STATEMENT OF
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Chairman Bingaman, Ranking Member Murkowski, Members of the Committee, thank you for inviting the U.S. Geological Survey (USGS) to testify at this hearing on induced seismicity. My name is Bill Leith. I am the Senior Science Advisor for Earthquake and Geologic Hazards at the U.S. Geological Survey (USGS). The USGS is the science agency for the Department of the Interior (DOI).

As part of its strategy to meet future energy needs, limit emissions of greenhouse gases, and safely dispose of wastewater, the United States is expanding the use of technologies that involve the injection, and in some cases the associated production, of fluid at depth. As detailed in the report released last week by the National Research Council (NRC), *Induced Seismicity Potential in Energy Technologies* (hereafter, NRC report), the injection and production practices employed in these technologies have, to varying degrees, the potential to introduce earthquake hazards. I would like to commend this Committee for requesting that such a study be undertaken and the Department of Energy (DOE) for funding the study. The members of the National Research Council panel who wrote the report have done an outstanding job and have made a significant and lasting contribution to the public discourse on this important issue.

The USGS is well positioned to provide solutions for challenging problems associated with meeting the Nation's future energy needs. Various new approaches to produce oil and gas and alternative energy entail deep injection of fluid that can induce earthquakes. The cause and effect of induced earthquakes pose a number of risks that must be understood. USGS scientists, along with scientists from the National Labs and Universities funded by DOE, are already involved in studying a number of these injection projects, and we possess substantial expertise in the associated science and technology of mitigating the effects of induced earthquakes.

I summarize here the research topics that the USGS can address in order to assist the Nation in meeting its future energy needs through an improved understanding of induced seismicity that leads to mitigation of the associated risks.

To put this hazard in perspective, since the beginning of 2011 the central and eastern portions of the United States have experienced a number of moderately strong earthquakes in areas of historically low earthquake hazard. These include earthquakes of magnitude (M) 4.7 in central Arkansas on February 27, 2011; M5.3 near Trinidad, Colorado on August 23, 2011; M5.8 in central Virginia also on August 23, 2011; M4.8 in southeastern Texas on October 20, 2011; M5.6 in central Oklahoma on November 6, 2011; M4.0 in Youngstown, Ohio, on December 31, 2011; and M4.8 in east Texas on May 17, 2012. Of these, only the central Virginia earthquake is unequivocally a natural tectonic earthquake. In all of the other cases, there is scientific evidence to at least raise the possibility that the earthquakes were induced by wastewater disposal or other oil- and gas-related activities. Research completed to date strongly supports the conclusion that the earthquakes in Arkansas, Colorado and Ohio were induced by wastewater injection. Investigations into the nature of the Oklahoma and Texas earthquakes are in progress.

The disposal of wastewater from oil and gas production by injection into deep geologic formations is a process that is being used more frequently in recent years. The occurrence of induced seismicity associated with wastewater disposal from natural gas production, in particular, has increased significantly since the development of technologies to facilitate production of gas from shale and tight sand formations. While there appears to be little seismic hazard associated with the hydraulic fracturing process that prepares the shale for production (hydrofracturing), the disposal of waters produced with the gas does appear to be linked to increased seismicity, as was made evident by the earthquake sequence near the Dallas-Fort Worth airport in 2008 and 2009. In addition, recent research by USGS seismologist Bill Ellsworth and colleagues has documented that M3 and larger earthquakes have significantly increased in the U.S. mid-continent since 2000, from a long-term average of 21 such earthquakes per year between 1970 and 2000, to 31 per year during 2000-2008, to 151 per year since 2008. Most of this increase in seismicity has occurred in areas of enhanced hydrocarbon production and, hence, increased disposal of production-related fluids.

Industry has been working to expand the development of unconventional geothermal resources known as Enhanced Geothermal Systems (EGS), because of their significant potential to contribute to the U.S. domestic energy mix. These geothermal resources are widespread throughout the United States and are areas of high heat flow but low permeability. To make EGS projects viable, the permeability of geologic formations must be enhanced by injecting fluid at high pressure into the low-permeability formations and inducing shear slip on pre-existing fractures. This process of permeability enhancement generally induces a large number of very small earthquakes with magnitudes less than 2 (microearthquakes). The microearthquakes provide critical information on the spatial extent and effectiveness of reservoir creation. Depending on the circumstances, however, the resulting seismicity can have serious, unintended consequences, such as project termination, if any of the induced events are sufficiently large (greater than magnitude 4) to result in surface damage or disturbance to nearby residents. As a means to address these issues, the DOE published an induced seismicity protocol in 2012, which is cited in the NRC study as “a reasonable initial model for dealing with induced seismicity that can serve as a template for other energy technologies.”

As emphasized in the NRC report, there is a potential seismic hazard associated with geologic carbon sequestration projects that involve the injection of very large quantities of CO_2 into sedimentary basins, some of which are located in or near major urban centers of the eastern and central United States. Because carbon dioxide storage requires a high porosity formation of high permeability that is capped by an impermeable seal (e.g., shale), there are two important sources of seismic risk. The first type of risk is due to the possibility of a large magnitude earthquake that causes damage to structures in the environs of the project. More importantly, there is the possibility that an induced earthquake rupture would breach the cap rock allowing the CO_2 to escape.

Historically, the USGS has contributed significantly toward understanding seismicity induced by liquid injection, starting with the Rocky Mountain Arsenal in the 1960’s, where it was first discovered that liquid waste disposal operations can cause earthquakes. Between 1969 and 1973, the USGS conducted a unique experiment in earthquake control at the Rangely oil field in western Colorado. This experiment confirmed the predicted effect of fluid pressure on earthquake activity and demonstrated how earthquakes can be controlled by regulating the fluid pressure in a fault zone. The state of the science on the earthquake hazard related to deep well injection was summarized by the USGS in 1990, in a review that proposed criteria to assist in regulating well operations so as to minimize the hazard. This study was part of a co-operative agreement with EPA and was used to inform site selection and operating criteria during the development of underground injection control regulations for Class I Hazardous wells. This 1990 study is the most recent review of this topic but is likely to be superseded by the new NRC report. With support from our partners, USGS scientists are currently investigating induced seismicity associated with brine disposal operations in the Paradox Basin of Colorado and the Raton Basin coal bed methane field along the Colorado-New Mexico border. We and our partners, including the DOE, are also investigating the state of stress, heat flow, and microseismicity within geothermal reservoirs to evaluate the effectiveness of hydraulic stimulation for EGS. The combination within USGS of expertise in both energy science and earthquake science has proven particularly effective in addressing current issues.

Some of the key questions that arise in connection with fluid injection and production projects are:

- What factors distinguish injection activities that induce earthquakes from those that do not?
- To what extent can the occurrence of earthquakes induced by deep liquid-injection and production operations be influenced by altering operational procedures in ways that do not compromise project objectives?
- Can deep liquid-injection operations interact with regional tectonics to influence the occurrence of natural earthquakes by, for example, causing them to occur earlier than they might have otherwise? Similarly, can induced earthquakes trigger much larger tectonic earthquakes?
- What distribution of earthquakes (frequency of occurrence as a function of magnitude) is likely to result from a specified injection operation?
- What is likely to be the magnitude of the largest induced earthquake from a specific injection operation?
- What is the probability of ground motion from induced earthquakes reaching a damaging level at a particular site, and what would be the consequences (e.g., injury and/or structural damage)?

In the recent NRC report and in workshops sponsored by the DOE, , a common need has been identified for research to address the science questions posed above. The USGS, as an independent and unbiased science organization, can play a major role in studying, assessing, and providing solutions to these problems. We are already working collaboratively with DOE and U.S. Environmental Protection Agency on some of these issues, in response to the President's establishment of the interagency hydraulic fracturing working group, as well as with the States.

Although our primary research is directed at natural earthquakes and hydrogeology, we have in the past assessed the hazards associated with induced earthquakes due to mining operations, reservoir impoundment, oil and gas production and fluid injection. Thus, for many of these items, the research would mostly involve modifying existing approaches to the specialized requirements of fluid injection- and production-induced earthquakes.

Addressing these science problems will require a multidisciplinary approach that includes research in seismology, hydrology, crustal deformation, laboratory rock mechanics, in situ stress and fracture permeability, heat transport, fluid flow and other areas of study. The research activities might potentially include field-scale experiments, laboratory rock mechanics experiments, and the development and application of numerical models that simulate the effects of fluid injection operations on fracturing, fault reactivation and stress transfer, especially in low-permeability formations. Careful analyses of published case histories involving seismicity caused by fluid injection and production operations would be an important component of a comprehensive research program.

The involvement of industry is welcomed and may be essential to make progress on many of the key science questions. We see value in establishing an experimental site, or sites, in cooperation with industry and other agencies that could further the early work on induced earthquake triggering that was conducted so long ago at the Rangely field in Colorado. We note that DOE has in fact proposed a government-managed test site for EGS in its FY13 budget proposal, at which such R&D could be conducted in a carefully controlled and instrumented environment.

While a comprehensive effort is needed, and is called for in the NRC's recent report, any federal research dollars spent to minimize the risks of induced seismicity will serve multiple goals. Not only is this research relevant to shale gas development, geothermal development and carbon sequestration, but it also addresses several important gaps in our knowledge of the natural earthquake process and fault behavior.

I wish to expand on two of the findings and recommendations in the NRC report:

The first of these is what I will call the "data gap", for which the report recommends, "Data related to fluid injection... should be collected by state and federal regulatory authorities in a common format and made publicly available (through a coordinating body such as the USGS)." Currently, the data on injection volumes, rates and pressures needed to address many of the research questions above are simply lacking for many sites of induced seismicity. Permitting requirements for Underground Injection Control (UIC) wells are defined under Safe Drinking Water Act regulations, administered by the EPA and the states. Unless the potential for induced seismicity has been identified as a local risk prior to issuing a UIC permit, data collection required under these permits may not be sufficient to make confident cause-and-effect statements about injection-induced earthquakes after the fact, making it difficult to provide useful information to the regulating authorities about whether a particular disposal operation has or will have increased local earthquake risk.

Without more precise and complete data, it will be very difficult to assess the hazard potential from the tens of thousands of UIC wells that are currently in operation and for which their earthquake potential is unknown. An equal challenge is posed by UIC wells that may be permitted and become active injectors in the future, particularly if the permitting agency for the well is not cognizant of the associated earthquake hazard, or not in communication with parties that would be sensitive to a change in earthquake risk. For example, how close to an existing nuclear power plant or a dam is "too close" to site a disposal well permitted for a specified volume and pressure? Whose responsibility is it to evaluate the risk? Who is responsible for notifying the parties at risk? Who carries the liability should a damaging earthquake occur? Getting answers to these questions requires accurately assessing the induced-earthquake hazard, but at present the needed statistics are lacking because of the data gap. The NRC report provides some helpful guidance on how to develop "best practice" protocols that could help to close the data gap if implemented The report cites the recently published DOE IS protocol as an important step towards establishing a best practices effort.

The NRC report also found: "To date, the various agencies have dealt with induced seismic events with different and localized actions. These efforts to respond to potential induced seismic events have been successful but have been ad hoc in nature." Above in this testimony, I detailed the large number of induced or potentially induced earthquakes that have occurred in 2011 and 2012. Further, USGS scientists have also documented a seven-fold increase since 2008 in the seismicity of the central U.S., an increase that is largely associated with areas of wastewater disposal from oil, gas and coal-bed methane production. Scientifically, USGS has a depth of expertise relevant to understanding induced seismicity and the increasing demand for better monitoring, analysis, assessment, and public information. We have also worked closely with colleagues in academia and the State Geological Surveys, which have also seen increasing demands.

To meet these increasing demands, we have increased research efforts within our current budget. Looking forward, the Administration has proposed to significantly increase our efforts on induced seismicity in the coming fiscal year, as part of a comprehensive initiative to address potential environmental, health, and safety issues associated with hydraulic fracturing, and we hope that the Congress will support that initiative.

Thank you again for the opportunity to testify and for your attention to this important matter. I would be happy to answer any questions you may have.

For More Information

Ellsworth, W.L., and others, 2012, Are Seismicity Rate Changes in the Midcontinent Natural or Manmade? Seismological Research Letters, v. 83, no. 2, p. 403.