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Evaluation of Seismic Safety for Existing Nuclear Installations

Safety Guide

No. NS-G-2.13



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EVALUATION OF SEISMIC SAFETY FOR EXISTING NUCLEAR INSTALLATIONS

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

IAEA SAFETY STANDARDS SERIES No. NS-G-2.13

EVALUATION OF SEISMIC SAFETY FOR EXISTING NUCLEAR INSTALLATIONS

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2009

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FOREWORD

by Mohamed ElBaradei
Director General

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.

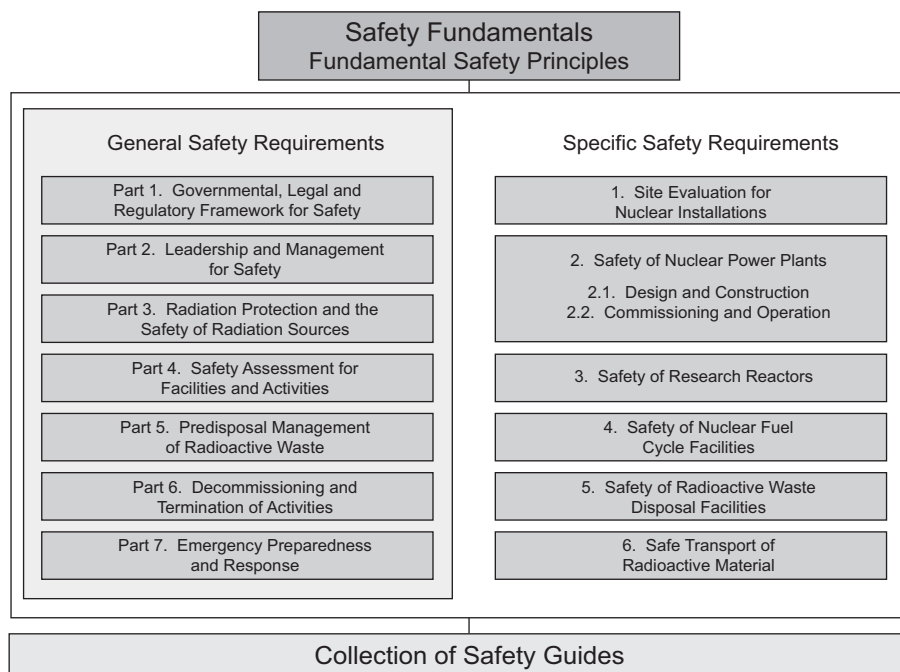


FIG. 1. The long term structure of the IAEA Safety Standards Series.

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

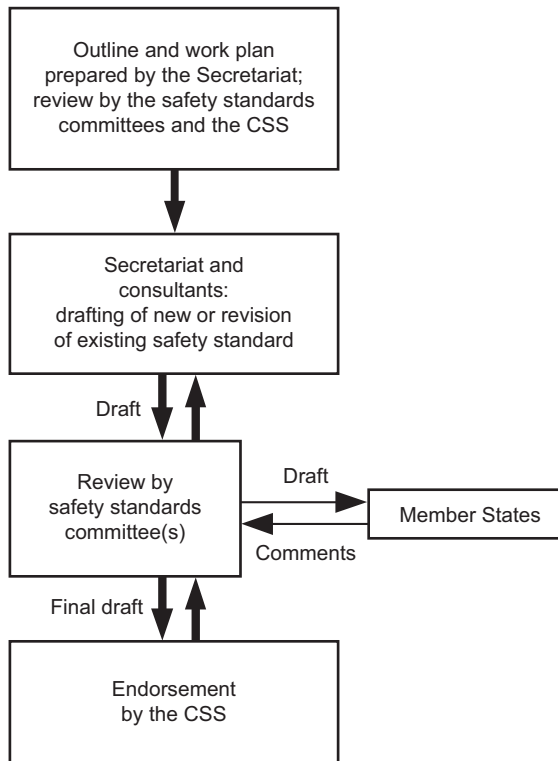


FIG. 2. The process for developing a new safety standard or revising an existing standard.

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. 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. This Safety Guide was prepared under the IAEA's programme for safety standards. It supplements and provides recommendations on meeting the requirements for nuclear installations established in the Safety Requirements publication on Safety of Nuclear Power Plants: Operation [1]; it also relates to a number of other IAEA safety standards, including Refs [2–4].¹

1.2. This Safety Guide on Evaluation of Seismic Safety for Existing Nuclear Installations complements the IAEA Safety Guide on Seismic Design and Qualification for Nuclear Power Plants [5] for the design and construction of new nuclear power plants. It provides recommendations on meeting the requirements in Ref. [1] and expands the scope to existing nuclear installations such as research reactors, nuclear fuel cycle and reprocessing facilities, and independent fuel storage facilities. Safety Reports Series No. 28 on Seismic Evaluation of Existing Nuclear Power Plants [6] provides detailed information relevant to this Safety Guide (a revision of Ref. [6] is planned).

1.3. The Safety Requirements publication on the Safety of Nuclear Power Plants: Operation [1] states that systematic safety reassessments of the plant are required to be performed by the operating organization throughout its operational lifetime. In the light of this and other requirements, as well as of the recommendations on external hazard analysis in periodic safety reviews [7], this Safety Guide addresses the seismic safety evaluation of existing installations.

1.4. Guidelines for the seismic safety evaluation of existing nuclear installations — mainly nuclear power plants — have been developed and used in many Member States.² Since the beginning of the 1990s, these methods have been adapted to specific situations and have been applied in the seismic safety evaluation of many nuclear installations. The IAEA has assisted a number of Member States in adapting and applying these methods for installations in

¹ A draft Safety Guide on seismic hazards in site evaluation for nuclear installations is in preparation, to supersede Ref. [4].

² The development and use of guidelines on the seismic safety evaluation of existing nuclear installations started in the United States of America, where such guidelines were developed and their application to all existing nuclear power plants was required.

operation for which seismic safety evaluation and upgrading programmes were required and were implemented.

1.5. Seismic design and qualification is distinct from seismic safety evaluation in that seismic design and qualification of structures, systems and components (SSCs) is most often performed at the design stage of the installation, prior to its construction. Seismic safety evaluation is applied only after the installation has been constructed. Of course, exceptions exist, such as the seismic design and qualification of new or replacement components after construction of the installation. Conversely, the seismic safety evaluation for assessing beyond design basis earthquake conditions for new designs prior to construction may make use of the criteria applied for seismic safety evaluation.

1.6. Consequently, the seismic safety evaluation of existing installations strongly depends on the actual condition of the installation at the time the assessment is performed. This key condition is denoted the ‘as-is’ condition, indicating that an earthquake, when it occurs, affects the installation in its actual condition, and the response and capacity of the installation will depend on its actual physical and operating configuration. The as-is condition of the installation is the baseline for any seismic safety evaluation programme. The as-is condition includes the ‘as-built’, ‘as-operated’ and ‘as-maintained’ conditions of the installation, and its condition of ageing at the time of the assessment.

OBJECTIVE

1.7. This Safety Guide provides recommendations in relation to the seismic safety evaluation of existing nuclear installations. Such an evaluation may be prompted by a seismic hazard perceived to be greater than that originally established in the design basis, by new regulatory requirements, by new findings on the seismic vulnerability of SSCs, or by the need to demonstrate performance for beyond design basis earthquake conditions, in line and consistent with internationally recognized good practices. This Safety Guide may also be used for nuclear installations whose purpose and associated radiological risks have changed, or are proposed to be changed, and in cases where the long term operation of the installation is under consideration.

1.8. This Safety Guide is intended for use by regulatory bodies responsible for establishing regulatory requirements and by operating organizations directly responsible for the execution of the seismic safety evaluation and upgrading programmes.

SCOPE

1.9. This Safety Guide addresses an extended range of existing nuclear installations, as defined in Ref. [8]: land based stationary nuclear power plants, research reactors, nuclear fuel fabrication plants, enrichment plants, reprocessing facilities and independent spent fuel storage facilities. Much of the methodology is independent of the type of nuclear installation or the reactor type, but aspects such as plant performance criteria, systems modelling, etc., are specific to each installation type. The methodologies developed for nuclear power plants are also applicable to other nuclear installations through a graded approach.

1.10. For the purpose of this Safety Guide, existing nuclear installations are those installations that are either (a) at the operational stage (including long term operation and extended temporary shutdown periods) or (b) at a pre-operational stage for which the construction of structures, manufacturing, installation and/or assembly of components and systems, and commissioning activities are significantly advanced or fully completed. In existing nuclear installations that are at the operational and pre-operational stages, a change of the original design bases, such as for a new seismic hazard at the site, or a change in the regulatory requirements regarding the consideration of seismic hazard and/or seismic design of the installation, may lead to a significant impact on the design and, consequently, to important hardware modifications.

1.11. Two methodologies are discussed in detail in this Safety Guide: the deterministic approach generally represented by seismic margin assessment (SMA) and the seismic probabilistic safety assessment (SPSA). Variations of these approaches or alternative approaches may be demonstrated to be acceptable also, as discussed in Section 2.

STRUCTURE

1.12. Section 2 provides general considerations and general recommendations on the seismic safety evaluation of nuclear installations. Section 3 describes data requirements (collection and investigations). Section 4 provides recommendations on the seismic hazard assessment of the site. Section 5 details the implementation of the deterministic SMA and SPSA methodologies for the seismic safety evaluation of existing nuclear power plants. Section 6 provides recommendations on applying a graded approach to the evaluation of nuclear installations other than nuclear power plants (with reference to Section 5

where appropriate). Section 7 presents considerations for upgrading. Section 8 provides information on management systems to be put in place for the performance of all activities, and identifies the need for configuration management in future activities to maintain the seismic capacity as evaluated. Sections 1–4, 7 and 8, in total or in part, apply to all nuclear installations. Section 5 is specific to nuclear power plants. The Annex presents a summary of the extensive background material on methodology development and applications to date, including related references. For definitions and explanations of technical terms, see the IAEA Safety Glossary [8]. Explanations of terms specific to this Safety Guide are provided in footnotes.

2. FORMULATION OF THE PROGRAMME FOR SEISMIC SAFETY EVALUATION

GENERAL CONSIDERATIONS

2.1. It is usually recognized that well designed industrial facilities, especially nuclear power plants, have an inherent capability to resist earthquakes larger than the earthquake considered in their original design. Conservatism is compounded through the seismic analysis and the design chain. This inherent capability or robustness — usually described in terms of the ‘seismic design margin’ — is a direct consequence of (a) the conservatism that is present in the seismic design and qualification procedures used according to previous or current practices in earthquake engineering and (b) the fact that in the design of nuclear plants the seismic loads may not be the governing loads for some SSCs.

2.2. Typically, current criteria for seismic design and qualification applicable to nuclear power plants introduce large seismic design margins; the measure of margin is frequently not specified and the amount is seldom quantified. It is known that a significant and adequate seismic design margin to failure exists and is ensured through the use of design criteria in industry standards and guidelines — particularly those applicable to nuclear installations. This has been demonstrated through the implementation of SMA or SPSA methodologies for existing nuclear power plants in several States. The introduction of the seismic design margins through the various stages of the original analysis and design leads to large expected variations throughout the

nuclear installation. The seismic design margin typically varies greatly from one location in the plant to another, from one structure, system or component to another, and from one location to another in the same structure. One of the main reasons for this variation, as mentioned in para. 2.1, is the fact that nuclear installations are designed for a wide range of internal and external extreme loads, for example, pressure and other environmental loads due to accident conditions, aircraft crash, tornado or pipe break, and seismic loads may not be the governing loads for some SSCs. Another reason is the method of equipment qualification in which envelope type response spectra are generally used. There should be a detailed examination of the actual design practice to understand the sources of conservatism. It should not be automatically assumed that there is excessive conservatism in the process, since this may lead to complacency in the seismic safety evaluation.

2.3. The methodologies presented in this Safety Guide are intended for evaluating and quantifying the seismic capacity of an existing installation according to the current as-is conditions.

2.4. In the seismic safety evaluation of a nuclear installation, the objective is to understand the true state of the SSCs in terms of their required safety function and their seismic capacity, and, as a result, to assess the seismic safety margin of the installation. It is therefore important to use realistic and best estimate values for the as-is condition of the SSCs and not to introduce safety factors that may unnecessarily bias the results. The approach used by the SMA methodology, for example, is to consider a higher level of seismic hazard (greater than the design ground motion) and to associate this with the realistic seismic capacity of the installation. In so doing, the inherent excess capacity of the SSCs may be taken into account.

2.5. Following the regulatory practice of the State, in either the SMA or the SPSA methodology, items other than those classified as Seismic Category I [5] that are used to prevent accidents or to mitigate accident conditions, and that were not seismically qualified in their original design basis, may be included in the programme for seismic safety evaluation; for example, existing systems that may be used in severe accident management.

2.6. The programmes for seismic safety evaluation performed for existing nuclear power plants, on the basis of the as-is condition of the installations, emphasized pragmatic evaluations rather than using extensive complex analyses. Limited non-linear analyses of relatively simple structural models or the use of higher damping values and ductility factors — provided that they are

used with care and are consistent with allowable deformations — may be particularly helpful in understanding post-elastic behaviour. However, detailed, sophisticated non-linear analyses are generally not undertaken in the usual practice.

2.7. Although peak ground acceleration is a parameter that is widely used to scale the seismic input, it is a known technical finding that the ability of seismic ground motions to cause damage to SSCs that behave in a ductile manner is not well correlated with the level of peak ground acceleration. It is recognized that other parameters such as velocity, displacement, duration of strong motion, spectral acceleration, power spectral density and cumulative absolute velocity should play a significant role in a judicious evaluation of the effects of seismic ground motions on SSCs. Another example is the effects caused by near field earthquakes of small magnitude (i.e. $M \leq 5.5$). Most such events have high frequency content and produce high peak ground acceleration levels, but they do not generate significant damage to structures and mechanical equipment. However, if the high frequency content produced by such near field earthquakes is transmitted to the structures, it may cause operability problems with certain types of equipment. It may also affect brittle materials such as glass. Related safety concerns include spurious behaviour of electrical equipment or devices and/or of instrumentation and control systems.

2.8. With regard to the behaviour of structures, mechanical components and distribution systems, numerous field observations and research and development programmes have demonstrated that a high capacity seismic design results when the ductile behaviour of SSCs accommodates large strains, rather than when only large calculated forces are balanced, such as the forces that are usually estimated on the basis of elastic behaviour and a static equivalent approach.

EVALUATION OF SEISMIC SAFETY

Reasons for and objectives of the seismic safety evaluation

2.9. As established in the Safety Requirements publication on Safety of Nuclear Power Plants: Operation, “Systematic safety reassessments of the plant in accordance with the regulatory requirements shall be performed by the operating organization throughout its operational lifetime, with account taken of operating experience and significant new safety information from all relevant sources” (Ref. [1], para. 10.1).

2.10. In accordance with this requirement and in line with international practice, an evaluation of the seismic safety of an existing nuclear installation should be performed in the event of any one of the following:

- (a) Evidence of a seismic hazard at the site that is greater than the design basis earthquake, arising from new or additional data (e.g. newly discovered seismogenic structures, newly installed seismological networks or new palaeoseismological evidence), new methods of seismic hazard assessment, and/or the occurrence of actual earthquakes that affect the installation;
- (b) Regulatory requirements, such as the requirement for periodic safety reviews, that take into account the 'state of knowledge' and the actual condition of the installation;
- (c) Inadequate seismic design, generally due to the vintage of the facility;
- (d) New technical findings, such as vulnerability of selected structures and/or non-structural elements (e.g. masonry walls), and/or of systems or components (e.g. relays);
- (e) New experience from the occurrence of actual earthquakes (e.g. better recorded ground motion data and the observed performance of SSCs);
- (f) The need to address the performance of the installation for beyond design basis earthquake ground motions in order to provide confidence that there is no 'cliff edge effect', that is, to demonstrate that no significant failures would occur in the installation if an earthquake were to occur that was slightly greater than the design basis earthquake (Ref. [2], paras 4.6 and 5.73);
- (g) A programme of long term operation of which such an evaluation is a part.

2.11. If, for the reasons above or for other reasons, a seismic safety evaluation of an existing nuclear installation is required, the purposes of the evaluation should be clearly established before the evaluation process is initiated. This is because there are significant differences among the available evaluation procedures and acceptance criteria, depending on the purpose of the evaluation. In this regard, the objectives of the seismic safety evaluation may include one or more of the following:

- (a) To demonstrate the seismic safety margin beyond the original design basis earthquake and to confirm that there are no cliff edge effects.
- (b) To identify weak links in the installation and its operations with respect to seismic events.

- (c) To evaluate a group of installations (e.g. all the installations in a region or a State), to determine their relative seismic capacity and/or their risk ranking. For this purpose, similar and comparable methodologies should be adopted.
- (d) To provide input for risk informed decision making.
- (e) To identify and prioritize possible upgrades.
- (f) To assess risk metrics (e.g. core damage frequency and large early release frequency) against regulatory requirements, if any.
- (g) To assess plant capacity metrics (e.g. systems level and plant level fragilities or high confidence of low probability of failure (HCLPF) values) against regulatory expectations.

2.12. The objectives of the seismic safety evaluation of an existing installation should be established in line with the regulatory requirements, and in consultation and agreement with the regulatory body. Consequently, and in accordance with such objectives, the level of seismic input motion, the methodology for capacity assessment and the acceptance criteria to be applied, including the required end products, should be defined. In particular, for evaluating seismic safety for seismic events more severe than the event specified in the original design basis, the safety objectives should include the functions required to be ensured and the failure modes to be prevented during or after the earthquake's occurrence.

2.13. The final documentation to be produced at the end of the evaluation should be identified from the beginning in agreement with the regulatory body and should be consistent with the established purpose of the programme. The end products of these evaluations may be one or more of the following:

- (a) Measures of the seismic capacity of the nuclear installation in deterministic or probabilistic terms;
- (b) Identification of SSCs with low seismic capacity, and the associated consequences for plant safety, for decision making on upgrading programmes;
- (c) Identification of operational modifications to improve seismic capacity;
- (d) Identification of improvements to housekeeping practices (e.g. storage of maintenance equipment);
- (e) Identification of interactions with fire prevention and protection systems, etc.;
- (f) Identification of actions to be taken before, during and after the occurrence of an earthquake that affects the installation, including arrangements for and actions in operational and management response,

analysis of the obtained instrumental seismic records and performed inspections, and the integrity evaluations to be performed as a consequence;

- (g) A framework to provide input to risk informed decision making.

Selection of the methodology for seismic safety evaluation

2.14. One of the first steps of the programme for seismic safety evaluation should be the selection of the methodology to be used. The objectives of the evaluation may determine the methodology to be used, the parameter values for the methodology, the use of generic data versus site specific and plant specific data, and other key elements. As indicated in the scope of this Safety Guide, two methodologies are recommended and discussed in detail: the deterministic SMA and the probabilistic SPSA. It is not intended that both methodologies be implemented, since either the SMA or the SPSA approach may satisfy the objectives of the programme. Variations of these methodologies or alternative approaches may also be demonstrated to be acceptable.

2.15. A clear distinction should be made between a seismic safety evaluation that does not entail a change in the design basis earthquake (i.e. SL-2, see Ref. [4]) and a seismic safety evaluation where a change in the design basis earthquake is required by the regulatory body. This Safety Guide focuses mainly on the methodologies for seismic safety evaluation that do not involve a change in the design basis earthquake, but that involve evaluation of the seismic safety of existing installations for seismic hazards more severe than those originally established for the design basis and a realistic determination of the available safety margin. It is clear that the agreement of the regulatory body should be obtained to define the seismic input and the acceptance criteria for this process. If current earthquake engineering methods and acceptance criteria applicable to the seismic design and qualification of new installations were used for these purposes, they would be likely to lead to significant, if not infeasible, upgrading requirements.

2.16. After selection of the evaluation methodology, the programme for seismic safety evaluation should cover the following aspects:

- (a) Definition of the seismic input, that is, the earthquake ground motion parameters (see Section 4).
- (b) Verification of the geological stability of the site with respect to the potential for surface faulting and use of the newly defined seismic hazard

(see Section 4) for the reassessment of other geological hazards (e.g. liquefaction).

- (c) Seismic behaviour of the installation when subjected to the earthquake hazard, that is, the seismic demand on SSCs and their seismic capacity or fragility, systems performance, etc. Section 5 discusses these aspects.
- (d) Acceptance criteria and the need for upgrading of the facility (both the installation and operations). Section 7 discusses these topics.

2.17. This Safety Guide deals with realistic failure modes of SSCs, that is, the inability of the SSCs to perform their required functions, either because of inadequate seismic capacity or due to seismic interaction. For structures, this function may be confinement, support and/or protection of other SSCs. For distribution systems and components, this function may be operability and/or fluid retention. For example, for piping systems, failure is the loss of ability to retain their flow capacity. For systems, failure is loss of acceptable performance. For structures and mechanical components, the seismic safety evaluation may permit some non-linear behaviour, but at levels lower than those allowed for conventional industrial facilities. The functions required from SSCs and the failure modes of these SSCs should be identified.

2.18. Evaluation of the seismic capacity or fragility of systems and components should rely to a significant extent on earthquake experience data and test data. There is already a significant amount of data that have been obtained, evaluated, reviewed and incorporated into procedures. These data consist of earthquake experience data and test data as follows:

- (a) Earthquake experience data have been obtained from a broad range of international sources and, generally, reflect the performance of mechanical and electrical equipment and distribution systems in industrial facilities subjected to strong earthquakes.
- (b) Test data are based on qualification tests or fragility tests of components. In some cases, the database of test data is dependent on component specific information, such as manufacturer, size, function and anchorage.

In all cases, the applicability of these earthquake experience data and test data should be verified with regard to the specific nuclear installation being evaluated.

2.19. The SMA methodology is based on defining a set of SSCs that, when shown to have acceptable seismic capacity, provide high confidence that the installation will successfully reach a safe state after an earthquake occurs. The identified SSCs constitute the 'success path'. The success path for a nuclear