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Seismic hazard assessments for European nuclear power plants: a review based on the results of the ENSREG Stress Tests

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In aftermath of the Fukushima Daiichi accident ENSREG and the European Commission reviewed the seismic safety of all European nuclear plants on the basis of a comprehensive and transparent risk and safety assessment ("Stress Tests"). This process resulted in the publication of a large amount of data describing approaches, methods and results previously used to assess seismic hazards for European NPPs (http://www.ensreg.eu/eu-stress-tests).

A review of the published documents reveals considerable differences between the approaches of seismic hazard assessment. Most of the EU countries use probabilistic or a combination of probabilistic and deterministic approaches to estimate hazard. A second group of countries relies on deterministic assessments. Reports from countries adopting probabilistic hazard assessment methodologies reveal a spread of exceedance frequencies defining the design base earthquake (DBE) between 10^{-3} and 10^{-5} per year with a majority of countries referring to a frequency of 10^{-4}. Deterministic approaches use the maximum earthquake intensities to define the DBE, mostly adding 1° of intensity as a safety margin. In very few cases only 0.5° or even no safety margin was added to the strongest intensity. The hazard levels obtained from both types of analyses are not comparable to each other as no benchmark studies appear to exist to define the occurrence probabilities of DBE values established by deterministic methods.

The Stress Tests documents do not allow for an in-depth check of the hazard assessments. Assessments for different countries/sites have been performed between the 1970s and 2011. Although it is conceded that all assessments were performed according to the state of the art of the time of their performance, only a part of the hazard assessments can be justified in terms of being compliant with current scientific standards. Due to the time elapsed since their implementation several decades ago some assessments do not take advantage of recent scientific advances that allow to integrate geological and paleoseismological data into hazard models. Such data, however, appears important as by far most of the European NPPs are situated in intra-continental areas of low to moderate seismicity where hazard derives from "slow" active faults, which produce earthquakes at very long recurrence intervals of 10^3 to 10^5 years. These recurrence times are several orders of magnitude longer than both, instrumental ($\sim 10^2$ years) and historical earthquake recording periods ($<10^3$ years). The reliability of hazard assessments that address very low exceedance frequencies (10^{-4} per year) but exclusively rely on seismological data with short time coverage may therefore be questioned.

Systematic paleoseismological evaluations of the site regions with the aim to identify "silent" active faults have only been performed for a small number of NPP sites. Some of these studies revealed evidences for active faults in the site vicinity and the near-region of some NPPs. The hazard contribution of such faults, which have not released historical/instrumental earthquakes, is not modelled in previous hazard assessments that solely relied on earthquake data. The unsatisfactory situation calls for the implementation of programs for obtaining a geological/paleoseismological database of active faults and their characterization.