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

**TITLE *Effect of pressure maintenance by fluid injection on seismic risk***

**Objective**

Worldwide, the production of natural gas from subsurface porous reservoirs leads to surface subsidence and induced seismicity, caused by the compaction of the depleting reservoir. Fluid injection during or after production is a potential measure to control the reservoir pressure and, hence limit, reservoir compaction. This intervention may result in a lower risk of induced seismicity compared to scenarios without fluid injection.

The first objective is to investigate and identify what the best method is to model and quantify the effect of fluid injection on the expected seismicity risk profile. Two main factors will be considered: (1) using various injection fluids ($N_2$, $CO_2$ and water) or a mixture of natural gas and an injected fluid, and (2) different injection scheme options, including reusing existing production facilities. The second objective is to find a reliable method to assess possible additional seismic risks associated with fluid injection itself (as it might locally trigger seismicity) and to determine which factors, circumstances or injection configuration and volumes may increase the probability of seismicity and vice versa.

The overall objective is to assess whether the net effect of fluid injection on the seismic risk profile can be positive and to give recommendations to optimise the risk reduction at minimum injection costs.

**State of the art, background**

In previous years, research has been conducted by TNO and NAM on the feasibility of pressure maintenance by large-scale fluid injection (2014-2016, see references).It was concluded that injection can maintain reservoir pressure in depleting reservoirs, such as the Groningen gas field, and the fluid injection is technically feasible. However, the overall net effect of large-scale fluid injection on the seismic risk profile was not quantified and the seismic risk associated with different fluid injection scenarios was only studied in a qualitative way. Therefore, it is unknown whether fluid injection can be used to minimise the risk of induced seismicity in depleting gas fields.

A feasibility study for the Groningen gas field (NAM, 2016) indicated that establishing a large-scale fluid injection operation in the short term was hardly feasible, due to the major investments required for the production of large volumes of injection fluid, as well as the lengthy time required to construct the injection well infrastructure. It was therefore decided by NAM not to pursue this option any further. However, various experts in the field advocate to continue investigating this option, especially for the Groningen gas field. This would require an extension of the current hazard and risk analysis (HRA) model used for assessing the seismic risk due to gas production in the Groningen field (developed by NAM and reconstructed by TNO), as the current version does not have the functionality to investigate the effect of fluid injection on seismic risk.

**Research Question**

***1. What are possible injection scenarios for pressure maintenance during production and for minimising the pressure difference across the field once production has stopped?***

Taking the Groningen gas field as a testcase, what are possible injection scenarios, including the fluid type used and the injection scheme (e.g. surrounding ring or centrally)? What scenarios could be used for pressure maintenance during production? What scenarios could be applied to minimise the pressure difference across the field during and after production?

***2. What are the reservoir stresses and pressures for various fluid injection scenarios (defined in question 1) around wells and over the entire gas field?***

Using a Groningen reservoir simulator, how can the development of reservoir pressures and stresses in response to fluid injection be modelled locally (i.e. around wells) and reservoir-wide? How to build and validate a database of reservoir stresses and pressures for the injection scenarios defined in question 1? Using forecasting results, how should the current seismic module in the HRA model be best adapted to incorporate fluid injection?

***3. How to adapt the Groningen seismic module for injection for pressure increase as well as pressure decrease?***

The current version of the seismic module of the HRA model cannot handle pressure increase. Which formulation can be used to upgrade the seismic module and what is an adequate model testing scheme? Is it suitable to be used for field assessment as well as for local areas around injection wells?

***4. What is the effect of fluid injection on the overall seismic risk?***

What is the effect of different injection scenarios defined in question 1 on the hazard and risk profile of the Groningen field compared to the most recent production strategy? How do the results compare?

***5. What is the effect of fluid injection on seismicity near injection wells?***

Locally around injection wells, fluid injection may lead to an increase in seismic risk. How can this effect be quantified in cases of one or multiple injection wells? Can forecasting be improved by incorporating fault distributions and stress regimes? For the Groningen reservoir, what is the expected spatio-temporal distribution of pressure increases around injection wells using different injection pressures and rates? In addition, what is the effect of fast and large pressure changes at the injection well?

***6. What is the most optimal configuration of injection wells?***

What is the safe distance between injection wells and faults and how does this depend on injection volumes and rates? What are the most optimal locations for (new) injection wells in terms of lowest seismicity? What is most optimal configuration if only existing wells are used?

***6. What is the overall effect of fluid injection on seismicity and what are the recommendations for the Groningen HRA model?***
What is the overall change in the seismic risk profile, considering both the expected decrease in seismicity by fluid injection and the expected local increase in seismicity around injection wells? Are there other recommendations to improve modelling of fluid injection in the HRA model?

**Deliverables expected**

1. Seismic model preparation and adaptation. Three models: 1) multiphase Groningen reservoir model, 2) adapted seismological model for $CH_4$, $N_2$, $CO_2$ and $H_2O$ fluids individually or as a mixture, and 3) inclusion of seismic model in the Groningen seismic hazard and risk model train.
2. Assessment report on the effect of pressure maintenance on seismicity for the Groningen field, including the results of the HRA model for various injection scenarios defined in question 1.
3. Assessment report on the effect of various injection well configurations (e.g. fluid types, injection rates, well configurations, and number of wells) on seismic hazards and risk profiles per region, including an evaluation of the suitability of these scenarios and suggestions for further action (if needed).
4. Presentation of the results and recommendations on optimal technical scenario for fluid injection (excluding socio-economical aspects). Integrated assessment report of the above.

**Timeline**

One year:
- 3 months for deliverable 1, go – no-go decision
- 6 months for deliverables 2 and 3, running in parallel
- 3 months on final integrated assessment report (deliverable 4)

**Expected use**

The results can be used by MEA and SSM to reassess their strategy on seismic risk reduction measures in Groningen and other gas fields.
The result can be used to underpin and explain technical questions on the option to use or not use a particular fluid injection strategy as a measure to reduce seismic risks.
The insight obtained can be used as recommendations or guidelines for a phased plan for fluid type, injection well configurations and rate (changes) of injection.

**Expertise and tools required for the team**

Knowledge of injection wells, reservoir fluid flow, geomechanics, and reservoir and fluid material properties.

Knowledge of and access to the Groningen HRA model.

**Quality assurance, Organisational and communication requirements**

The project should have a phased approach with milestone meetings to discuss results, client perspectives and decisions on and how to proceed.
The project needs access to:
- Groningen reservoir model (NAM, TNO)
- Groningen HRA (TNO)

**References**


- NAM, Groningen Pressure Maintenance Study', Shell Global Solutions, 2016
- NAM, Expert panel report: Induced seismicity resulting from injection (workshop Amsterdam 9-10 June 2016)
- 'TNO 2014 R11761 Literature review on Injection-Related Induced Seismicity and its relevance to Nitrogen Injection'
- 'TNO 2015 R10906 Injection-Related Induced Seismicity and its relevance to Nitrogen Injection: Description of Dutch field cases'
- 'TNO 2015 R11259 Injection Related Induced Seismicity and its relevance to Nitrogen Injection: Modelling of geomechanical effects of injection on fault stability'
- 'TNO 2015 R11648 Injection Related Induced Seismicity and its relevance to Nitrogen Injection: Main findings, recommendations and general guidelines'
- Description and analysis of field cases of injection in The Netherlands (TNO-rapport 2015 R10906, 5 November 2015).