**Notification: "Risk of Seismicity due to Cooling Effects in Geothermal Systems"**

**Organization: The Dutch State Supervision of Mines (SSM)**

**Reference: KEM-15 / 202004001**

## Purpose of the notification

The purpose of this notification is to determine whether there are parties interested to perform the research as described below.

## Objective

This research question aims at improving the understanding of the geomechanical effects due to cold water injection in geothermal systems. Of particular interest is to assess the risk of seismicity when faults are within the influence of a geothermal system, evaluating various parameters such as injection temperature, injected volume and distance to faults. The overall aim is to support SSM in its supervisory and regulatory tasks. It will also support the sector to optimise production plans, to estimate the life time of geothermal doublets and to assess safe and secure use of the subsurface.

It is important to develop better guidelines and tools to better assess initial conditions and to be able to define safe operating envelopes and procedures for geothermal injection (and production) wells.

## Background information

Within the Netherlands there are various efforts developing in what is called the "energy-transition", where fossil-fuel based energy resources are replaced by renewables. One branch of this transition - where relatively large steps can be made - is district heating, where heat from conventional central heating boilers is replaced by geothermal heat.

Within the Netherlands geothermal energy is commonly extracted from brine within hot sub-surface sedimentary aquifers, HAS (Willems et al., 2017). In some cases faults are actively used as well (e.g., Reith et al., 2019). In the latter category some small scale seismicity has been observed (to date up to ML 1.7, Buijze et al., 2019). Geothermal heat extraction is commonly executed using a doublet system (comprised of an injector and a producer) and a heat exchange facility at the surface. At the injector well, the cooled-down brine is re-injected. This causes a portion of the reservoir to cool down. The extent of this is noted as the cold front (e.g., Daniilidis et al., 2020). As a result of the temperature reduction, stress within the reservoir rock can drop due to a thermal contraction effect (e.g., Jeanne et al., 2017; Pandey et al., 2018). The effect is generally thought of as similar to the simple effective stress law, in the sense of lowering normal stresses in Mohr-Coulomb analysis (e.g., De Simone et al., 2013; Buijze et al., 2019).

The nature of the Dutch subsurface is such that normal faults are regularly encountered (e.g., Duin et al., 2006), and as such some existing and planned geothermal systems may influence the stress state on nearby faults due to operational parameters (e.g., Segall & Fitzgerald, 1998; Gan & Elsworth, 2014; Blöcher et al., 2018;). Faults can be bounding faults, as well as minor faults within the targeted reservoir. In some cases faults can be identified with confidence, for example through evaluation of seismic data prior to drilling activities. In other cases they are inferred from baffles found by interference tests between wells. Yet in other cases, faults are not identified, for example due to the offset being less than the seismic resolution.

If one therefore considers that faults are ubiquitous in the Dutch subsurface, then there are multiple scenario's imaginable where a cold front from a geothermal injection well reaches a fault, thereby cooling sections of that fault which results in reduction of stresses (e.g., Jacquey et al., 2015). In addition, sections of the fault can be locked while still at high temperature, while other parts that have already been cooled may be in an unstable stress state. The size of the fault-patch that is unstable will likely be a large influence on the maximum area that would slip in an earthquake event (e.g., Yoon et al., 2014; Wassing et al., 2014), and thereby directly influences the magnitude of a seismic event that may be expected.

To identify what data, in combination with an operational parameter space (or operational limits) are needed to be able to adequately assess safe use of the Dutch subsurface for geothermal heat extraction, SSM is looking to expand their knowledgebase, as well as that of the scientific and operator community. Anticipating larger scale geothermal operations and to help the sector with sound knowledge, clear
guidelines and risk assessment tools need to be available and to be continuously improved, taking into account the latest insights. To this end SSM has identified key research questions and deliverables.

**Research questions**

R1. For which generic scenarios (combinations of geometries, reservoirs, fault(s), doublet wells and far-field stress state) are there elevated risks of fault instability?

R2. Under what parameters are faults, within reach of the thermal front radiating from the injection well, within the lifetime of a typical geothermal system (i.e., before thermal breakthrough at the producer well)?

R3. What is the influence of fault permeability in relation with the reservoir permeability on the size of the fault plane that is cooled down due to the injection of cold water?

R4. How does the stress tensor change on various spots of a fault plane trough time with the development of a cooled patch?

R5. What is the magnitude of seismic events that can be expected due to combined thermal cooling effects?

**Deliverables expected**

As a general guideline the deliverable due date (M#) is listed as number of months after start of the project.

D1. A review study (literature study) that discusses how combinations of mechanical parameters (e.g., stress field, geometry, fault roughness) and operational parameters (e.g., flow rate, injection pressure, return temperature) may lead to seismicity. (M6)

D2. A numerical model study that verifies the main findings from D1. (M12)

D3. A numerical model study where scenario’s that are representative of the Dutch Subsurface are used to evaluate the significance of various mechanical and operational parameters. (M12)

D4. Based on D1, D2 and D3; a ranking of operational parameters (and magnitudes) that may lead to seismicity for conventional geothermal systems (i.e., HSA with faults in normal faulting regime) in the Netherlands. (M18)

D5. Similar to D4, but set in an Ultra Deep Geothermal / Enhanced Geothermal System- scenario, targeting depths below 4 km and temperatures above 120 °C (i.e., larger pressure/temperature differences). (M18)

D6. A combined recommendation of the data and studies that are required prior to the start of a geothermal project to assure safe operation for both types of geothermal systems. (M18)

D7. Reporting of above using a system of draft and final versions of reports on the above work.

All deliverables are open access, publication of results is explicitly encouraged.

**Timeline**

Generally following the chronology of the deliverables listed above, although some of the work can be done in parallel. Deadlines will be defined at a kick-off meeting. As a general guideline the deliverable due date (M#) is listed as number of months after start of the project. The study should be finalised within a period of 1.5 years (18 months) or sooner. The project has a desired start date in Q3 2020.

**Quality assurance, organisational and communication requirements**
SSM will organize a kick-off meeting (The Hague or teleconference) where due dates for deliverables are set. For quality assurance SSM asks to hold progress meetings, to be scheduled around milestones (M6, M12) so that progress, quality of work and deliverables can be discussed. Final results (following deliverable D6) will be communicated through the SSM website, along with a management summary (in Dutch) by SSM.

**Expertise and tools preferred for the team**
The applicant should have knowledge of the following skills: Geothermal reservoir engineering / modelling, seismological model, fault slip analysis. Furthermore there should be a track record of numerical modelling capability through equivalent studies, access to numerical codes and potentially field data, possibly from international sources.

**Expected use**
Deliverables will function as an internal SSM guideline, allowing SSM to adequately identify potential hazards caused by operational parameters. The focus of which will be on thermal effects on faults. SSM stimulates that deliverables are combined by the applicant to form contributions to (preferably peer reviewed) open access international scientific journals that are well read by the community, such that the work becomes available to the general public.

**Remarks and suggestions**
The project does not cover field and/or laboratory testing without third party funding, and in agreement with SSM. The applicant should have access to required benchmarked software packages. In case in-house developed code is used, adequate benchmarking prior to the start of the project needs to be demonstrated. Knowledge utilization by means of conference and/or journal contributions will need to be approved by SSM prior to submitting the work. In general such contributions are stimulated by SSM.

**Application**
Interested companies / consultants, fitting the above mentioned requirements, are invited to respond to the Procurement Office of the Ministry of Economic Affairs and Climate Policy, to the attention of Ms. J.C. van Domburg by e-mail IUCEZteam5@rvo.nl.
You do not have to send documents, only an e-mail if you are interested.

Interested parties will receive the request for the tender by e-mail as soon as possible after the deadline for responding to this notification.

The deadline for responding to this notification is set at **May 1st 2020**.

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