

IAEA Safety Standards

for protecting people and the environment

Geotechnical Aspects of Site Evaluation and Foundations for Nuclear Power Plants

Safety Guide

No. NS-G-3.6



IAEA

International Atomic Energy Agency

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The publications by means of which the IAEA establishes standards are issued in the **IAEA Safety Standards Series**. This series covers nuclear safety, radiation safety, transport safety and waste safety, and also general safety (i.e. all these areas of safety). The publication categories in the series are **Safety Fundamentals**, **Safety Requirements** and **Safety Guides**.

Safety standards are coded according to their coverage: nuclear safety (NS), radiation safety (RS), transport safety (TS), waste safety (WS) and general safety (GS).

Information on the IAEA's safety standards programme is available at the IAEA Internet site

<http://www-ns.iaea.org/standards/>

The site provides the texts in English of published and draft safety standards. The texts of safety standards issued in Arabic, Chinese, French, Russian and Spanish, the IAEA Safety Glossary and a status report for safety standards under development are also available. For further information, please contact the IAEA at P.O. Box 100, A-1400 Vienna, Austria.

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

OTHER SAFETY RELATED PUBLICATIONS

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

Reports on safety and protection in nuclear activities are issued in other publications series, in particular the **Safety Reports Series**. Safety Reports provide practical examples and detailed methods that can be used in support of the safety standards. Other IAEA series of safety related publications are the **Provision for the Application of Safety Standards Series**, the **Radiological Assessment Reports Series** and the International Nuclear Safety Group's **INSAG Series**. The IAEA also issues reports on radiological accidents and other special publications.

Safety related publications are also issued in the **Technical Reports Series**, the **IAEA-TECDOC Series**, the **Training Course Series** and the **IAEA Services Series**, and as **Practical Radiation Safety Manuals** and **Practical Radiation Technical Manuals**. Security related publications are issued in the **IAEA Nuclear Security Series**.

GEOTECHNICAL ASPECTS OF SITE EVALUATION AND FOUNDATIONS FOR NUCLEAR POWER PLANTS

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

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GEOTECHNICAL ASPECTS OF SITE EVALUATION AND FOUNDATIONS FOR NUCLEAR POWER PLANTS

SAFETY GUIDE

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2004

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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.

IAEA SAFETY STANDARDS

SAFETY THROUGH INTERNATIONAL STANDARDS

While safety is a national responsibility, international standards and approaches to safety promote consistency, help to provide assurance that nuclear and radiation related technologies are used safely, and facilitate international technical cooperation and trade.

The standards also provide support for States in meeting their international obligations. One general international obligation is that a State must not pursue activities that cause damage in another State. More specific obligations on Contracting States are set out in international safety related conventions. The internationally agreed IAEA safety standards provide the basis for States to demonstrate that they are meeting these obligations.

THE IAEA STANDARDS

The IAEA safety standards have a status derived from the IAEA's Statute, which authorizes the Agency to establish standards of safety for nuclear and radiation related facilities and activities and to provide for their application.

The safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment.

They are issued in the IAEA Safety Standards Series, which has three categories:

Safety Fundamentals

- Presenting the objectives, concepts and principles of protection and safety and providing the basis for the safety requirements.

Safety Requirements

- Establishing the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements, which are expressed as 'shall' statements, are governed by the objectives, concepts and principles of the Safety Fundamentals. If they are not met, measures must be taken to reach or restore the required level of safety. The Safety Requirements use regulatory language to enable them to be incorporated into national laws and regulations.

Safety Guides

- Providing recommendations and guidance on how to comply with the Safety Requirements. Recommendations in the Safety Guides are expressed as 'should' statements. It is recommended to take the measures stated 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. Each Safety Requirements publication is supplemented by a number of Safety Guides, which can be used in developing national regulatory guides.

The IAEA safety standards need to be complemented by industry standards and must be implemented within appropriate national regulatory infrastructures to be fully effective. The IAEA produces a wide range of technical publications to help States in developing these national standards and infrastructures.

MAIN USERS OF THE STANDARDS

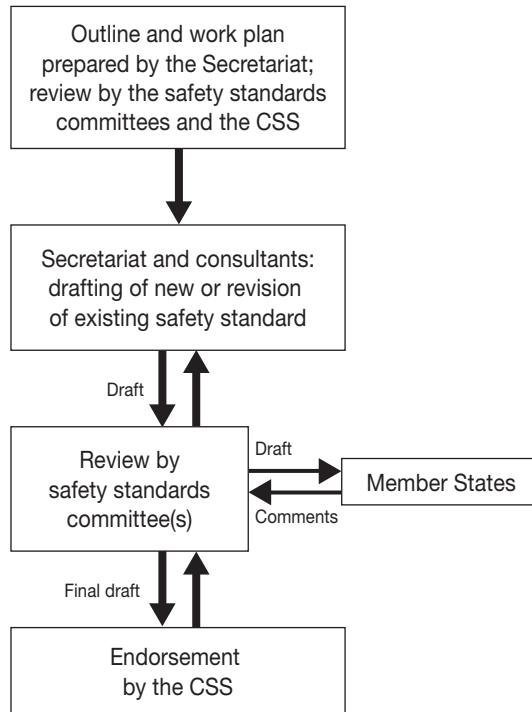
As well as by regulatory bodies and governmental departments, authorities and agencies, the standards are used by authorities and operating organizations in the nuclear industry; by organizations that design, manufacture and apply nuclear and radiation related technologies, including operating organizations of facilities of various types; by users and others involved with radiation and radioactive material in medicine, industry, agriculture, research and education; and by engineers, scientists, technicians and other specialists. The standards are used by the IAEA itself in its safety reviews and for developing education and training courses.

DEVELOPMENT PROCESS FOR THE STANDARDS

The preparation and review of safety standards involves the IAEA Secretariat and four safety standards committees for safety in the areas of 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 entire safety standards programme. All IAEA Member States may nominate experts for the safety standards committees and may provide comments on draft standards. The membership of the CSS is appointed by the Director General and includes senior government officials having responsibility for establishing national standards.

For Safety Fundamentals and Safety Requirements, the drafts endorsed by the Commission are submitted to the IAEA Board of Governors for approval for publication. Safety Guides are published on the approval of the Director General.

Through this process the standards come to represent a consensus view of the IAEA's Member States. 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 standards. Some 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 International



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

Labour Organization, the OECD Nuclear Energy Agency, the Pan American Health Organization and the World Health Organization.

The safety standards are kept up to date: five years after publication they are reviewed to determine whether revision is necessary.

APPLICATION AND SCOPE OF THE STANDARDS

The IAEA Statute makes the safety standards binding on the IAEA in relation to its own operations and on States in relation to operations assisted by the IAEA. Any State wishing to enter into an agreement with the IAEA concerning any form of Agency assistance is required to comply with the requirements of the safety standards that pertain to the activities covered by the agreement.

International conventions also contain similar requirements to those in the safety standards, and make them binding on contracting parties. The Safety Fundamentals were used as the basis for the development of the Convention on Nuclear Safety and the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. The Safety

Requirements on Preparedness and Response for a Nuclear or Radiological Emergency reflect the obligations on States under the Convention on Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency.

The safety standards, incorporated into national legislation and regulations and supplemented by international conventions and detailed national requirements, establish a basis for protecting people and the environment. However, there will also be special aspects of safety that need to be assessed case by case at the national level. For example, many of the safety standards, particularly those addressing planning or design aspects of safety, are intended to apply primarily to new facilities and activities. The requirements and recommendations specified in the IAEA safety standards might not be fully met at some facilities built to earlier standards. The way in which the safety standards are to be applied to such facilities is a decision for individual States.

INTERPRETATION OF THE TEXT

The safety standards use the form ‘shall’ in establishing international consensus requirements, responsibilities and obligations. Many requirements are not addressed to a specific party, the implication being that the appropriate party or parties should be responsible for fulfilling them. Recommendations are expressed as ‘should’ statements, indicating an international consensus that it is necessary to take the measures recommended (or equivalent alternative measures) for complying with the requirements.

Safety related terms are to be interpreted as stated in the IAEA Safety Glossary (<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 within the 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 main text (e.g. material that is subsidiary to or separate from the main text, is included in support of statements in the main text, or describes methods of calculation, experimental 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 standard. Material in an appendix has the same status as the main 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. An annex is not an integral part of the main text. Annex material published by the IAEA is not necessarily issued under its authorship; material published in standards that is under other authorship may be presented in annexes. 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, which supplements the Safety Requirements publication on Site Evaluation for Nuclear Installations, is issued under the IAEA's programme for establishing Safety Requirements and Safety Guides relating to land based nuclear installations.

1.2. The present Safety Guide supersedes a Safety Guide issued in 1986 as Safety Series No. 50-SG-S8, Safety Aspects of Foundations of Nuclear Power Plants. The revision involved principally an updating of the technical content in accordance with developments in geotechnical engineering and the feedback of experience, and reorganization of the text. In the revision process, it was decided to extend the scope to include earth structures, which were previously addressed in Safety Series No. 50-SG-D15, Seismic Design and Qualification for Nuclear Power Plants, which has now been superseded by Ref. [1].

OBJECTIVE

1.3. The purpose of this Safety Guide is to provide guidance on dealing with geotechnical engineering aspects that are important for the safety of nuclear power plants. Seismic aspects also play an important role in this field, and consequently the Safety Guide on Evaluation of Seismic Hazards for Nuclear Power Plants, Safety Standards Series No. NS-G-3.3 [2], which discusses the determination of seismic input motion, is referenced on several occasions. The present Safety Guide provides an interpretation of the Safety Requirements on Site Evaluation for Nuclear Installations [3] and guidance on how to implement them. It is intended for the use of safety assessors or regulators involved in the licensing process as well as the designers of nuclear power plants, and it provides them with guidance on the methods and procedures for analyses to support the assessment of the geotechnical aspects of the safety of nuclear power plants.

SCOPE

1.4. In the process of selection of a new site for a nuclear installation, a series of parameters are required to be considered, as established in Ref. [3]. These

parameters usually play a prominent role, and the site finally selected is seldom an ideal one with regard to geotechnical conditions (practically, a site may be dropped from consideration on geotechnical grounds only if the conditions are very poor). This Safety Guide therefore provides guidance for dealing with the realistic possibility of a situation in which complex geotechnical conditions are faced.

1.5. This Safety Guide discusses the geotechnical engineering aspects of the subsurface conditions and not the geological aspects, except where these directly affect the foundation system. It discusses the programme of investigations that should be carried out to obtain an appropriate understanding of the subsurface conditions, which is necessary for determining whether the conditions are suitable for the construction of a nuclear power plant. It also provides a description of the geotechnical profiles and the parameters that are suitable for use in performing the geotechnical analyses that are required for the design of a nuclear power plant. It also discusses the monitoring of the geotechnical parameters at the site.

1.6. Methods of analysis appropriate for the safety assessment of the site are discussed here, particularly for the assessment of the effects of an earthquake on the site, including the determination of site specific response spectra and estimation of the liquefaction potential. The Safety Guide also discusses methods of analysis appropriate for the safety assessment of the effects of static and dynamic interaction between the soil and the structures, and of the consequences for the bearing capacities and for settlements. A more detailed description of methods for the analysis of soil–structure interactions is given in Ref. [1]. In this Safety Guide only the site dependent information and the methods of analysis are addressed.

1.7. This Safety Guide discusses foundation works, including the consequences for the geotechnical profiles and parameters, the possible improvement of foundation material and the appropriate choice of the foundation system according to the soil capacities.

1.8. Also discussed are earth structures, including natural slopes, and buried structures, the safety of which may need to be assessed. The Safety Guide discusses appropriate methods for the analysis of the behaviour of such structures under static and dynamic loads.

STRUCTURE

1.9. Section 2 concerns the programme of investigations, addressing the different stages of the programme and the sources of data; a special subsection is dedicated to the investigation of complex subsurface conditions. Section 3 covers the assessment of the site as it is before any construction and the relevant methods of analysis. Subsections are dedicated to site characterization from soft to stiff sites, relevant parameters for the description of the mechanical characteristics of the soil profiles, free field seismic response spectra and site specific response spectra, and the assessment of liquefaction potential. Section 4 focuses on considerations relating to the foundations; that is, to the site as it is modified by building construction. Foundation works are addressed first, followed by soil–structure interactions and their consequences for stability and for settlements. Sections 5 and 6 are dedicated to special structures. Section 5 addresses earth structures, with subsections on natural slopes, dykes and dams, embankments and cuts and fills, seawalls and similar structures. Section 6 addresses buried structures in a wide sense, with subsections on retaining walls, embedded structures, buried pipes and tunnels. Section 7 deals with the monitoring of geotechnical parameters.

2. SITE INVESTIGATION

INVESTIGATION PROGRAMME

2.1. Investigation of the subsurface conditions at a nuclear power plant site is important at all stages of the site evaluation process. The purpose of this investigation is to provide information or basic data for decisions on the nature and suitability of the subsurface materials. At each stage of the site evaluation, the investigation programme should provide the data necessary for an appropriate characterization of the subsurface. Detailed subsurface investigations should be performed in the later stages. The specific requirements will vary greatly from stage to stage.

2.2. The programme of investigation should cater to all stages of the site evaluation process. For a nuclear power plant, site evaluation typically involves the following stages:

- *Selection stage.* One or more preferred candidate sites are selected after investigation of a large region, rejection of unsuitable sites, and screening and comparison of the remaining sites.
- *Characterization stage.* This stage is further subdivided into:
 - Verification, in which the suitability of the site to host a nuclear power plant is verified mainly according to predefined site exclusion criteria;
 - Confirmation, in which the characteristics of the site necessary for the purposes of analysis and detailed design are determined.
- *Pre-operational stage.* Studies and investigations begun in the previous stages are continued after the start of construction and before the start of operation of the plant to complete and refine the assessment of site characteristics. The site data obtained allow a final assessment of the simulation models used in the ultimate design.
- *Operational stage.* Selected investigations are pursued over the lifetime of the plant.

2.3. The programme of investigation differs in the various stages, in that the data requirements vary greatly. Generally, the necessary data will yield geological and engineering related information for use in safety evaluations or analyses. These data can be classified as:

- Geological information (stratigraphical and structural);
- Descriptions of the extent and nature of subsurface materials;
- Characterizations of soil and rock (in terms of properties);
- Information on groundwater (the groundwater regime, locations and characteristics of the hydrological units, physical chemistry of the water).

2.4. The results of the investigations described in this section should be properly documented with reference to the particular site conditions (soil or rock), the stage of the site evaluation process concerned and the verification analysis required.

2.5. The various methods of investigation — that is, the use of current and historical documents, geophysical and geotechnical exploration in situ and laboratory testing — are applicable to all stages of the site evaluation process, but to varying extents. This section indicates the level of investigation necessary for the evaluation of the site in terms of the performance of subsurface materials and earthworks under the anticipated loading conditions (static and dynamic).

Selection stage

2.6. The purpose of an investigation at the site selection stage is to determine the suitability of sites. In this stage, geological, geomorphological and geotechnical aspects are considered and regions or areas are usually identified that are excluded from further consideration. Subsurface information for this stage is usually obtained from current and historical documents and by means of field reconnaissance, including geological and geomorphological surveys, and it is used in the following assessments:

- *Unacceptable subsurface conditions.* A site with geological conditions that could affect the safety of a nuclear power plant and that cannot be corrected by means of a geotechnical treatment or compensated for by constructive measures is unacceptable. Geological hazards such as surface faulting (see Ref. [3] under ‘Potential for surface faulting at the site’), volcanic activity, landslides, permafrost, erosion processes, subsidence and collapse due to underground cavities (both natural and those deriving from human activities), or other causes should be identified and evaluated. The area of the investigation should be appropriate to the hazard under consideration.
- *Classification of sites.* The subsurface conditions at a site can be derived from the geological and geotechnical literature. A site may be classified as a rock site, a soft rock or stiff soil site, a soft soil site or a combination of these, and may be categorized as described in Section 3. The soil type is further divided into non-cohesive and cohesive soil. However, this rough classification may not apply for certain sites. For instance, quaternary formations may present complex interfaces between rock and clay that should be carefully investigated and monitored.
- *Groundwater regime.* The hydrogeological literature may allow an estimate to be made of the location of groundwater and the groundwater regime (see Ref. [4]).
- *Foundation conditions.* The type of soil, the depth to bedrock and the properties of the deposit may be determined. This permits the preliminary selection of acceptable foundation types.

2.7. On the basis of the above mentioned information on subsurface conditions, the potential or candidate sites can be ranked according to the suitability of the foundation. At this stage, inferences should also be made about geological hazards, seismic amplification effects, the liquefaction potential, the bearing capacity, potential settlement and swelling, soil–structure

interactions and groundwater conditions. After this stage, sites are selected for further consideration on the basis of geotechnical considerations.

Verification stage

2.8. In the verification stage, it is assumed that broadly generalized layouts and building loads have been established. The following factors should be considered in the evaluation, to account for both normal conditions and extreme conditions such as earthquake and flood conditions:

- Geological hazards;
- Geological and subsurface conditions;
- Liquefaction potential;
- Feasible foundation types;
- Preliminary bearing capacity and other factors of foundation stability;
- Preliminary settlement ranges;
- Groundwater levels and regimes;
- Previous use of the site;
- Site preparation requirements.

In this stage, the investigation programme should cover the site as a whole as well as a smaller scale appropriate for layout considerations.

2.9. The following site investigation techniques and related points should be noted:

- *Rotary borehole drilling.* In this method of drilling, all cores are recovered to provide an overall definition of site conditions. This usually involves locating the borings along two intersecting lines with a common boring at the intersection; in addition to the extraction of cores or other samples for rock or soil qualification and laboratory testing, the boreholes can be used for the installation of instruments for long term in situ testing, including instruments for monitoring the groundwater regime. The possible effects of boreholes on the potable water regime should be investigated [4]. If necessary, test pits or test tunnels should be used to facilitate a direct examination of the subsurface conditions.
- *In situ testing.* According to the subsurface conditions, various types of simple in situ tests should be carried out to measure the mechanical properties of the foundation materials. These tests should also include various in situ loading tests and piezometric measurements of the groundwater.

- *Seismic refraction and reflection survey.* A seismic refraction and reflection survey should be conducted to provide continuous lateral and depth information for the evaluation of subsurface conditions. Interpretation of the survey results provides stratigraphic and structural geological information, information on the location of the groundwater table and an estimate of wave velocities at the site. The borings provide vertical stratigraphic confirmation for the survey.
- *Laboratory testing.* Limited laboratory testing consisting of index and classification tests should be conducted on rocks or soils. If cohesive soil samples were obtained during the drilling operation, appropriate consolidation and shear strength testing should be conducted on undisturbed samples to allow the estimation of soil strength and settlement.

2.10. In the field investigations, careful attention should be paid to identifying undesirable subsurface characteristics, such as cavity zones, swelling rocks and shales, the occurrence of gas pockets, zones of weakness or discontinuities in crystalline rocks, and potential slide planes predetermined by unstable subsurface layers.

Confirmation stage

2.11. The purpose of the site confirmation stage is to provide confirmation of the results obtained in the previous stages. A subsurface exploration and a laboratory testing programme should be conducted at the site using either a grid boring scheme or an alternative boring scheme suited to the site and the installation under consideration. The grid spacing may vary depending on the geometry of the subsurface characteristics. The uniform grid method is especially adaptable to a site with relatively uniform soil conditions. Where dissimilarities and discontinuities are present, the usual exploration process should be supplemented with borings at spacings small enough to permit detection of the features and their proper evaluation. The consequences of boring for the groundwater regime, and possibly for potable water, should be considered.

2.12. As a minimum, the following indicators of potential cavities and susceptibility to ground collapse should be considered:

- Sinks, sink ponds, caves and caverns;
- Sinking streams;
- Historical ground subsidence;