

IAEA Safety Standards

for protecting people and the environment

Development and Application of Level 2 Probabilistic Safety Assessment for Nuclear Power Plants

Specific Safety Guide

No. SSG-4



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DEVELOPMENT AND APPLICATION
OF LEVEL 2 PROBABILISTIC
SAFETY ASSESSMENT FOR
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IAEA SAFETY STANDARDS SERIES No. SSG-4

DEVELOPMENT AND APPLICATION OF LEVEL 2 PROBABILISTIC SAFETY ASSESSMENT FOR NUCLEAR POWER PLANTS

SPECIFIC SAFETY GUIDE

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2010

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tel.: +43 1 2600 22417
email: sales.publications@iaea.org
<http://www.iaea.org/books>

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Printed by the IAEA in Austria
May 2010
STI/PUB/1443

IAEA Library Cataloguing in Publication Data

Development and application of level 2 probabilistic safety assessment for nuclear power plants : specific safety guide. — Vienna : International Atomic Energy Agency, 2010.

p. ; 24 cm. — (IAEA safety standards series, ISSN 1020-525X ; no. SSG-4)

STI/PUB/1443

ISBN 978-92-0-102210-3

Includes bibliographical references.

1. Nuclear power plants — Safety measures. 2. Nuclear power plants — Risk assessment. 3. Nuclear reactors — Safety measures. I. International Atomic Energy Agency. II. Series.

IAEAL

10-00624

FOREWORD

The IAEA's Statute authorizes the Agency to establish safety standards to protect health and minimize danger to life and property — standards which the IAEA must use in its own operations, and which a State can apply by means of its regulatory provisions for nuclear and radiation safety. A comprehensive body of safety standards under regular review, together with the IAEA's assistance in their application, has become a key element in a global safety regime.

In the mid-1990s, a major overhaul of the IAEA's safety standards programme was initiated, with a revised oversight committee structure and a systematic approach to updating the entire corpus of standards. The new standards that have resulted are of a high calibre and reflect best practices in Member States. With the assistance of the Commission on Safety Standards, the IAEA is working to promote the global acceptance and use of its safety standards.

Safety standards are only effective, however, if they are properly applied in practice. The IAEA's safety services — which range in scope from engineering safety, operational safety, and radiation, transport and waste safety to regulatory matters and safety culture in organizations — assist Member States in applying the standards and appraise their effectiveness. These safety services enable valuable insights to be shared and I continue to urge all Member States to make use of them.

Regulating nuclear and radiation safety is a national responsibility, and many Member States have decided to adopt the IAEA's safety standards for use in their national regulations. For the contracting parties to the various international safety conventions, IAEA standards provide a consistent, reliable means of ensuring the effective fulfilment of obligations under the conventions. The standards are also applied by designers, manufacturers and operators around the world to enhance nuclear and radiation safety in power generation, medicine, industry, agriculture, research and education.

The IAEA takes seriously the enduring challenge for users and regulators everywhere: that of ensuring a high level of safety in the use of nuclear materials and radiation sources around the world. Their continuing utilization for the benefit of humankind must be managed in a safe manner, and the IAEA safety standards are designed to facilitate the achievement of that goal.

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 measures¹ 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. The safety requirements use ‘shall’ statements together with statements of

¹ See also publications issued in the IAEA Nuclear Security Series.

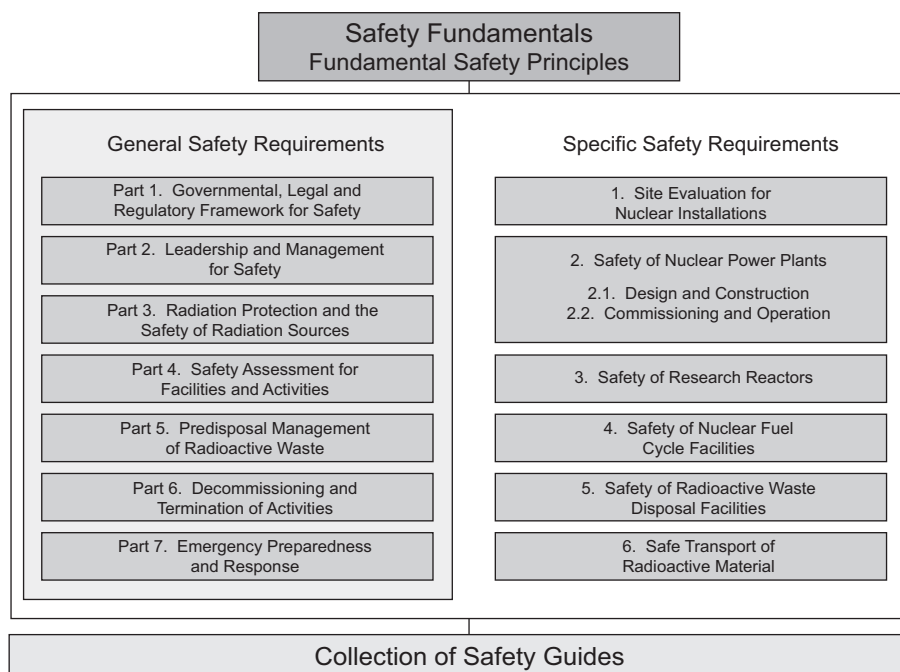


FIG. 1. The long term structure of the IAEA Safety Standards Series.

associated conditions to be met. 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 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 four safety standards committees, for 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).

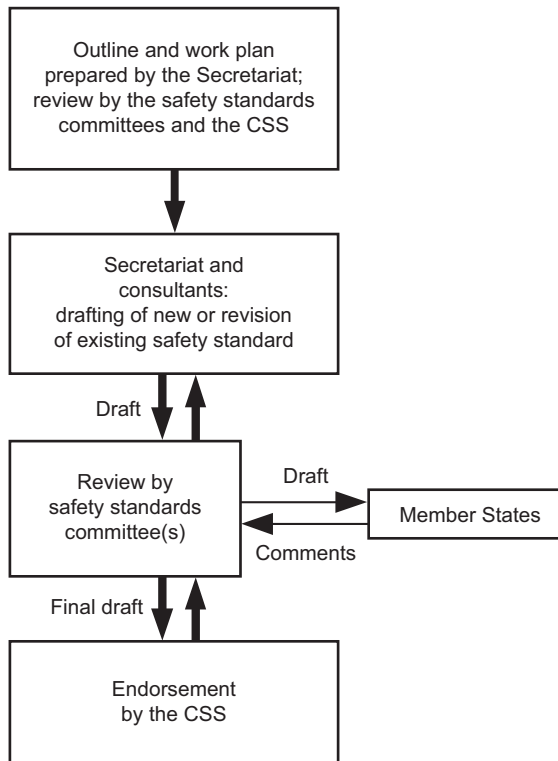


FIG. 2. The process for developing a new safety standard or revising an existing standard.

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. 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 <http://www-ns.iaea.org/standards/safety-glossary.htm>). 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. The Safety Fundamentals, Fundamental Safety Principles [1], establish principles to ensure the protection of workers, the public and the environment, now and in the future, from harmful effects of ionizing radiation. These principles emphasize the need to assess and manage the risk posed by nuclear facilities. In particular, Principle 5 of Ref. [1] (para. 3.22) on optimization of protection states:

“To determine whether radiation risks are as low as reasonably achievable, all such risks, whether arising from normal operations or from abnormal or accident conditions, must be assessed (using a graded approach) a priori and periodically reassessed throughout the lifetime of facilities and activities.”

1.2. Several IAEA Safety Requirements publications were developed to provide more specific requirements for risk assessment for nuclear power plants. The Safety Requirements publication on Safety Assessment for Facilities and Activities ([2], para. 4.13) emphasizing the need for a comprehensive safety analysis states:

“The safety assessment has to include a safety analysis, which consists of a set of different quantitative analyses for evaluating and assessing challenges to safety in various operational states, anticipated operational occurrences and accident conditions, by means of deterministic and also probabilistic methods.”

It is also stated in connection with Requirement 15 of Ref. [2] (para. 4.55) on deterministic and probabilistic approaches:

“The objectives of a probabilistic safety analysis are to determine all significant contributing factors to the radiation risks arising from a facility or activity, and to evaluate the extent to which the overall design is well balanced and meets probabilistic safety criteria where these have been defined.”

1.3. The Safety Requirements publication on Safety of Nuclear Power Plants: Design ([3], para. 5.69) establishes that:

“A safety analysis of the plant design shall be conducted in which methods of both deterministic and probabilistic analysis shall be applied. On the basis of this analysis, the design basis for items important to safety shall be established and confirmed.”

It is also emphasized further in Ref. [3] (para 5.73) that:

“A probabilistic safety analysis of the plant shall be carried out in order:

- (1) to provide a systematic analysis to give confidence that the design will comply with the general safety objectives;
- (2) to demonstrate that a balanced design has been achieved such that no particular feature or PIE¹ makes a disproportionately large or significantly uncertain contribution to the overall risk, and that the first two levels of defence in depth bear the primary burden of ensuring nuclear safety;
- (3) to provide confidence that small deviations in plant parameters that could give rise to severely abnormal plant behaviour (‘cliff edge effects’) will be prevented;
- (4) to provide assessments of the probabilities of occurrence of severe core damage states and assessments of the risks of major off-site releases necessitating a short term off-site response, particularly for releases associated with early containment failure;
- (5) to provide assessments of the probabilities of occurrence and the consequences of external hazards, in particular those unique to the plant site;
- (6) to identify systems for which design improvements or modifications to operational procedures could reduce the probabilities of severe accidents or mitigate their consequences;
- (7) to assess the adequacy of plant emergency procedures; and
- (8) to verify compliance with probabilistic targets, if set.”

1.4. Thus, a comprehensive probabilistic safety assessment (PSA) is required to be performed to assess and verify the safety of nuclear power plants in relation to potential internal initiating events and internal and external hazards. This Safety Guide complements the Safety Guide on Level 1 PSA [4], providing recommendations on what analyses need to be performed and what issues need to

¹ PIE: postulated initiating event.

be addressed to ensure that the Level 2 PSA meets the requirements on safety assessment established in Ref. [2].

1.5. PSA has been shown to provide important safety insights in addition to those provided by deterministic analysis. PSA provides a methodological approach to identifying accident sequences that can follow from a broad range of initiating events and it includes a systematic and realistic determination of accident frequencies and consequences. In international practice, three levels of PSA are generally recognized:

- (1) In Level 1 PSA, the design and operation of the plant are analysed in order to identify the sequences of events that can lead to core damage and the core damage frequency is estimated. Level 1 PSA provides insights into the strengths and weaknesses of the safety related systems and procedures in place or envisaged as preventing core damage.
- (2) In Level 2 PSA, the chronological progression of core damage sequences identified in Level 1 PSA is evaluated, including a quantitative assessment of phenomena arising from severe damage to reactor fuel. Level 2 PSA identifies ways in which associated releases of radioactive material from fuel can result in releases to the environment. It also estimates the frequency, magnitude and other relevant characteristics of the release of radioactive material to the environment. This analysis provides additional insights into the relative importance of accident prevention and mitigation measures and the physical barriers to the release of radioactive material to the environment (e.g. a containment building).
- (3) In Level 3 PSA, public health and other societal consequences are estimated, such as the contamination of land or food from the accident sequences that lead to a release of radioactive material to the environment.

PSAs are also classified according to the range of initiating events (internal and/or external to the plant) and plant operating modes that are to be considered.

1.6. If the aim of the PSA is to determine all the contributions to risk to public health and society, then the PSA should take account of the potential for release from other sources of radioactivity from the plant, such as irradiated fuel and stored radioactive waste. Such an aim is not detailed in this Safety Guide, which focuses, rather, on releases of radioactive material resulting from severe accidents.

1.7. Level 2 PSA is a structured process. Although there may be differences in the approaches for performing a Level 2 PSA, the general main steps are shown in Fig. 1 and are as follows:

- (1) Level 1 PSA provides information on the accident sequences that lead to core damage and hence provides the starting point for the Level 2 PSA. The accident sequences identified by the Level 1 PSA may not include information on the status of the containment systems that mitigate the effects of severe accidents.
- (2) The interface between Level 1 PSA and Level 2 PSA is where the accident sequences leading to core damage are grouped into plant damage states based on similarities in the plant conditions that determine the further accident progression. If the status of containment systems was not addressed in the Level 1 PSA, it needs to be considered by means of so-called ‘bridge trees’ of the interface between Level 1 PSA and Level 2 PSA or as the first step of the Level 2 PSA.
- (3) Containment event tree analysis² is where the accident progression is modelled to identify the accident sequences that lead to challenges to the containment and releases of radioactive material to the environment.
- (4) Source term analysis is used to determine the quantities of radioactive material released to the environment from each of the release categories.

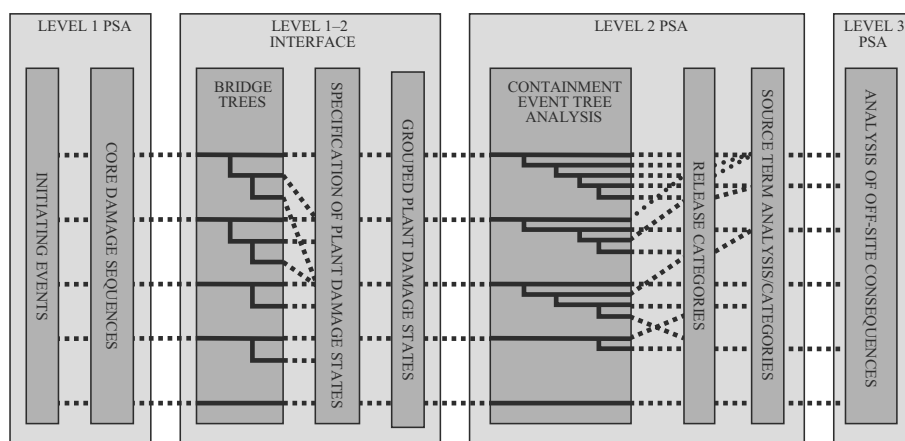


FIG. 1. General overview of the development of a typical Level 2 PSA.

² The term ‘accident progression event tree’ is also used by some practitioners for this part of the Level 2 PSA.

1.8. It should be noted that the process for carrying out PSA is not unique, but rather depends on the approach to the Level 2 PSA selected. For practical purposes, the Level 2 PSA process may require a number of grouping tasks to be carried out as indicated in Fig. 1:

- (a) The grouping of the core damage sequences (extended to include the status of containment systems) into the plant damage states that form the starting point for the Level 2 PSA;
- (b) The grouping of similar plant damage states into a condensed set of plant damage states to be taken forward into the containment event tree analysis;
- (c) The grouping of the severe accident sequences identified in the containment event tree analysis into release categories;
- (d) The grouping of the release categories into a condensed set of source term categories that are taken forward into the Level 3 PSA.

1.9. Level 1 PSAs have now been carried out for almost all nuclear power plants worldwide. Level 2 PSAs have been, or are being, carried out for most nuclear power plants worldwide. In addition, Level 3 PSAs have been carried out for some nuclear power plants in some States.

OBJECTIVE

1.10. The objective of this Safety Guide is to provide recommendations for meeting the requirements of Ref. [2] in performing or managing a Level 2 PSA project for a nuclear power plant; this Safety Guide therefore complements the Safety Guide on Level 1 PSA [4]. One of the aims is to promote a standard framework, standard terms and a standard set of documents for PSAs to facilitate regulatory and external peer review of their results.

1.11. This Safety Guide also provides a consistent, reliable means of ensuring the effective fulfilment of obligations under Article 14 of the Convention on Nuclear Safety [5].

1.12. The recommendations presented in this Safety Guide are based on internationally recognized good practices. However, they are not intended to pre-empt the use of equivalent new or alternative methods. On the contrary, the use of any method that achieves the objectives of Level 2 PSA is encouraged. The details of the methods of analysis are subject to change as understanding of severe accident phenomena improves. However, the framework for PSA outlined in this Safety Guide is expected to apply for the foreseeable future.

SCOPE

1.13. This Safety Guide addresses the necessary technical features of a Level 2 PSA for nuclear power plants in relation to its application, with emphasis on procedural steps and the essential elements of the PSA rather than on details of the modelling methods, since modelling is considered to be well documented in the relevant literature. This Safety Guide includes all the steps in the Level 2 PSA process up to, and including, the determination of the detailed source terms that would be required as input into a Level 3 PSA.

1.14. This Safety Guide describes all aspects of the Level 2 PSA that need to be carried out if the starting point is a full scope Level 1 PSA as described in Ref. [4]. If the objectives of the Level 2 PSA are restricted as described in paras 2.3–2.7, only the relevant parts of the recommendations presented in this Safety Guide will need to be met; if the scope of the Level 1 PSA is limited as described in paras 2.8–2.10, additional analysis to that described in this Safety Guide will need to be carried out.

1.15. Different plant designs use different provisions to prevent or limit the release of radioactive material following a severe accident. Most designs include a containment structure as one of the passive measures for this purpose. The phenomena associated with severe accidents are also very much influenced by the design and composition of the reactor core. The recommendations of this Safety Guide are intended to be technology neutral to the extent possible. However, the number and content of the various steps of the analysis assume the existence of some type of containment structure.

1.16. General aspects of performance, project management, documentation and peer review of a PSA and implementation of a management system that meets with the safety requirements in The Management System for Facilities and Activities [6] are described in the Safety Guide on Level 1 PSA [4] and are, therefore, not addressed here. This Safety Guide addresses only the aspects of PSA that are specific to Level 2 PSA.

STRUCTURE

1.17. This Safety Guide consists of eight sections and three annexes. Sections 2–7 provide recommendations for the performance of a Level 2 PSA. These sections correspond to the major procedural steps of a Level 2 PSA as shown in Fig. 2. Section 8 provides recommendations on the uses and

applications of a Level 2 PSA. Annex I gives an example of a typical schedule for the performance of a Level 2 PSA. Annex II discusses various types of computer code available for simulation of severe accidents and PSA studies. Annex III presents a sample outline of documentation for a Level 2 PSA.

2. PSA PROJECT MANAGEMENT AND ORGANIZATION

2.1. This section provides recommendations on meeting Requirement 22 of Ref. [2] on management of the safety assessment. The detailed aspects of project management and the organization of PSA set out in Section 3 of the Safety Guide on Level 1 PSA [4] are also applicable to Level 2 PSA and are not repeated here. Only those aspects that are particularly important for Level 2 PSA are presented in this section.

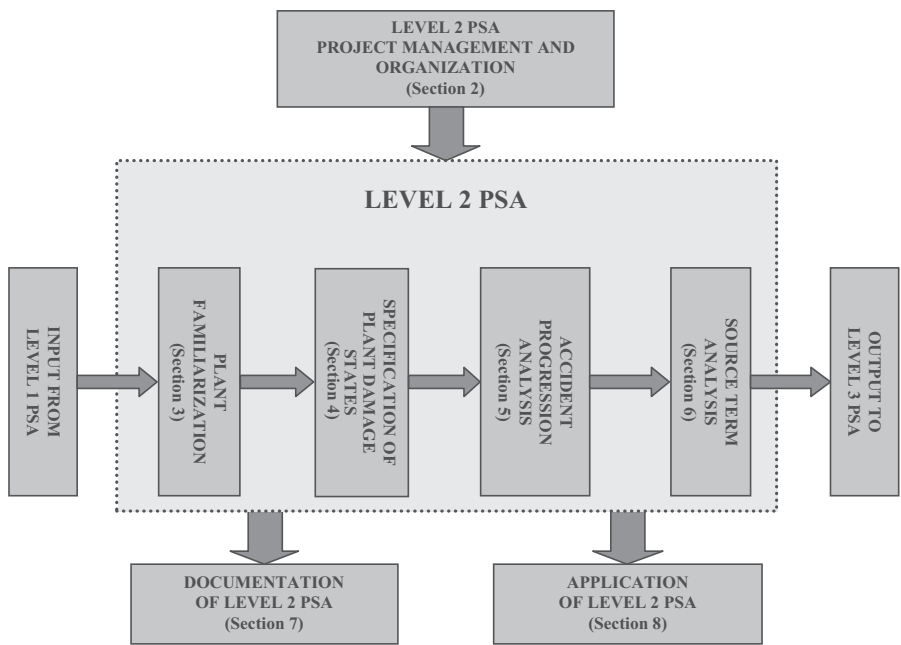


FIG. 2. Main steps in the performance of a Level 2 PSA.

DEFINITION OF THE OBJECTIVES OF LEVEL 2 PSA

2.2. Paragraphs 2.2–2.7 provide recommendations on meeting Requirement 4 of Ref. [2] on purpose of the safety assessment. A Level 2 PSA covers the progression of events that may occur in a nuclear reactor following an accident sequence that has led to significant damage to the reactor core (a severe accident). The main objective of the analysis is to determine if sufficient provisions have been made to manage a severe accident and mitigate the effects of such an accident. These provisions could include:

- (a) Systems provided specifically to mitigate the effects of the severe accident, such as molten core retention features, hydrogen mixing devices or hydrogen recombiners, or filtered containment venting systems;
- (b) The inherent strength of the containment structures or the capability for radioactive material retention within a confinement building, and the use for accident management of equipment provided for other purposes;
- (c) Guidance to plant operators on severe accident management.

2.3. Performance of Level 2 PSA is a structured process as described in Section 1 and shown in Fig. 1. The scope of Level 2 PSA will be determined by its specific intended uses and by plans to carry out a Level 3 PSA. Although the basic framework and methods of Level 2 PSA are well established, the analysis in Level 2 PSA demands high levels of expertise and technical resources. Even when high levels of resources are employed, analyses of the containment and the radiological source terms are subject to large uncertainties associated with phenomena.

2.4. Differing end uses place differing emphases and requirements on the various inputs into, and components of, a Level 2 PSA. At the start of the project, the requirements for the Level 2 PSA should therefore be set out fully and it should be ensured that the user or recipient of the PSA understands these requirements and believes them to be realizable.

2.5. The overall objectives of the Level 2 PSA should be defined. These can include the following:

- (a) To gain insights into the progression of severe accidents and the performance of the containment.
- (b) To identify plant specific challenges and vulnerabilities of the containment to severe accidents.
- (c) To provide an input into the resolution of specific regulatory concerns.

- (d) To provide an input into determining compliance with the probabilistic safety goals, or with probabilistic safety criteria if these have been set. Typically, such probabilistic safety goals or criteria relate to large release frequencies and large early release frequencies.
- (e) To identify major containment failure modes and their frequencies and to estimate the associated frequencies and magnitudes of radionuclide releases.
- (f) To provide an input into the development of strategies for off-site emergency planning.
- (g) To evaluate the impacts of various uncertainties, including uncertainties in assumptions relating to phenomena, systems and modelling.
- (h) To provide an input into the development of plant specific accident management guidance and strategies.
- (i) To provide an input into determining plant specific options for risk reduction.
- (j) To provide an input into the prioritization of research activities for the minimization of risk significant uncertainties.
- (k) To provide an input into Level 3 PSA consistent with the PSA objectives.
- (l) To provide an input into the environmental assessment of the plant.

Each of these objectives would place differing emphasis on one of the various aspects of the Level 2 PSA. The objectives reflecting the intended uses and applications of the Level 2 PSA should therefore be clearly specified at the beginning of the project.

2.6. The PSA model should be as realistic as possible. Appropriate consideration should be given to the significance of key uncertainties associated with phenomena. Care should be taken to avoid distorting the conclusions of the PSA through models and assumptions that are systematically biased towards particular outcomes (often for the sake of conservatism).

2.7. It should be noted that any limitations in the Level 1 PSA will be carried forward into the Level 2 PSA. This will need to be taken into account in the intended uses and applications of the Level 2 PSA.

SCOPE OF THE LEVEL 2 PSA

2.8. Paragraphs 2.8–2.11 provide recommendations on meeting Requirement 1 on graded approach and Requirement 14 relating to the scope of the safety analysis for a Level 2 PSA [2]. In undertaking a Level 2 PSA, there are two types

of situation likely to be encountered. In the first case, the Level 2 PSA is part of an integrated full scope PSA. In the second case, the Level 2 PSA is seeking to extend an existing Level 1 PSA. If the Level 2 PSA is performed as part of an integrated study, the requirements of the Level 2 PSA should be fed into the Level 1 PSA so that all plant related features that are important to the analysis of the containment response and source terms are considered wherever possible in the Level 1 PSA. If the Level 2 PSA is performed after the Level 1 PSA is complete, then some additional systems analysis may be necessary. In either case, in the linkage of the Level 1 and Level 2 PSA models, typically via the specification and quantification of plant damage states, it should be ensured that the Level 2 PSA takes fully into account the initial and boundary conditions from the Level 1 PSA model and the dependencies between the Level 1 PSA and the Level 2 PSA.

2.9. If the starting point is an existing Level 1 PSA, then its output may not explicitly cover all the features that need to be taken into account in the Level 2 PSA. Thus, if the objective of the Level 1 PSA was the quantification of core damage frequency, then the status of the containment and the containment safety systems may not have been directly addressed and therefore will have to be determined as part of the Level 2 PSA or as part of the modelling of the interface between Level 1 and Level 2 PSA (e.g. specification and quantification of the plant damage states).

2.10. If the scope of the PSA includes internal or external hazards (e.g. fire, earthquakes), their potential impact on the confinement function and the dependent failures they could cause should be taken into account as part of the Level 2 PSA, if they have not been previously taken into account in the Level 1 output. Examples of such dependent failures include failures in the containment isolation system due to cable fire, damage of containment structures due to seismic events, etc.

2.11. Finally, in determining the scope of the Level 2 PSA, consideration should be given to the input requirements for a Level 3 PSA, if one is contemplated. The ultimate product of a Level 2 PSA, then, will be a description of a number of challenges to the containment, a description of the possible containment responses and an assessment of the consequent releases to the environment and their associated frequencies. The description will include the inventory of material released, its physical and chemical characteristics, and information on the time, energy, duration and location of the releases.

PROJECT MANAGEMENT FOR PSA

2.12. Paragraphs 2.12–2.17 provide recommendations on meeting Requirement 5 of Ref. [2] on preparation for the safety assessment for Level 2 PSA. Information on the decisions that the PSA project managers should take and on the supervision, coordination and implementation of various tasks is provided in paras 3.3–3.14 of Ref. [4]. This information is also applicable to the Level 2 PSA and is not repeated here. One aim of project management for Level 2 PSA is to ensure that the PSA being produced does indeed represent the plant in its ‘as is’ condition and reflect realistic operating practices to the extent possible, and that it does take account of recent developments in methods, models and data.

2.13. In accordance with the requirements established in Ref. [6], a management system for the project should be implemented with due consideration given to the safety implications of the results of the Level 2 PSA and its intended uses. Owing to the complex phenomena addressed in Level 2 PSA and their associated uncertainties, as well as the extensive use of expert judgement and computational tools with limited resources for validation, the establishment of an adequate technical review system is of high importance (so as to meet Requirement 21 of Ref. [2] on independent verification). In particular, the application of expert judgment should be justified and managed through a controlled and documented process. Provisions should be made by the project management for establishing independent review processes or performing comparative studies, as appropriate. Further details on the specific needs for technical review of relevant aspects of the analysis, project documentation and configuration control are provided in Sections 3–7.

2.14. The production of a Level 2 PSA requires a high level of interaction between the analysts working on the analysis, who will offer a wide range of expertise. The project organization should provide working arrangements that ensure that there are good interactions and communication between all the members of the analysis team, including project managers and analysts. In addition, another objective of the overall management should be to ensure that, as the analysis progresses and insights are developed, the approaches to the different technical areas are modified as necessary to ensure that the analysis is progressing in a coherent way and that there is a reasonable balance of effort across all topics. The need to sustain good communication among the analysts during the entire PSA cannot be overemphasized.

2.15. The project management should aim to ensure that the insights gained from carrying out the analysis relating to plant vulnerabilities and severe accident management are properly understood by the plant management and operating staff, so that the operating organization gains ownership of the Level 2 PSA, and by the regulatory body or other relevant interested parties.

TEAM SELECTION

2.16. In the selection of the Level 2 PSA team, it should be ensured that there is an adequate level of expertise in the following areas: (i) knowledge of the design and operation of the plant, (ii) knowledge of severe accident phenomena and containment challenges, and (iii) knowledge of PSA techniques. The depth of the team's expertise can be different depending on the stage in the lifetime of the plant at which the PSA is carried out, the scope of the PSA and the intended applications of the PSA, but extensive participation of the plant engineers and utility personnel, or designers if performed at the design stage, and probabilistic safety analysts specialized in accident phenomena and other Level 2 PSA disciplines is essential.

2.17. For a nuclear power plant at operation, the Level 2 PSA team should comprise:

- (a) *Operators and operational analysts*: Specialists in the design and operation of the plant and key containment systems, the emergency operating procedures and the severe accident management guidelines.
- (b) *Specialists in phenomena*: Specialists in severe accident phenomena, containment performance, uncertainties associated with severe accidents, chemical and physical processes governing accident progression, containment loads, releases of radionuclides and computer codes for the analysis of severe accidents.
- (c) *Structural specialists*: Specialists in the structural design, the pressure capacity and the failure modes of the containment.
- (d) *Other PSA specialists*: Specialists in event tree analysis, fault tree analysis, human reliability analysis, uncertainty analysis, statistical methods, processes for expert elicitation and judgement, PSA computer codes and Level 1 PSA.

3. IDENTIFICATION OF DESIGN ASPECTS IMPORTANT TO SEVERE ACCIDENTS AND ACQUISITION OF INFORMATION

IDENTIFICATION OF DESIGN ASPECTS IMPORTANT TO SEVERE ACCIDENTS

3.1. This section provides recommendations on meeting Requirements 6–13 of Ref. [2] for Level 2 PSA. Before starting the analysis, the Level 2 PSA team should become familiar with the design and operation of the plant. The aim should be to identify and highlight plant systems, structures, components and operating procedures that can influence the progression of severe accidents, the containment response and the transport of radioactive material inside the containment. Design features that can influence the progression of a severe accident and Level 2 PSA include: fan coolers, containment sprays and/or filtered containment venting systems and suppression pools. This exercise should include the reactor building and/or the auxiliary building and the secondary containment or other relevant structures and buildings. For existing plants, familiarization with the plant should include a plant walk-through and should involve the participation of operating staff and engineers. The plant familiarization should involve all members of the Level 2 PSA team.

3.2. The specific plant features that can influence the progression of a severe accident should be identified and characterized. Examples of the features that need to be identified are as follows:

- (a) The area under the reactor pressure vessel is important with regard to the behaviour of molten core material after it exits the bottom of the reactor pressure vessel, since the area influences the extent to which the molten core material will spread and its coolability.
- (b) The flow paths from the area under the reactor pressure vessel to the main containment volume. Restrictions to the flow or other geometric aspects of the flow path will reduce the extent to which core debris is dispersed following a lower head failure. This is particularly important for high pressure melt ejection in a light water reactor.
- (c) A highly compartmentalized containment configuration will limit the extent to which combustible gases mix and become distributed in the containment atmosphere.
- (d) Features that could lead to containment bypass sequences.

These and other plant specific design features should be identified for further investigation.

3.3. Examples of key design features of the plant that are significant in respect of the progression and mitigation of severe accidents are listed in Table 1. In addition to plant features, relevant operating procedures and severe accident management guidelines should also be considered.

ACQUISITION OF INFORMATION IMPORTANT TO SEVERE ACCIDENT ANALYSIS

3.4. Paragraphs 3.4–3.6 provide recommendations on meeting Requirement 19 of Ref. [2] on use of operating experience data for Level 2 PSA. When the PSA team has developed a general understanding of the plant design and features that may influence severe accidents and releases of radioactive material, the quantitative data that are necessary to carry out the plant specific analysis should be collected and organized. The data necessary for the PSA depend in part on the scope of the analyses and the nature of the computational tools. For example, the amount and type of input data collected may depend on the plant specific computer model used to calculate accident progression. Detailed architectural and construction data for the containment structure should be collected to develop plant specific model calculations of the containment performance if such calculations are required by the scope of the containment performance analysis.

3.5. Data should be obtained from qualified sources, such as:

- (a) Design documents and/or plant licensing documents;
- (b) As built drawings;
- (c) Plant specific operating, maintenance or test procedures;
- (d) Engineering calculations or analysis reports;
- (e) Observations during plant walkdowns;
- (f) Construction standards;
- (g) Vendor manuals.

References to the source(s) of data should be recorded as part of the PSA documentation.

TABLE 1. EXAMPLES OF KEY PLANT AND/OR CONTAINMENT DESIGN FEATURES

Key plant and/or containment design feature	Comment
REACTOR	
Reactor type	Boiling water reactor, pressurized water reactor, advanced gas cooled reactor or other
Power level	Total thermal power at steady state
Type of fuel mix/type of cladding	Oxide, mixed oxide/zircaloy, stainless steel
CORE	
Mass of fuel and mass of cladding	Actual operational values
Fuel assembly geometry	Actual operational values
Type and mass of control rods	Actual operational values
Spatial distribution of reactor power	Typically axial and radial peaking factors
Decay heat	Total decay heat level as a function of time
Radioactive material inventory	Full inventory of radionuclides in the core
REACTOR COOLANT SYSTEM	
Reactor coolant and moderator types	Water, heavy water, CO ₂ , helium and others
Reactor coolant system coolant/moderator volume	As designed and fabricated
Accumulator volume and pressure set point	Actual operational values
Reactor coolant system depressurization devices and procedures	Specify set point and procedures
Pressure relief capacity	Actual operational values
Isolation of containment penetrations connected to the reactor coolant system	Potential for containment bypass
CONTAINMENT ^a	
Containment geometry	Shape and separation of internal volumes
Containment free volume	As built, taking into account displacement by structures
Containment design pressure and temperature	A realistic assessment of maximum capacity is required for the PSA
