Induced Seismicity—Stakeholder Engagement in Iceland

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Keywords

Reinjection, induced seismicity, Hellisheidi, Hengill, stakeholder engagement

ABSTRACT

Commissioning of the Húsmúli reinjection area for the Hellisheiði power plant in late 2011 caused significant induced seismicity that was felt in nearby communities. Seismicity risk and risk mitigation were not taken sufficiently into account when planning the commissioning. Reinjection into the Húsmúli area has now been ongoing for almost three years. The startup and operation of the reinjection has resulted in several lessons learned regarding stakeholder engagement and better work procedures for future projects and operation of the reinjection areas.

Introduction

The Hellisheiði Power Plant is located in the south west of Iceland, approximately 20 km from the capital city of Reykjavik and approximately 10 km from the geothermal town of Hveragerði. The geothermal field at Hellisheiði is situated in the southern part of the Hengill Volcanic System on the western flank of the South Iceland Seismic Zone. The area is characterized by hyaloclastites formations and a SW-NE orientated fissure swarm (Sæmundsson, 1995). A map of the Hellisheiði geothermal area is shown in Figure 1. The power plant was commissioned in stages from 2006-2011 and has an installed capacity of 303 MWe and 133 MWt.

Reinjection of all effluent water production from the Hellisheiði Power Plant is required by operation permits. This has proven to be a challenge (Gunnarsson, 2013). Originally, reinjection wells were drilled to the south of the power plant at Gráuhnúkar. Although this area has proven to be a good reinjection area, drilling in the area found temperatures above 300°C making it a prime target for further energy production. The company therefore invested in a new reinjection area to the north of the power plant, Húsmúli, to take over reinjection from the power plant. Large scale reinjection at Húsmúli began in the fall of 2011 but the area has not yet been proved receptive enough for all of the power plant's effluent water. Therefore both Gráuhnúkar and Húsmúli are currently used as reinjection areas. (Gunnarsson, 2013). In addition, during the commissioning of the Húsmúli area, significant induced seismicity was felt in nearby communities.

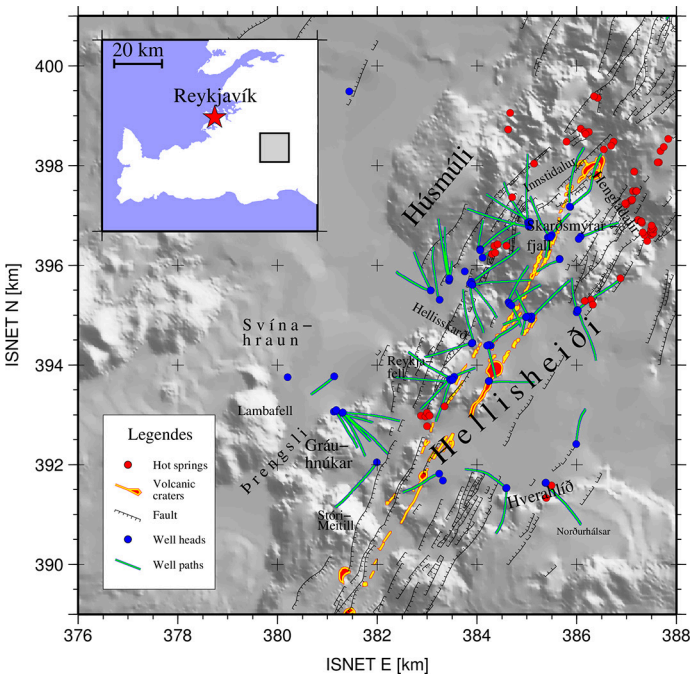

Figure 1. Hellisheidi geothermal field. The Húsmúli reinjection area is to the north of the field (Gunnarsson, 2013).

Induced Seismicity in 2011

Although some seismicity had occurred during the drilling and testing of the reinjection wells at Húsmúli, operators failed to take seismic risk sufficiently into account when planning the startup of the large scale reinjection. Induced seismicity associated with geothermal production was known in Iceland but had never caused problems despite a long and vast history of geothermal

utilization. In addition, the Húsmúli area was not known to be a particularly active seismic area and the injection pressure of 28 bar was far below the critical stress state of the rock (Gunnarsson, 2013). However, the large scale reinjection caused significant induced seismicity with about 40 earthquakes registering over magnitude M_L 2.5 and eight earthquakes registering between M_L 3.0-4.0. Most of the earthquakes above M_L 2.5 were felt in the nearby town of Hveragerði and the biggest earthquakes were also felt in the capital city of Reykjavik (Bessason, et al., 2012).

Current Reinjection

Despite the induced seismicity, reinjection into the area continued at full pace. Over the next few months, as the area reached a new stress state under these new conditions of large scale reinjection, seismicity subsided and events that could be felt in nearby communities dropped dramatically. Seismic activity is monitored with the Icelandic Meteorological Office's seismic network (SIL) (Stefánsson, et al., 1993) and data is presented real time on their website. Figure 2*(a)* shows the magnitude of the induced seismicity (M_L) and the accumulated number of events (N_{tot}) plotted vs. time from the start of reinjection in 2011 until April 2014.

The Húsmúli reinjection zone has now been in operation for almost three years. The area has displayed temperature dependent injectivity and a relationship between significant changes in reinjection and associated seismicity (Gunnarsson, 2013). Figure 2(b) shows the total flow of reinjected water (Q) and its temperature (T) in relation to seismicity in the area (Figure 2(a)).

Independent Report

The induced seismicity in 2011 generated a strong response from the general public, media, regulators and Reykjavik Energy (the operator of the field[1]). Two days after the biggest seismological events occurred Reykjavik Energy held a town meeting in nearby Hveragerði to discuss the reinjection operation. During the meeting, it was decided to appoint a panel of independent experts to evaluate the current reinjection and to provide recommendations for future reinjection operations.

The independent panel consisted of experts from Icelandic Geosurvey, the Icelandic Metrological Survey (IMO), the University of Iceland, Reykjavik Energy and the town of Hveragerði. The panel's report was published in late 2012 (Bessason, et al., 2012).

The panel found that seismic risk had not been taken sufficiently into account during the commissioning of the Húsmúli area. Monitoring equipment had not been sufficient and a risk mitigation plan for seismic events had not been in place. The panel also gave several recommendations, five of which were critical:

1. Make all production data from the beginning of reinjection into the Húsmúli area available to scientists in as close to real time as possible.
2. Temporarily increase seismic network coverage in the area.
3. Increase continuous GPS monitoring in the area.
4. Install a strong motion seismometer at the Hellisheiði power plant to measure ground acceleration.
5. Put in place a formal communication route to nearby communities that can alert the public to sudden changes in reinjection that could increase seismic risk.

These recommendations are in line with the International Energy Agency's Protocol for Induced Seismicity (Majer, Baria, & Stark, 2008).

Formal Channel of Communication

All of these measures were put in place quickly except the last recommendation. Although communication with local communities and their leaders was increased immediately, finding the proper channel and level of communication was difficult. It was important to strike the correct balance between alerting the public when seismic risk was thought to be increased without crying wolf too many times and thus decreasing the value of the public announcements. After several meetings, phone calls and emails a formal route was finally decided upon in early 2014. Now, when the reinjection at the Hellisheiði power plant is disrupted or changed in a significant or unusual way that could increase seismic risk information is sent out through three channels. Firstly, the IMO´s seismic monitoring watch is notified as they are responsible for monitoring all seismic activity in Iceland 24/7. Secondly, the Icelandic Civil Protection Department is notified. They in turn notify the corresponding nearby communities both through direct communication with local civil protection committees and through a public announcement on their website. Finally, Reykjavik Energy puts out a notice on its website alerting the public to the increased risk. Once the reinjection operations are

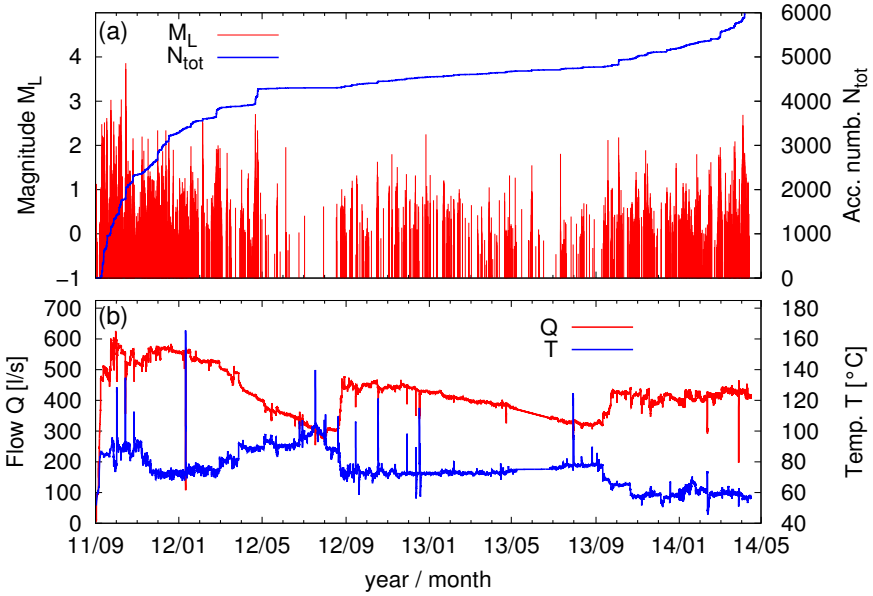

Figure 2. (a) Seismicity in the Húsmúli area from the start of large scale reinjection in September 2011 till the end of April 2014. The magnitude (M_L) and the accumulated number of events (N_{tot}) are plotted vs. time. (b) Total flow of reinjected water (Q) and its temperature (T). Both (a) and (b) are shown in the same time scale.

stable again, these same three lines of communication are used to alert the public of decreased seismic risk.

This new formal communication route has only been in place for a few months and experience on its effectiveness is limited. However, it has been presented to all major stakeholders including nearby community leaders and regulators, to the general satisfaction of all.

Revised Work Procedures

Reykjavik Energy and its subsidiary Our Nature (the current owner and operator of the Hellisheiði Power Plant) also revised its work procedures regarding reinjection and a new traffic light process was put in place for starting large scale reinjection or when significant changes are made in the reinjection from the power plant (see Figure 3). The traffic light procedure is modeled on similar procedures used in other geothermal projects such as AltaRock Energy's Newberry EGS demonstration project (AltaRock Energy, Inc, 2011) and has been introduced to all major stakeholders. At this time ground motion measurements are not available in real time, and it was therefore decided to use seismic event magnitudes as trigger levels. However, ground motion measurements might be added as trigger levels at a later time.

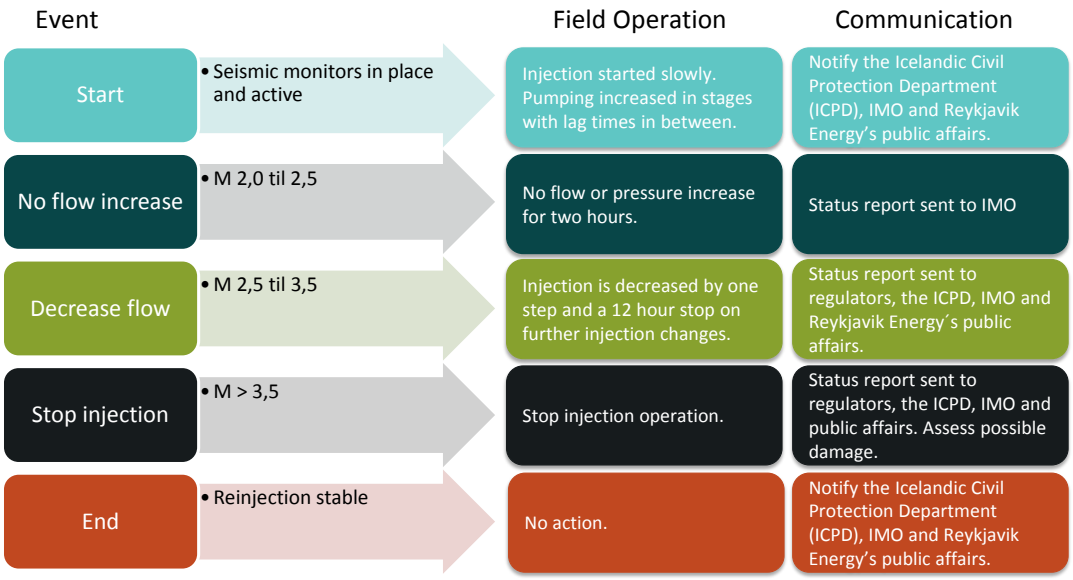

Figure 3. Reykjavik Energy's work procedure for large scale reinjection after a temporary shutdown or when significant changes are made in reinjection from the power plant. The procedure is modeled after AltaRock Energy's decision tree for triggers and mitigation actions from its Newberry EGS demonstration project.

Increased Stakeholder Engagement

In addition to the formal route of communication, Reykjavik Energy and Our Nature make a concerted effort to communicate information about ongoing work and studies to the general public. The companies are owned by three municipalities in the south west of Iceland and have the responsibility to inform and educate the public (its owners) about their operations. In addition to an open annual meeting on the companies' operations, an annual Science Day was added to the calendar in 2014. The Science Day's purpose is to communicate results of scientific studies undertaken for or in cooperation with Reykjavik Energy and Our Nature. This year, a whole session was dedicated to seismicity studies.

Cooperation with the seismicity watch at the Icelandic Meteorological Office is also an important factor. The operation of the SIL network seismometers that are closest to the power plant are funded by Our Nature and communication with and feedback from the IMO is frequent.

Conclusion

The commissioning of the large scale reinjection area at Húsmúli would have benefitted from much better preparation with regard to seismic risk and communication with nearby communities and other stakeholders before the start of injection. Mistakes are often the most valuable experience, and so it can be said of this project. Since 2011 the operator has reviewed and revised its work procedures and processes regarding reinjection, increased monitoring in the geothermal field and increased engagement with local communities and public authorities regarding seismic risk.

References

AltaRock Energy, Inc. (2011). *Induced Seismicity Mitigation Plan - Newberry EGS Demonstration.* AltaRock Energy, Inc.

Bessason, B., Ólafsson, E. H., Gunnarsson, G., Flóvenz, Ó. G., Jakobsdóttir, S. S., Björnsson, S., et al. (2012). *Verklag vegna örvaðrar skjálftavirkni í jarðhitakerfum.* Reykjavik: Reykjavik Energy.

Böðvarsson, R., Rögnvaldsson, S. T., Slunga, R., & Kjartansson, E. (1999). The SIL data acquisition system—at present and beyond year 2000. *Physics of the Earth and Planetary Interiors, 113*(1), 89–101.

Gunnarsson, G. (2013). Temperature Dependent Injectivity and Induced Seismicity - Managing Reinjection in the Hellisheiði Field, SW-Iceland. *GRC Transactions, Vol. 37.*

Majer, E., Baria, R., & Stark, M. (2008). *Protocol for induced seismicity associated with enhanced geothermal systems.* (incorporating comments by: C. Bromley, W. Cumming, A. Jelacic and L. Rybach), Task D Annex I. International Energy Agency-Geothermal Implementing Agreement.

Stefánsson, R., Böðvarsson, R., Slunga, R., Einarsson, P., Jakobsdóttir , S., Bungum, H., et al. (1993). Earthquake prediction research in the South Iceland Seismic Zone and the SIL project. *Bulletin of the Seismological Society of America, 83*(3), 696-716.

Sæmundsson, K. (1995). *Hengill, Geological Map (bedrock) 1:50.000.*

[1] *On January 1st, 2014, Our Nature, a subsidiary of Reykjavik Energy, took over ownership and operation of the Hellisheidi geothermal field and power pl*ant.