.28. For internal hazards that do not trigger, or result from, an anticipated operational occurrence or an accident, an assessment should be performed to demonstrate that the plant can be brought to, and maintained in, a safe state even in the event of a single failure, including when equipment is unavailable owing to

preventive maintenance considered in the design. In practice, a functional analysis is normally performed to demonstrate that an adequate number of functions remain available to reach and maintain a safe state.

3.29. For internal hazards that could trigger, or result from, an anticipated operational occurrence, an assessment should be performed to demonstrate that the plant can be brought to, and maintained in, a safe state even in the event of a single failure, including when equipment is unavailable owing to preventive maintenance considered in the design. A specific analysis of transients is normally not necessary as this is provided by the corresponding analysis of anticipated operational occurrences. In such cases, the analysis of the internal hazards is limited to a functional analysis that should demonstrate that an adequate number of functions to control anticipated operational occurrences and to reach and maintain a safe state are provided by the design.

3.30. For internal hazards resulting from accidents without significant fuel degradation, the objective of the assessment should be to demonstrate that the boundary conditions, in particular for systems credited in the accident analysis, are not affected by the hazard. A specific accident analysis is normally not necessary as this is provided by the corresponding accident analysis in which the rules for design basis accidents or the rules for design extension conditions without significant fuel degradation should be applied, as appropriate (see IAEA Safety Standards Series No. SSG-2 (Rev. 1), Deterministic Safety Analysis for Nuclear Power Plants [5]). As stated in para. 2.11, design basis accidents or design extension conditions induced by internal hazards should be avoided to the extent practicable. If an internal hazard could lead to an accident without significant fuel degradation, the objective of the assessment should be to demonstrate that the fundamental safety functions are fulfilled and that the plant can be brought to, and maintained in, a safe state.

3.31. For the deterministic assessment of an internal hazard triggered by design extension conditions with core melting, it should be demonstrated by using the corresponding rules [5] that the boundary conditions, in particular for systems credited in the accident analysis, are not affected by the hazard. It should be demonstrated that the SSCs necessary to maintain the integrity of the containment are not affected by the hazard. In particular, the integrity of instrumentation providing necessary measurements should be ensured.

## SPECIFIC ASPECTS OF DESIGN FOR PROTECTION AGAINST INTERNAL HAZARDS

3.32. For a site containing multiple units, steps should be taken to ensure that an internal hazard in one unit under construction, in operation or under decommissioning would not have any safety consequences for a neighbouring operating unit or other installations on the site (e.g. spent fuel pool, radioactive waste management facility). Measures for temporary separation should be put in place if necessary to protect the operating units. Consideration should be given to the possibility of internal hazards involving facilities shared between units: see para. 5.63 of SSR-2/1 (Rev. 1) [1].

3.33. The main control room and the supplementary control room should be adequately separated from possible sources of internal hazards as far as applicable. The means by which the control is transferred from the main control room to the supplementary control room should be resilient against internal hazards to prevent malfunction or spurious actuation<sup>4</sup>.

3.34. Additional guidance on assessment and verification of specific internal hazards is given in Section 4. Further information on the approach to hazard combinations is provided in Appendix I.

## 4. RECOMMENDATIONS FOR SPECIFIC INTERNAL HAZARDS

### INTERNAL FIRES

#### General

4.1. Nuclear power plants contain a range of combustible materials, as part of the structure, equipment, fluids, cabling or miscellaneous items in storage. Fire can be assumed to occur in any plant area where combustible materials are present. Where it is not practicable to eliminate these materials, design measures for fire prevention should be applied to all the fixed and transient (temporary) fire

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<sup>4</sup> Spurious actuation of plant components (of the same type or combinations of different types of component) has the potential to place a given plant into an unsafe operating condition that might not be bounded by the plant's safety analyses.

loads. Such measures include minimization of fixed fire loads, prevention of their accumulation, and control or (preferably) elimination of sources of ignition.

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

### **Identification and characterization of fire hazards**

4.3. A fire hazard analysis of a plant site should be undertaken to demonstrate the overall adequacy of fire protection measures. In particular, the fire hazard analysis should determine the necessary fire resistance rating of fire barriers and the necessary fire detection and extinguishing capabilities (see the detailed recommendations on fire hazard analysis in Appendix II).

4.4. The fire hazard analysis should be carried out in accordance with the recommendations in para. 3.23.

### **Fire prevention**

4.5. The following measures should be taken in the design to minimize the likelihood of internal fires:

- (a) Removal, minimization and segregation of fixed and transient fire loads, as far as practicable.
- (b) Elimination of potential ignition sources to the extent practicable; otherwise, the strict control of any such sources.
- (c) Segregation of ignition sources from fuel sources.

#### *Minimizing fire loads*

4.6. Paragraph 6.54 of SSR-2/1 (Rev. 1) [1] states that:

“Non-combustible or fire retardant and heat resistant materials shall be used wherever practicable throughout the plant, in particular in locations such as the containment and the control room.”

4.7. In order to reduce the fire load to the extent possible, thus minimizing the fire hazard, the following aspects should be considered in the plant design:

- (a) The use of non-combustible construction materials (e.g. structural materials, insulation, cladding, coatings, floor materials) and plant fixtures, as far as practicable.
- (b) The use of non-combustible air filters and filter frames, as far as practicable; otherwise low combustible materials could be used.
- (c) The use of a protected pipe or double pipe design for lubricating oil lines and for collection of leakages.
- (d) The use of hydraulic control fluids of low flammability for the control systems of steam turbines and other equipment.
- (e) The selection of dry type transformers, as far as practicable.
- (f) The use of non-combustible materials in electrical equipment, such as switches and circuit breakers, and in control and instrumentation cubicles, and use of flame retardant non-corrosive cables or cables with suitable qualifications.
- (g) The use of non-combustible scaffolding and staging materials.
- (h) Segregation and compartmentation of fire loads, as far as practicable, to reduce the likelihood of fire and other effects spreading to other SSCs important to safety.

4.8. 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.

4.9. Design measures should be implemented to provide for the proper storage of transient combustible materials that arise during operation; either separated from items important to safety, or otherwise protected.

4.10. 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.

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

4.12. Systems containing flammable liquids or gases should be designed to have a high degree of integrity in order to prevent leaks. They should be protected from degradation effects (e.g. corrosion) and destructive effects (e.g. vibration,

effects of hazards) and maintained in good condition. 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.

#### *Minimizing ignition sources*

4.13. In the design, the number of ignition sources should be minimized to the extent practicable (e.g. a resilient design for the electrical protection system could be used).

4.14. Systems that contain pressurized combustible liquids, such as hydraulic fluids and lubricating oil, should be provided with spray guards, as far as practicable. Equipment should be appropriately rated, consistent with the hazards present in the environment, to prevent it providing a source of ignition for flammable gases and ignitable sprays.

4.15. Potential ignition sources arising from plant systems and equipment should be controlled.

4.16. As far as is practicable, systems and equipment should be made safe through design, so as not to provide any ignition source. Where this is not practicable, such systems and equipment should be separated from combustible materials, or else insulated or enclosed. 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.

4.17. Cables should be laid on trays or in installed conduits, or placed in other acceptable structures made out of non-combustible materials; steel is often used for this purpose. 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. Further recommendations are provided in IAEA Safety Standards Series No. SSG-39, Design of Instrumentation and Control Systems for Nuclear Power Plants [6], and IAEA Safety Standards Series No. SSG-34, Design of Electrical Power Systems for Nuclear Power Plants [7].

## Fire mitigation

### *Timely detection and extinguishing of fires*

4.18. Requirement 74 of SSR-2/1 (Rev. 1) [1] states:

**“Fire protection systems, including fire detection systems and fire extinguishing systems, fire containment barriers and smoke control systems, shall be provided throughout the nuclear power plant, with due account taken of the results of the fire hazard analysis.”**

These systems and equipment should be designed to provide a timely alarm in the event of fire, and the rapid extinguishing of fires, in order to minimize adverse effects on items important to safety and on plant personnel performing actions important to safety.

4.19. Active and passive means of fire protection that are needed to protect SSCs important to safety against a fire following a different event (e.g. an earthquake) should be identified, adequately designed and qualified to resist the effects of this event.

4.20. Active and passive means of fire protection that do not need to maintain a functional capability following a postulated initiating event should be designed and qualified so that they do not fail in a way that could adversely affect safety.

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

4.22. Paragraph 6.51 of SSR-2/1 (Rev. 1) [1] states:

**“Fire extinguishing systems shall be capable of automatic actuation where appropriate. Fire extinguishing systems shall be designed and located to ensure that their rupture or spurious or inadvertent operation would not significantly impair the capability of items important to safety.”**

In addition, fire extinguishing systems should be designed and located so that they would not simultaneously affect redundant parts of safety groups, and thereby cause the measures taken to meet the single failure criterion to become ineffective.