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An in-situ stimulation experiment in crystalline rock – assessment of induced seismicity levels during stimulation and related hazard for nearby infrastructure

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A decameter in-situ stimulation experiment is currently being performed at the Grimsel Test Site in Switzerland by the Swiss Competence Center for Energy Research – Supply of Electricity (SCCER-SoE). The underground research laboratory lies in crystalline rock at a depth of 480 m, and exhibits well-documented geology that is presenting some analogies with the crystalline basement targeted for the exploitation of deep geothermal energy resources in Switzerland. The goal is to perform a series of stimulation experiments spanning from hydraulic fracturing to controlled fault-slip experiments in an experimental volume approximately 30 m in diameter. The experiments will contribute to a better understanding of hydro-mechanical phenomena and induced seismicity associated with high-pressure fluid injections. Comprehensive monitoring during stimulation will include observation of injection rate and pressure, pressure propagation in the reservoir, permeability enhancement, 3D dislocation along the faults, rock mass deformation near the fault zone, as well as micro-seismicity.

The experimental volume is surrounded by other in-situ experiments (at 50 to 500 m distance) and by infrastructure of the local hydropower company (at ∼100 m to several kilometres distance). Although it is generally agreed among stakeholders related to the experiments that levels of induced seismicity may be low given the small total injection volumes of less than 1 m3, detailed analysis of the potential impact of the stimulation on other experiments and surrounding infrastructure is essential to ensure operational safety. In this contribution, we present a procedure how induced seismic hazard can be estimated for an experimental situation that is untypical for injection-induced seismicity in terms of injection volumes, injection depths and proximity to affected objects. Both, deterministic and probabilistic methods are employed to estimate that maximum possible and the maximum expected induced earthquake magnitude. Deterministic methods are based on McGarr's upper limit for the maximum induced seismic moment. Probabilistic methods rely on estimates of Shapiro's seismogenic index and seismicity rates from past stimulation experiments that are scaled to injection volumes of interest. Using rate-and-state frictional modelling coupled to a hydro-mechanical fracture flow model, we demonstrate that large uncontrolled rupture events are unlikely to occur and that deterministic upper limits may be sufficiently conservative. The proposed workflow can be applied to similar injection experiments, for which hazard to nearby infrastructure may limit experimental design.