GEA Issue Brief

Geothermal Energy and Induced Seismicity

Seismic events caused by human activities, or instances of induced seismicity, are an issue for a range of industries. The oil, gas, mining, hydropower and other extractive industries have long histories and substantial experience with seismicity due to hydrofracturing and other surface and subsurface activities. An excellent resource for information on these issues is available online through the bibliography published by Darlene Cypser: http://www.darlenecypser.com/induceq/induceq.html.

Induced Seismicity and Geothermal Energy

Earthquake activity, or seismicity, is generally caused by displacement across active faults in tectonically active zones. An earthquake occurs when a body of rock is ruptured and radiates seismic waves that shake the ground. Although it typically occurs naturally, seismicity has at times been induced by human activity, including development of geothermal fields, through both production and injection operations. In these cases, seismicity has resulted in the form of low-magnitude events known as “microearthquakes” which have Richter magnitudes below 2 or 3 and which are generally not felt by humans. The injection of geothermal fluid back into the geothermal system can sometimes cause these microearthquakes to occur in the vicinity of the injection site. The microearthquakes sometimes associated with geothermal development are not considered to be a hazard to the geothermal power plants or the surrounding communities and will usually go undetected unless sensitive seismometers are located nearby. As the authors of the final Environmental Impact Statement (EIS) for the Fourmile Hill geothermal project reported, “geothermal production areas have experienced increased seismic activity in the magnitude range of 1 to 3 on the Richter scale as development proceeded. These event magnitudes are too low to be felt by humans and are not of concern to the safe operation of the project.” However, around some geothermal fields, particularly The Geysers in California, there have been complaints about increased seismicity in nearby communities.

Seismicity typically takes place in areas with high levels of tectonic activity, such as volcanic regions and fault zones. Because geothermal operations usually take place in areas that are also tectonically active, it is often difficult to distinguish between geothermal-induced and naturally occurring events. Many regions where geothermal development has occurred or has been planned are already known as areas with high levels of fault activity. For example, the fault activity associated with the Cascade volcanoes and the Modoc Plateau had the potential to produce surface rupture and strong ground shaking in the Klamath National Forest area prior to any geothermal development in the region.[1] Indeed, several earthquakes have occurred in the

[1] Fourmile Hill Environmental Impact Statement, 3-6.

region, which has yet to be developed for geothermal power production, including a 4.6 quake fifteen miles southwest of the proposed geothermal site in 1978, a swarm of low-magnitude quakes fourteen miles west of the proposed site in 1981, and several quakes near Medicine Lake in 1989, approximately two miles southeast of the proposed plant.[2] Virtually all the regions of California where geothermal development has occurred are located in what has long been known as "earthquake country" even prior to geothermal development. These regions frequently experience earthquakes of various magnitudes, though few are felt by humans.

For reference purposes, the University of Nevada Reno provides the following qualitative description of different earthquake levels:[3] (Note: the Richter scale is logarithmic.)

Richter Magnitudes	**Earthquake Effects**
Less than 3.5	Generally not felt, but recorded.
3.5–5.4	Often felt, but rarely causes damage.
Under 6.0	At most, slight damage to well-designed buildings. Can cause major damage to poorly constructed buildings over small regions.
6.1–6.9	Can be destructive in areas up to about 100 km across where people live.
7.0–7.9	Major earthquake. Can cause serious damage over larger areas.
8 or greater	Great earthquake. Can cause serious damage in areas several hundred kilometers across.

Seismic Monitoring[4]

Experts at The Geysers agree that geothermal field development and expansion has resulted in seismic activity, though many of these induced microearthquakes require sensitive instrumentation to be detected.[5] As a result of a project Environmental Impact Report (EIR) to bring in supplemental water from Lake County for injection at The Geysers, a Seismic Monitoring Committee (SMAC) was established to provide an open forum for concerned individuals and parties, even though the EIR determined that a geothermal facility would induce less than significant increases in seismic activity.

[2] Ibid.
[3] http://www.seismo.unr.edu/ftp/pub/louie/class/100/magnitude.html
[4] Telephone Flat Environmental Impact Statement, 3.1-5.
[5] Personal Correspondence with geophysicist Mitch Stark, Calpine SMAC participant. September 27, 2004.

While the largest earthquake ever detected in The Geysers area measured 4.6 on the Richter scale, seismic activity elsewhere in the region can be much more dangerous. In 1969, Santa Rosa, California, 40 miles from the geothermal site, experienced an earthquake of magnitude 5.7, and the USGS estimates that the Healdsburg-Rodgers Creek Fault is likely to experience an earthquake of Richter magnitude 6.5 within 30 years. The USGS monitors the region but does not treat the seismic activity at The Geysers as a significant concern compared to the larger-magnitude seismicity in the region, and therefore does not specifically focus monitoring efforts on The Geysers field.[6] Calpine, which operates most of The Geysers power plants, monitors field-wide seismicity more closely. Both the USGS and the Calpine data sets are made available to the public and are used for research purposes.

EGS and Induced Seismicity

The development of Enhanced Geothermal Systems (EGS) technology holds the key to unlocking the vast energy contained in the heat of the earth. A report conducted by the Massachusetts Institute of Technology (*The Future of Geothermal Energy*, January 2006) estimates that hundreds of thousands of megawatts of geothermal power could be produced just in the United States as a result of pursuing research into EGS systems.

Australia is a leading country in the development of EGS. Regarding the seismic (earthquake) risk from EGS development, the Australian Government states: "Experience in Australia and elsewhere in the world to date suggests that the risks associated with hydrofracturing induced seismicity are low compared to that of natural earthquakes and can be reduced by careful management and monitoring." ("Induced Seismicity and Geothermal Power Development in Australia," at: www.ga.gov.au/minerals/research/national/geothermal/.)

The Australian Government statements are consistent with the published findings of Ernest Majer, et al, of Lawrence Berkeley Laboratory in their paper entitled *Induced Seismicity Associated with Enhanced Geothermal Systems* published in 2006. The following is the complete abstract from that report:

> *Abstract*
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> *Enhanced Geothermal Systems (EGS) have the potential to make a significant contribution to the world energy inventory. One controversial issue associated with EGS, however, is the impact of induced seismicity or microseismicity, which has been the cause of delays and threatened cancellation of at least two EGS projects worldwide. Although microseismicity has in fact had few (or no) adverse physical effects on operations or on surrounding communities, there remains public concern over the amount and magnitude of the seismicity associated with current and future EGS operations. The primary objectives of this paper are to present an up-to-date review of what is already known about the seismicity induced during the creation and operation of EGS, and of the gaps in our knowledge that, once addressed, should lead to an improved understanding of the mechanisms generating the events. Several case histories also illustrate a number of*

6 *A Guide to Geothermal Energy and the Environment*, April 2007, GEA

technical and public acceptance issues. We conclude that EGS-induced seismicity need not pose a threat to the development of geothermal energy resources if site selection is carried out properly, community issues are properly handled and operators understand the underlying mechanisms causing the events. Induced seismicity could indeed prove beneficial, in that it can be used to monitor the effectiveness of EGS operations and shed light on geothermal reservoir processes.

("Induced Seismicity Associated with Enhanced Geothermal Systems," Ernest L. Majer, Lawrence Berkeley National Laboratory, 2006, LBNL-61681, at: http://repositories.cdlib.org/lbnl/LBNL-61681/)

For EGS projects funded by the U.S. Department of Energy, the field operator is required to develop a protocol for monitoring and managing induced seismicity, including public outreach activities (U.S. DOE Funding Opportunity Announcement, DE-PS36-09GO99019, March 4, 2009). The International Energy Agency provides additional information and links about induced seismicity, including ***Geothermal Energy from Fractured Reservoirs- Dealing with Induced Seismicity***, available at: **http://www.iea.org/impagr/cip/pdf/Issue48Geothermal.pdf**. Their web site on geothermal energy is at: http://www.iea-gia.org/publications.asp.

Suggested Additional Reading (available at http://www.geo-energy.org/):

- Geothermal 101: Basics of Geothermal Energy Production and Use. This 53-page booklet covers the basics of geothermal energy, from the types of power plants in use to common myths with numerous charts, graphs and pictures.
- A Guide to Geothermal Energy and the Environment. This 87-page booklet covers a wide range of environmental topics as well as provides an introduction to geothermal energy as this resource is being used today.

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