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SAFETY ASSESSMENT OF NUCLEAR INSTALLATIONS FOR EXTERNAL EVENTS EXCLUDING EARTHQUAKES

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ABSTRACT

Article III of Statute of the International Atomic Energy Agency (IAEA, 1989) authorizes the agency 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*." With regard to nuclear safety and the protection of the public and the environment against the harmful effects of ionizing radiation, the agency produces safety standards that are broadly categorized into three series of publications:

1. Safety Fundamentals: This document, SF-1 (IAEA, 2006) presents the fundamental safety objective and principles that the supporting safety requirements and safety guides seek to fulfil.

2. Safety Requirements: The agency publishes a number of safety requirements documents that establish the requirements that need to be met to ensure the protection of people and the environment.

3. Safety Guides: Safety guides provide recommendations and guidance on how to comply with the safety requirements. Safety guides are sent to Member States for comment and represent internationally recognized good practices and may be considered to be consensus documents.

The agency is currently drafting a new safety guide, *Safety Evaluation of Nuclear Installations for External Events Excluding Earthquakes, DS552*, (IAEA, 2023a) that will provide general guidance for evaluating the safety of nuclear installations for external events other than earthquakes. This paper provides additional detail and summarizes the general content of this future safety guide.

The new safety guide (IAEA, 2023a) will provide specific recommendations on the conduct of safety assessments for both new and existing nuclear installations in relation to external events other than earthquakes. The guide will reflect lessons learnt based on applied practices following the Great East Japan Earthquake and Tsunami of 2011 and the subsequent Fukushima Daichi accident. It also will provide recommendations on the use of a graded approach in safety assessments that account for inherent safety features and consequences.

The new safety guide will highlight the need for maintenance of the safety assessment of the nuclear installation throughout its life cycles. Re-evaluation of the safety assessment may be triggered by new information, advanced methodologies, or regulatory requirements. The methodologies developed for the safety evaluation of nuclear power plants in relation to external events are also applicable to other nuclear installations through the use of a graded approach. The new guide will address external events in the safety evaluation of nuclear installations taking into account all operational and accidental conditions for those external events outlined in IAEA Safety Standards Series No. SSG-68 (IAEA,2021a), *Design of Nuclear*

Installations Against External Events Excluding Earthquakes, to include natural external events (e.g. floods, extreme meteorological conditions, extreme winds, volcanism), human induced external events (e.g. aircraft crashes, external explosions, external fire) and combinations of external hazards. This new safety guide will be complementary to SSG-68 (IAEA, 2021a). SSG-68 is focused on design of installations for external events, whereas the new guide will focus on safety assessments and not design.

INTRODUCTION

Background

IAEA Safety Standards Series No. SF-1, Fundamental Safety Principles (IAEA, 2006), provides safety principles that constitute the basis for establishing safety requirements to achieve the fundamental safety objective of protecting people and the environment from harmful effects of ionizing radiation. Safety requirements for design, assessment and periodic review of safety against external hazards are established in a number of publications:

- IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), Safety Assessment for Nuclear Facilities and Activities (IAEA, 2016b).
- IAEA Safety Standard Series No. SSR-1, Site Evaluation of Nuclear Installations (IAEA, 2019b).
- IAEA Safety Standard Series No. SSR-2/1 (Rev. 1), Safety of Nuclear Power Plants: Design (IAEA, 2016a).
- IAEA Safety Standard Series No. SSR-2/2 (Rev. 1), Safety of Nuclear Power Plants: Commissioning and Operation (IAEA, 2016c).
- IAEA Safety Standard Series No. SSR-3, Safety of Research Reactors (IAEA, 2016d).
- IAEA Safety Standard Series No. SSR-4, Safety of Nuclear Fuel Cycles Facilities (IAEA, 2017a).

Meeting the safety requirements established in these IAEA standards will ensure that the fundamental safety objective of SF-1 is achieved. SSR-2/1 (Rev. 1) requires that a comprehensive safety assessment be carried out for design of nuclear power plants. The safety assessment should investigate the capability of the design to withstand postulated initiating events and accidents – including those triggered by external hazards. Requirement 17 of SSR-2/1 (Rev. 1) requires that items important to safety be designed for protection against internal and external hazards. The external hazards include seismic, meteorological, hydrological, volcanic hazards, and human induced events.

Recommendations on seismic safety assessment are provided in IAEA Safety Standards Series No. SSG-89 (IAEA, 2024), *Evaluation of Seismic Safety for Nuclear Installations*, and practical guidance is provided in Safety Report No. 103, *Methodologies for Seismic Safety Evaluation of Existing Nuclear Installations* (IAEA, 2020). However, a safety guide that provides recommendations on conducting safety evaluations of nuclear installations in relation to external events other than earthquakes does not currently exist within IAEA documentation. This new publication will provide recommendations on methodologies for the safety assessment for external events excluding earthquakes, validated by the current international state of the practice and intended to meet the requirements for nuclear facilities established in SSR-1, SSR-2/1 (Rev. 1), SSR-3 and SSR-4.

The need for such a safety guide has been communicated to the IAEA by Member States at both technical meetings and in consultancies. This safety guide will complement existing safety standards on external events. It will also present methods for the use of a graded approach which may be applicable to nuclear installations other than power plants.

Plan of Development

The new safety guide, *Safety Evaluation of Nuclear Installations of External Events Excluding Earthquakes, DS552*, will likely consist of eleven (11) main sections and several annexes that provide examples in applying the guidance. Section 1, Introduction, will provide background scope and a plan of development for the remainder of the publication. Section 2, Safety Requirements Applicable to External Hazards Safety Assessment, will describe the overall approach and provide a link to the safety requirements that the guide is intending to meet. Recall that safety requirements are provided in requirements documents such as SSR 2/1, while safety guides provide guidance intended to enable the user to meet the requirements. Section 3, General Concepts for Safety Assessment of Nuclear Installations Against External Hazards other than Seismic, will provide an overview of the overall approach and describe a screening process that is encouraged. Section 4, Identification of Potential Site-Specific Hazards, will aid the user in identifying hazards and combinations of those hazards. Section 6, Safety Assessment of Hazards not Screened, will provide an overview of the evaluation process. Section 7, Deterministic Hazard Assessment, will describe a deterministic approach for safety assessments, while Section 8 will present probabilistic approaches. Section 9 will describe the application of the overall process to installations other than nuclear power plants. Section 10 will provide some examples of how the safety assessments may be applied or triggered. Section 11 will describe a management system for the safety assessment. The content of the references and appendices are under development.

Schedule

The safety guide is currently being developed through a working group with representatives from regulators, technical service organizations, researchers, designers, and safety analysts. The IAEA has a formal review process which must be followed prior to publication of a safety guide, and which may result in changes to the content. This includes an internal departmental review, a review by the Commission on Safety Standards (CSS), review by one or more Safety Standards Committees, and review by Member States. A summary of the overall process is shown in Figure 1.

The entire process from development of an outline and work plan to endorsement of the publication by the Commission on Safety Standards generally takes from 3 to 5 years. This standard, *Safety Evaluation of Nuclear Installations of External Events Excluding Earthquakes*, *DS552*, is currently in the drafting phase and is scheduled to be reviewed by the safety standards committees in November of 2025. Following review by the safety standards committees, it will then go to Member States for their review and comment. The Commission on Safety Standards will then review the final publication. Final publication is currently scheduled for October 2028. Preprints of IAEA documents are generally available up to one year before final publication.

PREVIEW OF CONTENT

Purpose

The purpose of DS552, *Safety Evaluation of Nuclear Installations of External Events Excluding Earthquakes*, is to provide IAEA Member States guidance on performing safety evaluations of nuclear installations subject to natural phenomena hazards. The IAEA has existing guidance on the evaluation of safety for earthquakes, but little for other natural hazards.

Scope

DS552 addresses all types of new and existing nuclear installations as defined in the IAEA Nuclear Safety and Security Glossary (IAEA, 2022), including:

- Nuclear power plants;
- Research reactors (including subcritical and critical assemblies);
- Radioisotope production facilities;
- Interim storage facilities for spent fuel and radioactive waste;
- Facilities for the enrichment of uranium;
- Conversion facilities;
- Facilities for the reprocessing of spent fuel;
- Facilities for the predisposal management of radioactive waste arising from nuclear fuel cycle facilities;
- Nuclear fuel cycle-related research and development facilities;
- Nuclear fuel fabrication facilities;

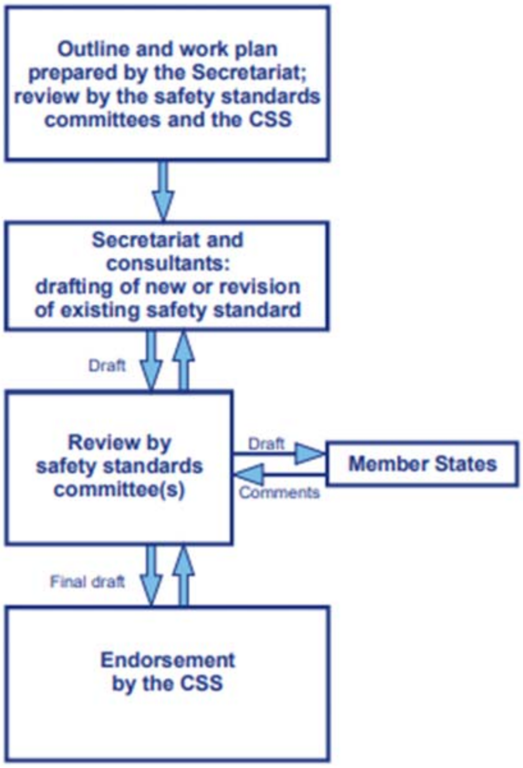

Figure 1. Overall Process for the Development of the IAEA Safety Standards

The recommendations provided in DS552 apply to a range of operating modes. DS552 will not apply to facilities for mining or processing of uranium or thorium ores and long-term storage facilities.

Other types of facilities are not explicitly included within the document, but the overall guidance provided in DS552 is expected to be generally applicable.

The recommendations provided in DS552 were primarily written from the perspective of safety assessment for nuclear power facilities operating at power. However, the overall processes remain applicable to other types of nuclear installations and modes of operation. Commentary is provided to support assessments for other types of facilities under a graded approach. The graded approach is intended to ensure that the rigor level of the safety assessment is consistent with the underlying potential of adverse consequences associated with an installation. Performance criteria and systems modeling are specific to each installation type.

DS552 will address external hazards including both natural phenomena hazards (e.g. external flooding, high winds, other meteorological hazards) and human induced hazards (e.g. hazards from aircraft crash, explosion pressure waves, accidents at nearby industrial facilities) that often originate from outside the plant boundary or are not connected with its operation. However, in some cases, events or hazards originating within the site boundary (e.g., failure of onsite cooling water impoundments, hazardous chemical releases, or accidents at co-located non-nuclear facilities) are classified as external hazards and within the scope of this document. Malevolent external hazards and seismically induced hazards are outside the scope of DS552. DS552 will address safety assessments along a continuum from deterministic to probabilistic.

The guide assumes that an internal events safety assessment is available as the basis or starting point for the external hazards safety assessment. While performing an internal events safety assessment is not required before performing an external hazards safety assessment, it is generally good practice and more efficient to begin with the internal events safety assessment.

General Considerations for Safety Assessment of Nuclear Installations Subject to External Hazards

As per Safety Assessment for Facilities and Activities, IAEA Safety Standards Series No. GSR Part 4 (IAEA, 2016b), a safety assessment should be conducted at the design stage for new facilities or activities, or as early as possible in their lifetime. The safety assessment considers available information for each nuclear installation, varying data availability for new versus existing installations. It is important to consider the intended operating lifetime of new versus existing installations and how this affects methodology selection, particularly in the context of a periodic safety assessment.

The graded approach should be used to ensure the application of safety requirements is commensurate with the characteristics of the facilities and activities and with the magnitude and likelihood of radiological exposures. The use of a graded approach is intended to ensure that the necessary levels of analysis, documentation and actions are commensurate with, for example, the magnitudes of any radiological hazards and non-radiological hazards, the nature and the particular characteristics of a facility, and the stage in the lifetime of a facility. A graded approach should consider use of a qualitative categorization of the nuclear installation. An example of a graded approach for safety assessment for research reactors is presented in SSG-22 (IAEA, 2023b).

The IAEA General Safety Requirements (GSRs) and Specific Safety Requirements (SSRs) outline safety requirements that should be applied when conducting external hazard safety assessments. Section 1 of DS552 will present the applicable requirements to be considered when conducting a safety assessment.

Overview of the Safety Assessment Process for External Hazards

Figure 2 illustrates the overall safety assessment process. External hazard safety assessments should begin with the identification of natural and human-induced external events that could give rise to hazards with potential consequences for the safety of the nuclear installation. Both individual hazards and credible combinations of those hazards should be considered. DS552 will provide guidance on selection of hazards.

Next, a screening assessment should be performed to determine which hazards (1) may occur with a non-negligible likelihood and (2) have the potential, individually or in combination, to adversely affect a nuclear installation. Hazard screening is intended to focus the detailed safety assessment on those hazards that represent a credible threat to plant safety. As a result, while hazard screening may involve deterministic and probabilistic criteria and considerations, the screening assessment should generally be conservative to ensure that no potentially significant hazards are inappropriately excluded from more detailed consideration.

The screening assessment may involve hazard grouping. Grouping may occur prior to screening such that hazards with common phenomenological origin or common plant effects are grouped and the entire group is either screened out of further safety assessment consideration or retained. Grouping may also occur after screening such that a group of hazards is considered collectively in the remainder of the safety assessment.

For each hazard (or group of hazards) that is not screened from further consideration within the safety assessment, an evaluation method should be selected to perform the safety assessment methods. Safety assessments may involve primarily deterministic methods, primarily probabilistic methods, and methods that combine deterministic and probabilistic components.

The process of selecting an approach to use for a safety assessment should generally be iterative and progressive, beginning with conservative (potentially bounding) deterministic safety analyses and, as needed, increasing the level of realism and sophistication through a process of progressive refinement.

Given the use of progressively refined hazard assessments, a clear distinction cannot always be made between screening and limited-scope (unrefined) conservative deterministic assessments. In both cases, assessments may depend on modelling assumptions, parameter values, etc., that are specified to maximize the severity of the hazard(s) being assessed. The assumptions made in such assessments may approach (and in some cases surpass) the limits of what is physically possible given the occurrence of one or more hazards. However, screening assessments will typically involve simplified and conservative assessments intended to show that the potential for a hazard to adversely affect a site is sufficiently low. Assessments that are conservative but that involve detailed modelling or assumptions that may change over time (e.g., as a result of non-stationarities or changes in knowledge) should generally be classified as limited-scope hazard assessments rather than as screening assessments. This is particularly relevant because the need to archive, maintain or update assessments may differ depending on whether an assessment is classified as “screening”. Examples of screening approaches are given in IAEA technical documents 1974 (IAEA, 2021b) and 1980 (IAEA, 2021c).

The external hazard safety analysis for a hazard or set of hazards should typically involve three key components: (1) hazard characterization, (2) SSC performance assessment, and (3) installation response assessment. Analysis results should yield information that can be used to establish whether an adequate level of safety has been achieved and whether specific safety criteria or objectives are met. Selection of these objectives and criteria should consider the type of assessment being performed (e.g., deterministic versus probabilistic), suitability for the installation type, the purpose of the safety assessment (e.g., initial design, design extension, or assessment of the significance of an adverse condition), the applicable general safety requirements (e.g., safety goals), and the applicable regulatory requirements.

Deterministic methods typically focus on the assessment of installation safety under conservatively defined scenarios involving external event-induced hazards and their effects on the installation, including the SSCs that are available to protect against or mitigate these effects. Safety should typically be demonstrated through confirming that safety functions are maintained with sufficiently high confidence in these scenarios.

Probabilistic methods typically assess plant safety by estimating the annual frequencies of hazards that may adversely affect an installation, the conditional probabilities of adverse effects on plant SSCs, and the systematic evaluation of plant response through the identification and quantification of accident sequences. Safety is typically demonstrated through a comparison of quantitative risk metrics against target values and consideration of other risk insights.

Margins-type methods have been developed where installation safety is evaluated for a specified hazard scenario (i.e., similar to deterministic methods) while leveraging probabilistic methods for characterizing the capacities of SSCs and the plant response against those hazards.

While deterministic, probabilistic, and margins-type methods are often described and visualized as discrete options (e.g., as illustrated in Figure 2), they represent a graded continuum of options spanning from fully deterministic to fully probabilistic methods.

Deterministic methods may leverage relatively simplified evaluations based on conservative assumptions that implicitly account for uncertainties. In contrast, probabilistic methods increase the degree of realism included in the analysis and involve more systematic and explicit treatment of uncertainty. As a result, probabilistic methods are more resource-intensive than deterministic methods.

The method selection and the technical rigor used may differ by hazard (or group of hazards). These modeling decisions should be based on the projected significance of a hazard (or group of hazards) to the installation safety and the level of realism needed to support a particular application or decision for which the safety assessment is performed. For example, a simplified, deterministic assessment involving conservatively defined hazards and SSC capacities with limited credit for mitigating capabilities may be adequate to demonstrate safety for certain hazards or applications, while other situations may necessitate more refined analyses. The safety assessment method selection process may be iterative (e.g., the level of detail may start with simplified, conservative idealizations and introduce increasing realism and rigor as warranted).

When the purpose of the safety assessment includes obtaining insights regarding potential vulnerabilities, overly conservative assumptions may mask key insights or result in misleading conclusions. However, in some cases, the level of information available to support an assessment may dictate the sophistication that can be used to assess safety against some hazards.

The safety assessment (including identification, screening, hazard, SSC performance, and plant response assessment) should be updated as needed, per the regulatory requirements associated with the purpose or application for which the safety assessment is performed.

SUMMARY

The IAEA is in the process of developing a new safety guide that will provide guidance on performing safety assessments for nuclear installations for external event hazards. The guidance will generally be applicable to all nuclear installations. Guidance will be provided for both probabilistic, deterministic and combinations of those analyses following a graded approach. The document is currently in the drafting stage, with a target date to be published in October of 2028. This paper highlights some of the overall guidance contained in the draft safety guide.

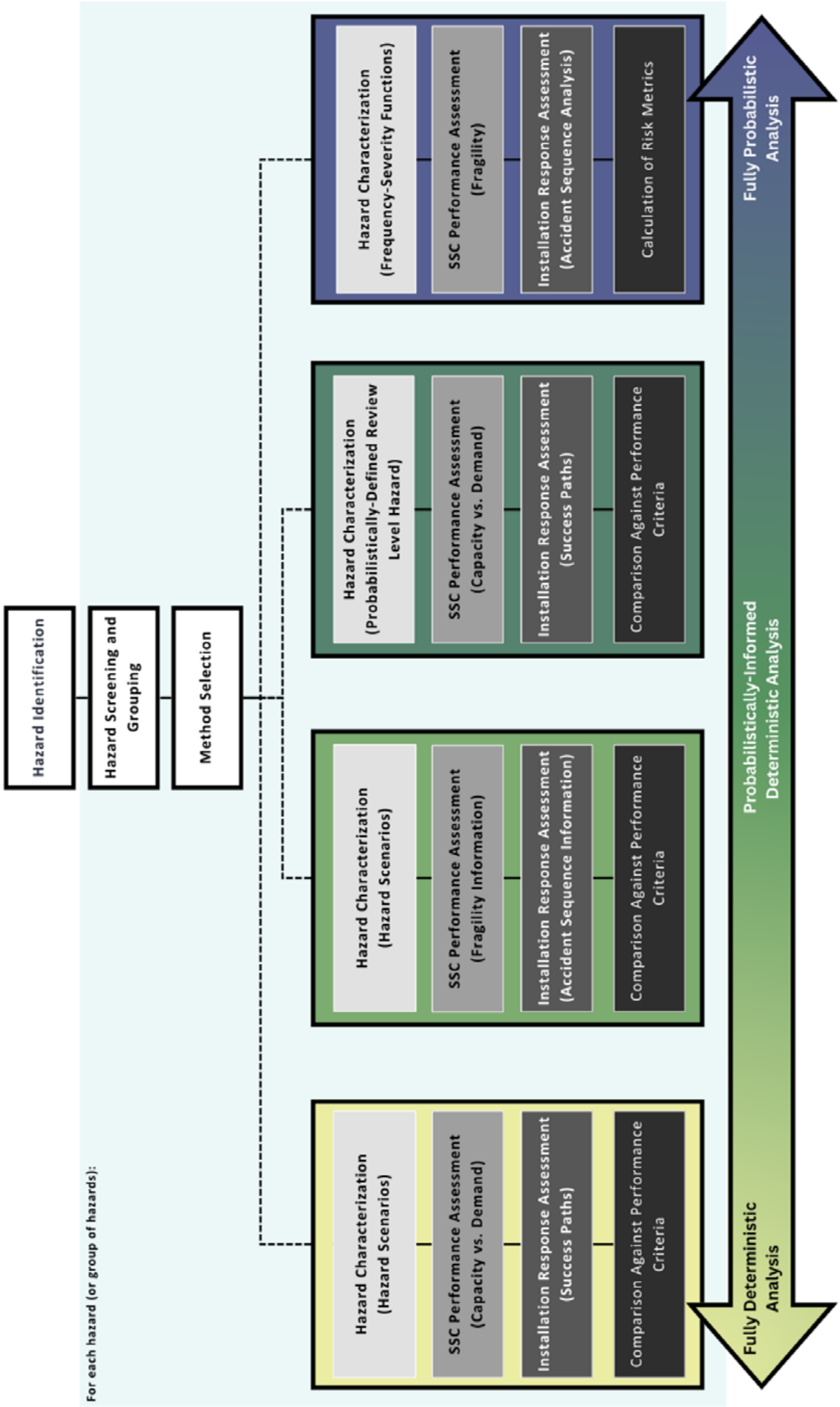

Figure 2 . Safety Analysis Process

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