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Zürich, April 8 2017

Dear

The State supervision of Mines has asked me on March 31 to review a report by NAM, entitled "*Report recent earthquakes Wirdum and Garsthuizen 2016/2017*". Below please find my comments on the report:

- 1) First of all, I would like to point out that interpretations based on seismicity rates in the Groningen area should be viewed with caution: Not only does the induced seismicity change substantially with time, the seismic monitoring network and procedures to assess magnitudes and locations are simultaneously changing. While the network densification is a much desired and much needed development, it also raises the potential for systematic changes, which may in terms result in (substantial) changes in rate. In my view, these changes are understudied today, although it would not be too challenging to address them. These additional uncertainties will in my view add substantial uncertainty to the interpretation of observed transients.
- 2) In the same direction: The number of events observed in the Groningen area is overall quite small, but could likely be sustainably improved using modern post-processing techniques (template matching, double difference relative re-location). While such studies have to my knowledge been initiated, they are not yet complete and are not used here to improve the completeness and homogeneity of the earthquake record. Better absolute and relative hypocenters should now be possible, allowing for a better seismotectonic understanding and correlation with faults. Smaller events will also allow for more robust assessments of the relative earthquake size distribution and it changes with space and time. These improvements are key ingredients for the next generation forecasting models.
- 3) While clustering based on earthquake-earthquake interaction is not a major factor in Groningen seismicity, it does potentially mask some of the trends in seismicity. The analysis should ideally be based on a declustered catalog.

- 4) The report is addressing the issue of an apparent increase in seismicity rate from a broad perspective, discussing the various potential causes. However, the report is superficial and a bit unfocused in places, not reproducible and overall nPot of the same quality than other elements of the hazard and risk assessment presented by NAN or its subcontractors in the past. The work is overall not very quantitative but rather speculative; it is also not reproducible.
- 5) The report remains mostly inconclusive, highlighting the fact that first of all the understanding of the physical processes and boundary conditions are limited, but also owing to the fact that the processes of earthquake genesis are somewhat random in nature. While forecasting the overall behavior of the induced seismicity in the field may be possible on a statistical average, forecasting the behavior of individual clusters remains much more difficult. Even more difficult would be to define targeted mitigation measures for addressing individual clusters. The major limitation of the analysis is the lack of a validated physics based model that connects reservoir properties (production/subsidence/pressure ...) with induced seismicity, especially for sub-areas of the field. Without such a widely-accepted model, the interpretation and mitigation remains limited.
- 6) The increase in rate of smaller events is in my view not immediately alarming and within the bounds of the predictability of the system and the induced events. It is also so far below the pre-defined action threshold. It seems sensible to optimize procedures to minimize sudden changes in stress/production rate, while at the same time accelerating the work on the seismicity analysis and on developing and validating an improved forecasting model. From my limited insight, more 'dramatic' measures seem not necessarily warranted, based on the current state of knowledge and taking into account that larger events are possible in all places, as is an increase in seismicity somewhere else.

I hope these comments are helpful for your assessment of the situation.

With best regards