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REVISION OF IAEA SAFETY GUIDE ON SEISMIC SAFETY EVALUATION FOR NUCLEAR FACILITIES

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ABSTRACT

The International Atomic Energy Agency (IAEA) safety standards form the basis for national regulations for nuclear facility design and operation in many countries. IAEA Safety Guide NS-G-2.13, "Evaluation of Seismic Safety for Existing Nuclear Installations," has recently been revised, and its scope has been expanded to cover both new and existing installations. The original guide was published in 2009. The revised standard involves the following major new elements:

- Added new nuclear installation designs to scope.
- Added guidance for an additional seismic safety assessment methodology.
- Updated guidance to incorporate lessons learned from the Fukushima Dai-ichi accident.
- Added explicit considerations for Defence in Depth (DiD) Level 4.
- Introduced guidance on the need (or not) for site-specific seismic hazard studies.
- Revised guidance for non-nuclear power plant (NPP) installations.

The revised safety guide is undergoing the final review steps in the IAEA clearance process under the draft document DS522. It expected to be endorsed for publication in 2022. This paper provides a summary of the substantial updates incorporated in this revision and the context of their introduction.

INTRODUCTION

In 2009, the IAEA published Safety Guide NS-G-2.13, "Evaluation of Seismic Safety for Existing Nuclear Installations." This document was a major contribution that compiled in one IAEA publication a large spectrum of international knowledge that spanned the Individual Plant Examination of External Events (IPEEE) in the USA (USNRC, 1995) and other IAEA Member States that followed US regulations, and seismic safety evaluations in Eastern Europe that typically followed other regulations. NS-G-2.13 captured an international body of knowledge and lessons learned up to circa 2007. Its publication coincided with the publication of the American Society of Mechanical Engineers (ASME) / American Nuclear Society (ANS) Probabilistic Risk Assessment (PRA) Standard RA-Sa-2009 (ASME 2009).

The Fukushima Dai-ichi nuclear accident in 2011 occurred after the publication of NS-G-2.13. It led to new insights, lessons learned, regulations, and revisions to Standards throughout IAEA Member States. The IAEA introduced new safety requirements for nuclear installation and NPP design against external hazards (IAEA, 2016, 2016a, 2016b, 2016c, 2016d, 2016e, and 2017). The new requirements included

demonstration of safety for beyond design basis events (BDBE) for new NPP designs. Requirement 11 in SSR-2/1 Rev. 1 (IAEA, 2016a) states that the design shall:

- *provide for an adequate margin to protect items important to safety against levels of external hazards to be considered for design, derived from the hazard evaluation for the site, and to avoid cliff edge effects*; and
- *provide for an adequate margin to protect items ultimately necessary to prevent an early radioactive release or a large radioactive release in the event of levels of natural hazards exceeding those considered for design.*

NS-G-2.13 is a Safety Guide that supports higher level Safety Requirements. Its revision addresses the updated requirements in SSR-2/1 Rev. 1 (IAEA, 2016a) and other IAEA Safety Requirements for new installations. The revision also incorporates international experience and lessons learned between 2007 and 2020 for existing installations and adds enhanced guidance for specific actions.

OVERVIEW OF UPDATED CONTENT

Figure 1 shows a comparison between the tables of contents for the original and revised documents. Much of the core content of the original NS-G-2.13 is maintained and enhanced to reflect current practices. New and revised material is added. Limited reorganization is introduced to increase clarity.

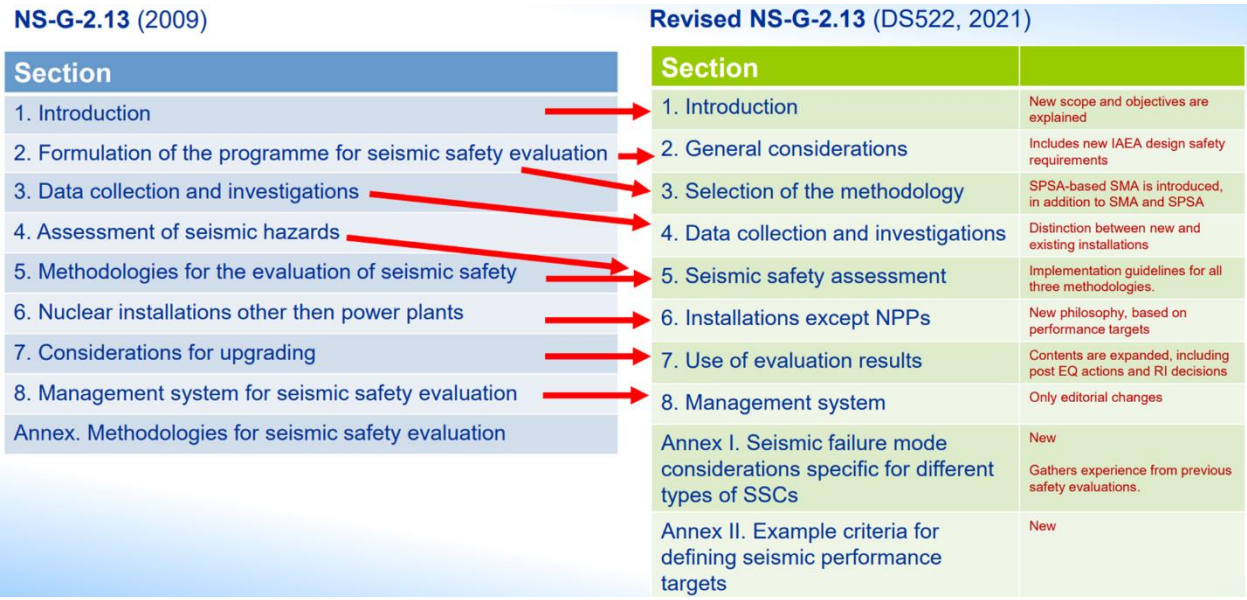

Figure 1. Comparison between Original and Updated Tables of Contents.

The revised guidance includes the following main elements:

- Revised the objective and scope to be consistent with new IAEA Safety Requirements.
- Added new nuclear installation designs to scope and made corresponding changes throughout the document.
- Added a section dedicated to the selection of the safety assessment methodology.
- Added guidance for the probabilistic safety assessment (PSA)-based seismic margin assessment (SMA) seismic safety assessment method.

- Updated implementation guidance for seismic safety assessment methods that incorporates lessons learned from the Fukushima Dai-ichi accident.
- Added explicit consideration of DiD Level 4 for NPPs.
- Introduced guidance on the need (or not) for site-specific seismic hazard studies.
- Revised guidance for non-NPP installations.
- Updated guidance on the use of evaluation results in decision-making.
- Added an annex that contains detailed guidance, obtained from recent industry experience, for seismic walkdown and capacity evaluations of common failure modes. observed in typical structures, systems, and components (SSCs) in nuclear installations.
- Added an annex that illustrates the development of graded-approach performance criteria for non-NPP installations.

REVISION OF OBJECTIVE AND SCOPE

The revised objective and scope in Section 1 include the following elements:

- The Safety Guide supports IAEA General Safety for facilities and activities and Specific Safety Requirements for site evaluation, NPP design and operation, research reactors, nuclear fuel cycle facilities, , and safety assessment for facilities and activities in IAEA GSR Part 4, SSR-1, SSR-2/1 Rev. 1, SSR-2/2 Rev. 1, SSR-3, and SSR-4, respectively (see references).
- The scope is extended to include new nuclear installations.
- All new facilities should demonstrate an adequate margin beyond their DBEs to meet performance goals and avoid potential cliff-edge effects.
- Safety assessment of existing facilities should be periodically reviewed, including considering potential revisions to seismic hazard characterization.

ADDITION OF NEW NUCLEAR INSTALLATIONS

Safety assessment of new nuclear installations designs is performed when the design has sufficiently matured such that SSC seismic capacities and plant response logic to accident sequences can be characterized. New installations in this may be in the design or construction changes but are not operational. They include standard plant designs, which is the current trend in NPP new builds.

New installations present fundamentally different considerations than existing ones for the execution of seismic safety assessment. The safety guide is expanded to highlight and cover these contrasting considerations. These different considerations include the following:

- The reasons and objectives of performing the safety assessment (in Section 2)
- Selecting the safety assessment methodology (in Section 3)
- Availability and collection of site data and as-built, as-operated conditions (in Section 4)
- Feasibility and guidance for performing seismic walkdowns (in Section 5)
- Decision-making uses of the safety assessment outcome (in Section 7)

SAFETY ASSESSMENT METHODOLOGY SELECTION

Section 3 is added to present dedicated guidance on the selection of the seismic safety assessment methodology. Three methodologies are introduced: SMA, PSA-based SMA, and seismic PSA (SPSA). The applicability, advantages, uses, and limitations of each method are discussed. Trade-offs that should be

considered when multiple methodologies satisfy the objectives and constraints of the safety assessment are introduced for new and existing installations.

INTRODUCING PSA-BASED SMA METHODOLOGY

The PSA-based SMA methodology is a hybrid between the SMA and SPSA methodologies, both of which were included in the original NS-G-2.13. It combines the typically less resource-intensive hazard assessment, fragility characterization, and Boolean logic solution approaches of the SMA methodology with the accident sequence event tree and fault tree analysis from the SPSA. The PSA-based SMA outcome includes the installation-level high confidence of low probability of failure (HCLPF) capacity (more accurate than that produced by SMA) and HCLPF capacities for all accident sequences of interest (i.e., minimal cut-sets) that can lead to an installation performance unacceptable to safety (not available from SMA). The outcome may be extended to include an estimate of the installation-level fragility curve (albeit less accurate than produced by SPSA). The accident sequence-level HCLPF capacities are typically taken to be the highest SSC HCLPF capacity in each cut-set.

Section 3 of the revised Safety Guide introduces the PSA-based SMA methodology and the considerations that may apply to its selection for the safety assessment: its advantages and limitations, its end products, and its suitability for common safety evaluation objectives. Section 5 of the revised Safety Guide introduces implementation guidance for this methodology.

UPDATED IMPLEMENTATION GUIDANCE FOR SMA AND SPSA METHODOLOGIES

Section 5 of the revised Safety Guide introduces implementation guidance for the three seismic safety assessment methodologies: SMA, PSA-based SMA (discussed above), and SPSA. The implementation guidance for SMA and SPSA is updated to reflect current industry Standards and practice, and to incorporate lessons learned from the Fukushima Dai-ichi accident. In particular, guidance was added or enhanced for:

- Determination of the reference level earthquake
- Characterizing or screening of earthquake hazard for non-vibratory ground motions, e.g., geotechnical failures
- Characterization or screening of concomitant phenomena hazard triggered by earthquakes, e.g., flooding due to upstream dam failures or tsunami
- Scope definition of the seismic safety assessment
- Inclusion of mitigation and emergency response systems and operator actions in accident sequence modelling and the selected SSCs list
- Enhancement of the seismic evaluation walkdown guidance and customization for new vs. existing facilities
- Enhanced guidance on operator actions and random failures for the SMA methodology
- Streamlined implementation guidance for the three methodologies, as follows:
    - Detailed guidance for elements common to all three methodologies
    - Relatively detailed guidance for the SMA methodology
    - Streamlined guidance for the PSA-based SMA and SPSA methodologies that leverage the commonalities with the SMA methodology and focuses on contrasts
- Enhanced guidance for the fragility development approaches in the SPSA methodology
- Enhanced guidance for modelling human failure probabilities in the SPSA methodology

Throughout the updated implementation guidance in Section 5, the use of probabilistic and semi-probabilistic methods is emphasized and promoted compared to purely deterministic methods. While both

deterministic and probabilistic methods are presented and considered acceptable, use of probabilistic methods provides more reliable and detailed insights and support for risk-informed decision-making, and its methods have become more standardized and streamlined since publication of the original NS-G-2.13. Meanwhile, deterministic methods continue to be preferred in some Member States, and they offer lower-cost results.

EXPLICIT DID LEVEL 4 CONSIDERATION FOR NPPs

Section 5 of the revised Safety Guide includes a sub-section that identifies specific considerations for evaluating NPP seismic safety performance for DiD Level 4, which corresponds to the mitigation of severe accident consequences and the prevention of large releases. This guidance corresponds to Requirement 17 of SSR-2/1 (Rev. 1), Requirement 19 of SSR-3, and Requirement 16 of SSR-4. The added sub-section includes guidance on NPP items to include in the selected SSCs list, target performance goal for the DiD Level 4 evaluation, and consideration of uncertainty in seismic margin.

ADDED GUIDANCE ON SITE-SPECIFIC VS. GENERIC HAZARD

Section 2 of the revised Safety Guide adds guidance on when a site-specific seismic hazard characterization is required for the safety evaluation. Generally, a site-specific hazard is preferred. However, depending on the safety assessment objective and the methodology selected for safety assessment, a seismic hazard characterization that is not specific may be applicable or acceptable, which may save significant effort and time. Site-specific hazard characterization is required when the objectives include determining seismic risk metrics or necessitate using the SPSA methodology.

The guidance in Section 2 discusses the applicability and limitations of generic hazard characterization. Additional guidance in Section 3 discusses the implications of either option on the safety assessment methodology selection considerations. Section 6 further discusses the guidance presented in Section 2 in the specific context of non-power reactor installations.

REVISED GUIDANCE FOR APPLICATION TO NON-NPP INSTALLATIONS

Section 6 of the revised Safety Guide introduces guidance that follows a performance-based graded approach for non-NPP installations. The graded approach is based on selecting target performance goals that are a function of the hazard category of the installation. The hazard category is a function of the severity of the radiological and toxicological effects that may result as a consequence of the installation unacceptable performance. This hazard categorization approach is consistent with IAEA Draft Safety Standard DS490 (IAEA, 2021). The graded approach guidance starts with a conservative screening approach, includes design-code approaches that use prescriptive methods, and ends with safety evaluations similar to those performed for NPPs. Annex II was added to support Section 6 by example consequence-based SSC target performance criteria from ANS and American Society for Civil Engineers (ASCE) Standards.

UPDATED GUIDANCE ON USE OF SAFETY EVALUATION RESULTS

Section 7 is updated to encompass guidance on post-earthquake actions, risk-informed decision-making for existing and new installations, considerations for designing modifications and upgrades in existing installations, changes in inspection, and operational procedures of the installation.

GUIDANCE ON FAILURE MODE CONSIDERATIONS FOR DIFFERENT SSCs

Annex I is added to provide guidance, based on recent industry experience, for failure mode considerations applicable to classes of SSCs typically found in nuclear installations. These considerations include actions applicable to the planning and execution of seismic evaluation walkdowns, seismic capacity and fragility

analysis for vibratory ground motions, and considerations for non-vibratory ground motion-induced failures. The list of SSC classes includes the following: buildings and structures, mechanical equipment, electrical equipment, instruments and devices, distribution systems, seismic interaction between SSCs, operator travel paths, and the reactor system and containment of NPPs. In addition, considerations are introduced for non-vibratory ground motion-induced failures.

CONCLUSION

This paper presented a summary of the draft revision of IAEA Safety Guide NS-G-2.13 and identified the main elements in this revision. This revision expands the scope of the Safety Guide to include new nuclear installations and brings the guidance up to date with current IAEA Safety Requirements and industry practice. While the core content and general organization of the original Safety Guide were maintained, several new or significantly revised elements were introduced, and limited reorganization was applied to increase clarity. Publication of this new Safety Guide is expected in 2022.

ACKNOWLEDGEMENT

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