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Application of the performance-goal based approach for establishing the SSE site specific response spectrum for new nuclear power plants in South Africa

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HIGHLIGHTS

- Criteria for import of performance goals defined in ASCE 43-05 are established.
- Derivation of performance goals from radiological safety criteria is demonstrated.
- Evaluation of mean exceedance frequencies from performance goals is illustrated.
- Simple formulae for the definition of a capable fault are presented.

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ABSTRACT

Nuclear installation license holders in South Africa have become increasingly interested in the performance-goal based approach defined in the American Society of Civil Engineering Standard ASCE/SEI 43-05 for establishing the safe shutdown earthquake (SSE) site specific design response spectrum (SSRS) for new nuclear power plants. This approach has been adopted by the U.S. Nuclear Regulatory Commission (NRC) and has now been followed at more than 20 sites in that country. Quantitative performance goals are required when establishing seismic design basis parameters using the performance-goal based approach. However, the quantitative performance goals recommended in ASCE/SEI 43-05 were established based on country-specific operating experience and seismic probabilistic risk assessment (SPRA) applications conducted for existing plants designed and operated to meet specific safety criteria, set by a specific regulatory body. Whilst ASCE/SEI 43-05 provides enough flexibility for the selection of other user-specified quantitative performance goals, there is no guidance on how quantitative performance goals should be established in the absence of extensive operational experience accompanied by data derived from rigorous SPRA applications. This paper presents two practical approaches that can be used to provide a technical basis and to demonstrate the derivation of quantitative values of target performance goals when no data related to past and present operational experience exist to justify technical specifications.

1. Introduction

The South African nuclear regulatory requirements demand the performance of a probabilistic risk assessment (PRA), including a seismic probabilistic risk assessment (SPRA), to demonstrate safety of new nuclear installations against natural hazards (SA NNR, 2010). These requirements are non-prescriptive, making it possible for current nuclear installation license holders and future nuclear installation applicants to follow international standards and guidelines provided they have been justified and demonstrated to be consistent with local regulatory requirements. Consequently, South African nuclear utilities have become increasingly interested in the performance-goal based approach for establishing the safe shutdown earthquake (SSE) site specific design response spectrum (SSRS) for future nuclear power plants defined in the American Society of Civil Engineering Standard ASCE/SEI 43-05 (ASCE, 2005). This approach has been adopted by the U.S. Nuclear Regulatory Commission (NRC) in their Regulatory Guide 1.208 (US NRC, 2007), and has now been followed at more than 20 sites in that country (Kennedy, 2011).

The performance-goal based design approach is characterized by the use of performance goals. For each performance goal, both quantitative and qualitative criteria are established. Qualitative criteria are established by specifying acceptable or unacceptable structural behaviour limits or damage states while quantitative criteria are represented by annual probabilities of exceeding the

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specified structural behaviour limits. When these performance goals have been adopted by the relevant nuclear regulatory authority they form part of technical specifications (TS) and or regulatory requirements which define the limits and conditions as a way to ensure that nuclear installations are designed and operated safely and in a manner which is consistent with the assumptions made in the plant safety analyses. In general, technical specifications and regulatory requirements have been developed, applied and improved based on deterministic analysis and PRA techniques. However, the latter techniques rely on knowledge and operational experience accumulated over time. Where no sufficient knowledge exists, these are supplemented by the use of engineering and expert judgement as to the amount of margin of conservatism that is necessary for any part of technical specifications.

Technical specifications and regulatory requirements are strictly followed for the design, construction and operation of all nuclear installations. Therefore it is essential that important requirements are stated clearly, demonstrated to be capable of being met and consistent with risk considerations. Any inconsistency can lead to a time-consuming conflict of views and opinions between the nuclear regulatory authority and the nuclear installation license holder or applicant. The performance-based approach which is defined in the American Society of Civil Engineering Standard ASCE/SEI 43-05for establishing the safe shutdown earthquake (SSE) site specific design response spectrum (SSRS) for future nuclear power plants, was developed to fulfil these essential nuclear industry needs. However, the quantitative performance goals recommended in this standard were established based on country-specific operating experience and SPRA applications conducted for existing plants designed and operated to meet specific safety risk criteria. Currently, there is no guidance on how quantitative performance goals should be established in the absence of extensive operational experience accompanied by SPRA applications. For example, according to Kennedy (2011), the basis for selecting a mean quantitative target performance goal of 1×10^{-5}/yr in ASCE/SEI 43-05 for nuclear power plants, is that this figure represents approximately the average seismic-induced core damage frequency (CDF) reported for those nuclear power plants which have performed seismic probabilistic risk assessments (SPRAs) and presented their results to the U.S. NRC.

There is a need for clear guidelines on how quantitative performance goals should be established in the absence of extensive operational experience accompanied by SPRA applications. This would apply for instance to a country establishing a nuclear infrastructure for the first time or a country with very limited operational experience, such as when a country operates a very small fleet of nuclear installations. This paper presents two practical approaches that can be used to provide a technical basis and to demonstrate the derivation of quantitative values of target performance goals when a country lacks data related to past and present operational experience to justify technical specifications.

In the first approach referred to in this paper as the “direct import approach”, the quantitative performance goals established in ASCE/SEI 43-05are recommended for use without modification provided it can be demonstrated that their adoption represents the most pessimistic and bounding scenario both for the site and installation. Suitable criteria for providing evidence to this demonstration are established in this paper. In the second method, it is shown that similar quantitative performance goals can be derived from principal radiological safety criteria, such as annual dose limits or annual fatality risk limits, by defining a “performance-goal to radiological risk reduction factor”. When this approach is used to derive quantitative target performance goals, the resulting values can be varied proportional and consistent with quantitative values of the corresponding principal safety criteria. This demonstrates the robustness of the method. This paper also illustrates the evaluation of mean seismic hazard exceedance frequencies from chosen quantitative target performance goals using the Simplified risk equation defined in ASCE/SEI 43-05. Finally, the last part of the paper presents simple expressions that can be used to evaluate numerical parameters required for the definition of a capable fault consistently with the chosen quantitative performance goals and other design basis assumptions.

2. Direct import approach

Quantitative target performance goals required for seismic design of future nuclear installations using the performance-based approach can be established based on country-specific operational experience and PRA applications conducted for existing plants designed and operated to meet specific safety risk criteria (Kennedy, 2011). However, if such data does not exist, it is still desirable to derive quantitative performance goals that are consistent with chosen principal safety criteria. This may apply for instance to a country establishing its maiden nuclear infrastructure. One way of deriving these performance goals in the absence of operational experience is to demonstrate that the performance goals specified in ASCE/SEI 43-05can be imported directly and be safely applied to the country and or site of the proposed nuclear installation, and that they are consistent with regulatory safety criteria used by the relevant regulatory authority. This requires proof and evidence that their adoption represents the most pessimistic and bounding scenario both for the proposed nuclear installation and the site. This evidence needs to be supplied by applicants for new nuclear installations.

The main criteria for demonstrating evidence to support direct import of the quantitative target performance goals recommended in ASCE/SEI 43-05 and Regulatory Guide 1.208 for future nuclear power plants can be established by considering important elements of the research investigations and the procedures that were followed to establish them. Some elements that can be considered essential in these criteria are discussed below.

2.1. Seismic tectonic regions, regional and site geology characteristics

As a general requirement, it should be demonstrated that the range of seismic tectonic regions, style of faulting, regional and site geology characteristics incorporated in SPRAs used to develop the recommendations of ASCE/SEI 43-05 and Regulatory Guide 1.208 represent an equivalent or a more pessimistic scenario when compared to the same characteristics at the site or country of the proposed installation. According to Kennedy (2011), a specific number of SPRAs studies were drawn from Western U.S. sites near major tectonic plate boundaries to represent to represent the seismic risk in active regions, while some studies were drawn from Central and Eastern U.S. (CEUS) sites to represent the seismic risk in stable continental regions.

2.2. Man-induced seismicity

The extent to which man-induced seismicity due to mining activities and impounding of dams was incorporated in SPRAs used to develop the quantitative performance goals recommended in ASCE/SEI 43-05 should be established and the situation compared to potential risk due to man-induced seismicity in the importing country. This should include all mining activities, impounding and or flooding of dams, reservoirs quarry sites active and abandoned mines, underground caves, etc.

South Africa is characterized by a dual source of seismicity comprising mine related events and natural or tectonic earthquakes. The largest mine related event documented in the history of South