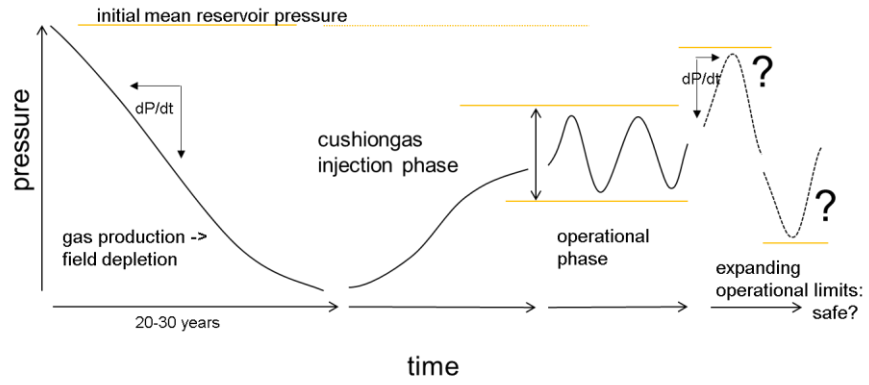
KEM Innovation/Research Question (max. 4 pages + annex)

TITLE ***Geomechanical factors determining fault criticality during pressure cycling of underground gas storage in reservoirs***

Objective

The objective of the proposed study is to re-assess the basic geomechanical causes of seismicity, specific risk factors, and safe operational bandwidths for reservoir storage conditions, that have not been addressed in previous studies. In particular, the study should focus on those factors that fall beyond the well-known causes for fault slip and seismicity at peak depletion /minimum reservoir pressure (and consequently maximum effective stress conditions). For instance, one UGS shows micro-seismicity during the injection phase near the maximum allowed reservoir storage pressure, on a fault that was not active during depletion. Another Dutch UGS showed an observed seismic event after re-injection of the cushion gas and initial work volume at a near-virgin reservoir pressure. In both cases, these were conditions under which fault criticality was least expected. Seismicity during injection of the cushion gas was also observed for the UGS Castor in Spain, with events as large as M=4.0. Hence, from a traditional fault stability point of view, we may be missing important causal mechanisms. Is the micro-seismicity observed in some of the Dutch UGS sites, at stress conditions and locations where it was not expected, a warning that higher magnitude events can occur at gas pressures where they are not expected?



What will not be included:

- No storage issues in salt caverns.
- No caprock integrity issues; which is a less limiting factor, as any Dutch UGS operation occurs below the initial reservoir pressure (before production).
- No simulations of parameter space to quantify bandwidth of main controlling factors.

State of the art, background

Natural gas in the Netherlands is stored in underground gas storage (UGS) facilities to manage gas demand and supply on a seasonal and daily basis. This study focusses on the geomechanical factors that may cause fault slippage and seismicity on faults in and around the reservoirs that are used for storage. Gas storage in salt caverns is not part of this project. Currently there four such UGS facilities operational in the Netherlands: at Bergermeer, PGI Alkmaar, Norg and Grijpskerk. Three of these reservoirs have experienced multiple seismic events during gas extraction. The reservoir configurations were subject to geomechanical studies before receiving storage licenses and validated storage plans. These studies (sees references) examined the geomechanical conditions of fault reactivation causing the observed seismicity during the depletion and re-injection phases, based on which monitoring and risk management programs were installed.

Research Questions

Which main factors control the reactivation of faults and seismicity under cyclic storage conditions?

- **Provide an overview of induced events related to UGS facilities globally, focussing on both the re-injection and the production phases.**
- **Relate the induced events to possible physical mechanisms that explain their occurrence during both phases.**
- **Find root causes for seismicity during reinjection, during depletion at peak production rates and under minimum gas pressures (average and near-well), as well as during injection at peak injection rates and at maximum (average and near well) gas pressures.**
- **Identify critical factors influencing the activation of faults and seismicity during re-injection and storage operations, which**

could be used as hazard indicators in a risk matrix risk assessment.

- **The study should focus on underexplored natural and operational conditions for which fault criticality is perceivable upon re-evaluation. Previous focus has been on seismicity under peak depletion conditions.**
  - **UGS operational conditions under yearly pressure cycling are obviously different with regard to dP/dt and ΔP/P , as compared to gas depletion during the production period over decade(s) (above Figure).**
  - **Differences occur between the average reservoir gas pressure, and the gas pressure near the wells, and the differential gas pressures between reservoir blocks.**
- **Identify, if possible, generic guidelines for a safe operational bandwidth (e.g. pressure range/rates).**

Deliverables expected

a) Inventorisation of the mechanical factors causing unforeseen seismicity from global UGS operations (i.e., lessons learned elsewhere).
b) A root-cause analysis template based on potential mechanical factors that determine seismicity at different storage cycle stages.
c) A report containing conceptual geomechanical model results, interpretations, and underpinning deliverables a & b.
d) A recommendation toward a recipe (formulation of a ranking system) for determining safe operational bandwidth, regarding seismicity, including the main factors and their weight.

Timeline

This study will form the first of two phases.
This 1st phase should preferably start before 01-10-2017, and its results should feed into phase 2 by 01-02-2018 and finalized ultimately by 31-03-2018. Delay would entail postponing phase 2, and would imply that the project objective for an internal guideline by the end of Q1 2018 cannot be achieved.

The project timeline of this project is set to five months, starting preferably in October 2017.

Expected use

The deliverables will be

(i) input for a phase 2 with application of the root cause analysis and ranking system to the Dutch UGS, and
(ii) input for an internal SodM guideline.