

IAEA Safety Standards

for protecting people and the environment

Seismic Hazards in Site Evaluation for Nuclear Installations

Specific Safety Guide

No. SSG-9



IAEA

International Atomic Energy Agency



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SEISMIC HAZARDS
IN SITE EVALUATION
FOR 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. SSG-9

SEISMIC HAZARDS IN SITE EVALUATION FOR NUCLEAR INSTALLATIONS

SPECIFIC SAFETY GUIDE

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2010

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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 all Member States are urged 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. Requirements, including numbered ‘overarching’ requirements, are expressed

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

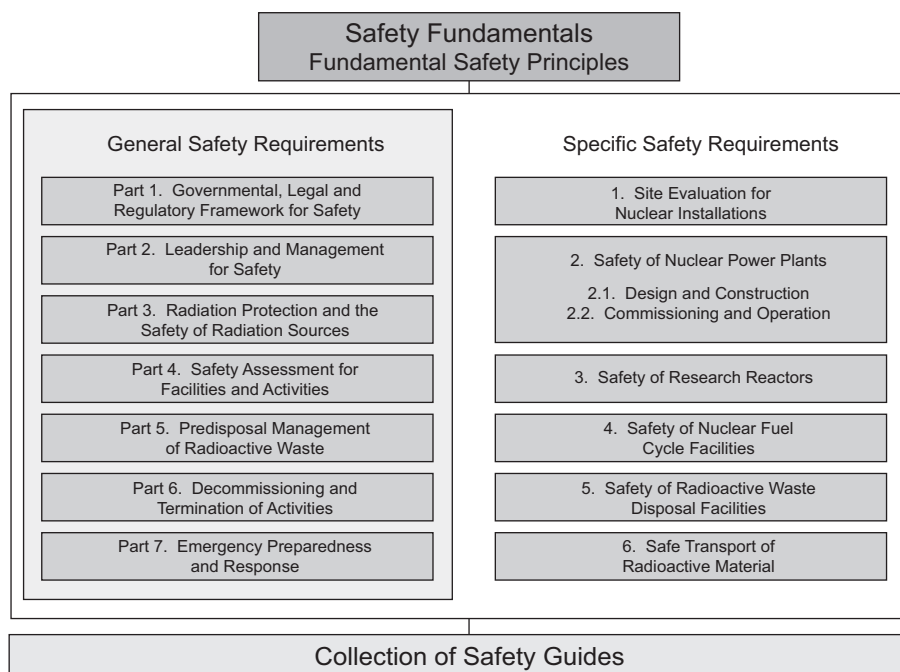


FIG. 1. The long term structure of the IAEA Safety Standards Series.

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 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).

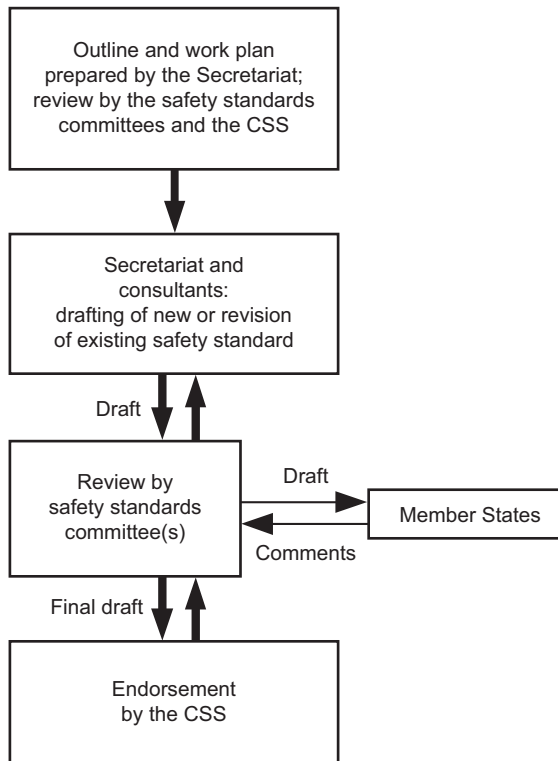


FIG. 2. The process for developing a new safety standard or revising an existing standard.

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. This Safety Guide was prepared under the IAEA programme for safety standards for nuclear installations. It supplements the Safety Requirements publication on Site Evaluation for Nuclear Installations [1]. The present publication provides guidance and recommends procedures for the evaluation of seismic hazards for nuclear power plants and other nuclear installations. It supersedes Evaluation of Seismic Hazards for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-3.3 (2002).

1.2. In this publication, the following was taken into account: the need for seismic hazard curves and ground motion spectra for the probabilistic safety assessment of external events for new and existing nuclear installations; feedback of information from IAEA reviews of seismic safety studies for nuclear installations performed over the previous decade; collective knowledge gained from recent significant earthquakes; and new approaches in methods of analysis, particularly in the areas of probabilistic seismic hazard analysis and strong motion simulation.

1.3. In the evaluation of a site for a nuclear installation, engineering solutions will generally be available to mitigate, by means of certain design features, the potential vibratory effects of earthquakes. However, such solutions cannot always be demonstrated to be adequate for mitigating the effects of phenomena of significant permanent ground displacement such as surface faulting, subsidence, ground collapse or fault creep.

OBJECTIVE

1.4. The objective of this Safety Guide is to provide recommendations and guidance on evaluating seismic hazards at a nuclear installation site and, in particular, on how to determine: (a) the vibratory ground motion hazards, in order to establish the design basis ground motions and other relevant parameters for both new and existing nuclear installations; and (b) the potential for fault displacement and the rate of fault displacement that could affect the feasibility of the site or the safe operation of the installation at that site.

1.5. This Safety Guide is intended for use by regulatory bodies responsible for establishing regulatory requirements, and for operating organizations directly responsible for the assessment of seismic hazards at a nuclear installation site.

SCOPE

1.6. The guidance and procedures recommended in this Safety Guide can appropriately be used in site evaluations and in evaluations of seismic hazards for nuclear installations in any seismotectonic environment.

1.7. Other seismic hazard phenomena involving permanent ground displacement (e.g. liquefaction, slope instability, subsidence, ground collapse, seismically induced soil settlements) as well as seismically induced floods are treated in detail in the Safety Guides relating to geotechnical aspects of site evaluation and foundations and to external floods (see Refs [2, 3], respectively).

1.8. This Safety Guide addresses an extended range of nuclear installations as defined in Ref. [4]: land based stationary nuclear power plants, research reactors, nuclear fuel fabrication facilities, enrichment facilities, reprocessing facilities and independent spent fuel storage facilities. The methodologies recommended for nuclear power plants are applicable to other nuclear installations by means of a graded approach, whereby these recommendations can be customized to suit the needs of nuclear installations of different types in accordance with the potential radiological consequences of their failure when subjected to seismic loads. The recommended direction of grading is to start with attributes relating to nuclear power plants and eventually to grade down to installations with which lesser radiological consequences are associated¹. If no grading is performed, the recommendations relating to nuclear power plants are applicable to other types of nuclear installations.

1.9. This Safety Guide addresses issues relating to site evaluation for nuclear installations. Design related seismic safety aspects of nuclear power plants are covered in Ref. [5].

1.10. For the purpose of this Safety Guide, existing nuclear installations are those installations that are: (a) at the operational stage (including long term operation

¹ For sites at which nuclear installations of different types are collocated, particular consideration should be given to using a graded approach.

and extended temporary shutdown periods); (b) at a pre-operational stage for which the construction of structures, the manufacturing, installation and/or assembly of components and systems, and commissioning activities are significantly advanced or fully completed; or (c) at temporary or permanent shutdown stage while nuclear fuel is still within the facility (in the core or the pool). In existing nuclear installations that are at the operational and pre-operational stages, a change of the original design bases may lead to a significant impact on the design and, consequently, to important hardware modifications [6]. Such a change in the original design bases may be made for a new seismic hazard at the site or a change in the regulatory requirements regarding the consideration of seismic hazards and/or seismic design of the installation.

1.11. The probabilistic seismic hazard analysis recommended in this Safety Guide also addresses what is needed for probabilistic safety assessments (PSAs) conducted for nuclear installations. In accordance with Ref. [7], seismic PSAs are required for seismic evaluation of nuclear power plants.

STRUCTURE

1.12. Recommendations of a general nature are provided in Section 2. The acquisition of a database containing the information needed to evaluate and address all hazards associated with earthquakes is discussed in Section 3. Section 4 covers the use of this database for the construction of a seismotectonic model. Section 5 reviews vibratory ground motion hazards using the databases developed (Section 3) and the seismotectonic model (Section 4). Sections 6 and 7 discuss probabilistic and deterministic methods of evaluating vibratory ground motion hazards. Section 8 reviews methods for evaluation of the potential for fault displacement. Section 9 discusses the development of design basis ground motion and fault displacement. Sections 3 to 9 provide detailed guidance for nuclear power plants. Section 10 discusses the evaluation of seismic hazards for nuclear installations other than nuclear power plants using a graded approach. Section 11 addresses project management, including quality assurance and peer review requirements. The annex provides an example of typical output deriving from probabilistic seismic hazard analyses.

2. GENERAL RECOMMENDATIONS

2.1. As established in the Safety Requirements publication, Site Evaluation for Nuclear Installations [1]:

“The seismological and geological conditions in the region and the engineering geological aspects and geotechnical aspects of the proposed site area shall be evaluated.” (Ref. [1], para. 3.1.)

“The hazards associated with earthquakes shall be determined by means of seismotectonic evaluation of the region with the use to the greatest possible extent of the information collected.” (Ref. [1], para. 3.3.)

“Hazards due to earthquake induced ground motion shall be assessed for the site with account taken of the seismotectonic characteristics of the region and specific site conditions. A thorough uncertainty analysis shall be performed as part of the evaluation of seismic hazards.” (Ref. [1], para. 3.4.)

“The potential for surface faulting (i.e. the fault capability) shall be assessed for the site. . . .” (Ref. [1], para. 3.5.)

Detailed requirements are also included in Ref. [1], paras 3.2, 3.6 and 3.7.

2.2. In accordance with these requirements and in line with international practice, the geological, geophysical and seismological characteristics of the region around the site and the geotechnical characteristics of the site area should be investigated as recommended in this Safety Guide for the purpose of evaluating the seismic hazards at the nuclear installation site.

2.3. Where necessary, the site region should include areas extending beyond national borders and the relevant offshore area for sites located near a coastline. The database acquired should be homogeneous for the entire region to the extent possible or, at a minimum, should be sufficiently complete for characterizing, from a seismotectonic point of view, features relevant to the site that are located in other States or in offshore areas.

2.4. The size of the region to be investigated, the type of information to be collected and the scope and detail of the investigations should be determined in accordance with the nature and complexity of the seismotectonic environment. In

all cases, the scope and detail of the information to be collected and the investigations to be undertaken should be sufficient for determining the vibratory ground motion and fault displacement hazards. If the site is close to major tectonic structures such as plate boundaries, thrust zones and subduction zones, including those in offshore areas, these structures should be considered in the investigations not only as seismogenic but also as features that may strongly affect the travel path and the site response.

2.5. The seismic hazard evaluation should be done through implementation of a specific project for which clear and detailed objectives are defined, and in accordance with a work plan, as recommended in Section 11 of this Safety Guide. This seismic hazard evaluation project should be carried out by a multidisciplinary team of experts, including geologists, seismologists, geophysicists, engineers and possibly other experts (e.g. historians). The members of the team for the seismic hazard evaluation project should demonstrate the expertise and experience commensurate with their role in the project.

2.6. The general approach to seismic hazard evaluation should be directed towards reducing the uncertainties at various stages of the evaluation process in order to obtain reliable results driven by data. Experience shows that the most effective way of achieving this is to collect a sufficient amount of reliable and relevant data. There is generally a trade-off between the time and effort necessary to compile a detailed, reliable and relevant database and the degree of uncertainty that the analyst should take into consideration at each step of the process.

2.7. The collection of site specific data tends to reduce uncertainties. However, part of the data used indirectly in seismic hazard evaluation may not be site specific; for example, in many cases the strong motion data used to develop the attenuation relationships. There may be, therefore, a part of the uncertainty which is irreducible with respect to site specific investigations. This should be recognized and taken into consideration by including aleatory uncertainty (i.e. uncertainty that is intrinsic or random in nature) and epistemic uncertainty (i.e. uncertainty that is extrinsic in nature or is associated with modelling) within the framework of seismic hazard evaluation.

2.8. The overall uncertainty will involve both aleatory uncertainties, and epistemic uncertainties that arise owing to differences in interpretation on the part of informed experts participating in the seismic hazard evaluation. Every aspect of the identification, analysis and characterization of seismic sources and estimation of ground motion hazards may involve subjective interpretation by

experts. By taking due consideration of this, such interpretations should be treated in the seismic hazard analysis in a consistent manner, providing for a suitable representation of current thinking in seismic source and ground motion modelling. Particular care should be taken to avoid bias in these interpretations. Expert opinion should not be used as a substitute for acquiring new data. The project team for the seismic hazard evaluation should not promote any one expert hypothesis or model. It should, however, evaluate all viable hypotheses and models using the data compiled, and then develop an integrated evaluation that incorporates both knowledge and uncertainties.

2.9. To cover the diversity of scientific interpretations, one approach is to involve a team of experts qualified in each of the relevant disciplines. When such an approach is not feasible, an alternative approach to hazard analysis can be taken. In such a case, it should be demonstrated that a similar level of uncertainty in the input can still be represented. This may be possible by developing a detailed analysis of relevant data and scientific research and by incorporating into the analysis all scientifically valid alternative hypotheses, associated uncertainties and sensitivity analyses. A systematically conducted sensitivity analysis should be used to support the evaluation of the significance of the contributions of the various input data in the model.

2.10. Uncertainties that cannot be reduced by means of site investigations (e.g. uncertainties arising from the use of ground motion attenuation relationships derived for other parts of the world) do not permit hazard values to decrease below certain threshold values. For this reason, and regardless of any lower apparent exposure to seismic hazard, a minimum level should be recognized as the lower limit to any seismic hazard study performed for a nuclear power plant using this Safety Guide.

2.11. In that regard, generically, this level should be represented by a horizontal free field standardized response spectrum anchored to a peak ground acceleration value of 0.1g (where 'g' is the acceleration due to gravity). It should also be recognized that when geological and seismological data have deficiencies in comparison with what is recommended in Section 3, the value of 0.1g will not represent a sufficiently conservative estimate of the hazard. This fact should be properly represented in defining the design basis and re-evaluation parameters discussed in Refs [5, 6], respectively.

3. NECESSARY INFORMATION AND INVESTIGATIONS (DATABASE)

OVERVIEW

3.1. A comprehensive and integrated database of geological, geophysical, geotechnical and seismological information should be acquired and incorporated in a coherent form for evaluating and resolving issues relating to all hazards associated with earthquakes.

3.2. It should be ensured that each element of every database has been investigated as fully as possible before an integration of the various elements is attempted. The integrated database should include all relevant information; that is, not only geological, geophysical, geotechnical and seismological data, but also any other information that is relevant to evaluating the ground motion, faulting and geological hazards at the site.

3.3. Investigations should be conducted on four spatial scales — regional, near regional, site vicinity and site area — leading to progressively more detailed investigations, data and information. The detail of these data is determined by the different spatial scales. The first three scales of investigation lead primarily to progressively more detailed geological and geophysical data and information. The site area investigations are aimed at developing the geotechnical database. To achieve consistency in the presentation of information, whenever possible the data should be compiled in a geographical information system with adequate metadata information. All data should be stored in a uniform reference frame to facilitate comparison and integration.

3.4. The compilation of the seismological database will normally be less dependent on the regional, near regional and site vicinity scales than that of other databases. However, seismogenic structures in the near region and in the site vicinity will usually be more important for seismic hazard evaluation, depending on the rates of activity, the expected maximum potential magnitudes and the regional attenuation of ground motion. Particularly for some intraplate tectonic settings, attention should be paid to compiling seismological data for more distant seismic sources that may be beyond the typical boundaries of the region. In offshore regions, adequate investigations should be conducted in order to fully analyse the tectonic characteristics of the region and to compensate for any lack of or deficiency in the seismological data.

3.5. When a seismic hazard analysis is performed for any reason during the operating lifetime of the nuclear power plant (e.g. for a periodic safety review or a probabilistic seismic hazard analysis for a seismic probabilistic safety assessment), the integrated database should be updated to cover the time elapsed from the most recent compilation of data until the present, and recent scientific findings should be incorporated.

GEOLOGICAL, GEOPHYSICAL AND GEOTECHNICAL DATABASE

3.6. As established in Ref. [1], para. 2.19: “The size of the region to which a method for establishing the hazards associated with major external phenomena is to be applied shall be large enough to include all the features and areas that could be of significance in the determination of the natural and human induced phenomena under consideration and for the characteristics of the event.”

Regional investigations

3.7. The size of the relevant region may vary, depending on the geological and tectonic setting, and its shape may be asymmetric in order to include distant significant seismic sources of earthquakes. Its radial extent is typically 300 km. In intraplate regions, and in the particular case of investigations into the potential for tsunamis (Ref. [3]), the investigations may need to consider seismic sources at very great distances from the site. If it can be demonstrated easily that there are major tectonic structures closer to the site than the radius indicated, then studies should concentrate on this part of the region.

3.8. The purpose of obtaining data on a regional scale is to provide knowledge of the general geodynamic setting of the region and the current tectonic regime, as well as to identify and characterize those geological features that may influence or relate to the seismic hazard at the site. The most relevant among these geological features are structures that show potential for displacement and/or deformation at or near the ground surface; that is, capable faults. The data obtained from any type of published and unpublished geological and geophysical source (e.g. data derived from existing galleries, road cuts, geophysical surveys or boreholes) should be presented on maps with appropriate cross-sections.

3.9. Where existing data are inadequate for the purpose of delineating seismogenic structures, in terms of location, extent and rate of ongoing deformation, it may be necessary to verify and complete the database by acquiring new geological and geophysical data. This may involve investigations