Region 3 framework for evaluating seismic potential associated with UIC Class II permits

Scientists have long recognized that human activities, such as construction of dams and water reservoirs, mining and oil and gas production, can trigger seismic events, including those that are felt by humans. Under certain conditions, disposal of fluids through injection wells has the potential to cause human-induced seismicity. However, induced seismicity associated with fluid injection is uncommon, as additional conditions necessary to cause seismicity often are not present. Seismic activity induced by Class II wells is likely to occur only where all of the following conditions are present: (1) there is a fault in a near-failure state of stress; (2) the fluid injected has a path of communication to the fault; and (3) the pressure exerted by the fluid is high enough and lasts long enough to cause movement along the fault line. In the United States, EPA Region III is aware of fewer than 10 documented cases of injection well-induced seismicity, compared to more than 30,000 wastewater disposal injection wells in operation. *Induced Seismicity Potential in Energy Technologies*, National Academy Press , 2013, at p. 10-11.

The presence of a fault in a receiving formation potentially creates a more vulnerable condition for a future seismic event. A fault is a fracture or a crack in the rocks that make up the Earth's crust, along which displacement has occurred. During an earthquake, energy is radiated away from the area of the fault in the form of seismic waves. This causes the ground to move as the seismic waves travel away from the fault. Depending on the force of an earthquake, seismic waves can travel far away from the epicenter, and thus be felt far from where the fault is located. The United States Geological Survey (USGS) tracks, records and maps earthquake epicenters and faults in certain areas throughout the United States. For areas where not much seismic activity has occurred, the USGS may not have much information about seismic events originating or faults located in those areas.

Scientists believe that injection can cause seismicity when the pore pressure (pressure of fluid in the pores of the subsurface rocks) in the formation increases to such levels as to overcome the friction force that keeps a fault stable. Pore pressure increases with increases in the volume and rate of injected fluid. Thus, the probability of triggering a significant seismic event during injection, where a fault exists in the receiving formation, increases with the volume and rate of fluid injected. In addition, the larger the volume injected over time (rate of injection), the more likely a fault could be intersected, because the fluid will travel farther within a formation. When injected fluid reaches a fault, frictional forces that have been maintained within that fault can be reduced by the fluid. At high enough pore pressure, the reduction in frictional forces can cause the formation to shift along the fault line, resulting in a seismic event. Therefore, limiting the rate and volume of the fluids injected limits the potential for seismicity.

Because increases in pore pressure due to the rate and the volume of injected fluid can act on existing faults and provide a mechanism for induced seismicity, most examples of injection-induced seismicity are in cases where the receiving formation has low permeability and/or the pressure or volume of fluid injected over time is quite large. Formations such as crystalline basement rock (deeper geological formations of igneous or metamorphic rock that underly layers of sedimentary rock), have very low permeability. Permeability is the ease with which a fluid can flow through the pores in a rock layer. For example, in the case of the Northstar 1 injection well in Youngstown, Ohio, injection occurred into very low permeability, crystalline bedrock.

Where permeability is low, injected fluid cannot flow easily through the pores in this rock and therefore flow is oriented mainly through existing fractures or faults in the rock. These kinds of rock formations have high transmissivity and low storability. This means that the formation cannot store a lot of fluid; rather fluid moves farther and faster in these formations than in more porous formations. Because of the high transmissivity and low storativity of these kinds of rocks, the potential exists to induce pore pressure increases at considerable distances away from the injection well. Injection into a more permeable sedimentary formation is much less likely to induce seismicity.

Because of the likelihood of greater permeability and the reduction in pore pressure, injecting into formations with a significant history of oil and gas production is unlikely to cause seismicity. The production of oil and gas, with the accompanying brine produced during such operations, results in the removal of large amounts of fluid from the formation. That means there has been a corresponding decrease in pore pressure in the formation. If injection occurs into these depleted reservoirs, pore pressure may not reach the original levels, or in some cases, may not increase at all due to the relative volumes of injection versus extraction. For this same reason, injection for the purpose of enhanced recovery has very low potential to induce seismicity. In such cases there is little total change in formation pressure as the injection fluid replaces the volume of oil and gas extracted. Also, in formations with a long-term history of oil and gas production, more information is generally available about the geology of the formation, such as well drilling records that can provide information about injection and extraction rates and displacement of geologic formations (which could be indicative of faults).

Further, history of past, as well as currently active, injection for disposal and enhanced recovery wells (as opposed to production wells) into a formation without induced seismicity is also supporting evidence that seismicity is unlikely, either because no faults are present or because increases in formation pore pressure due to injection have not caused sufficient pressure changes for movement to occur along the fault. For example, that active injection has been occurring for decades into a formation without triggering a seismic event indicates that the formation has high permeability and that formation pore pressure is not very responsive to injection at the existing rates.

Finally, to minimize conduits for fluid to potentially contaminate underground sources of drinking water (USDWs), operating conditions in an injection well permit can expressly limit the injection pressure to prevent fracturing (or cracking of the rock) of the injection zone. Limiting injection pressure provides the secondary benefit of preventing fractures that also could act as conduits through which fluid could flow and act upon an existing fault. In order to induce seismicity, pressure from the fluid injection first would have to be great enough to create or reopen fractures that would act as conduits for the fluid to reach the fault and second would have to exert enough pressure and flow to overcome the frictional forces in, and thereby destabilize, the fault. During the construction of a well, a completion process will take place whereby the operator obtains data on the amount of pressure necessary to fracture the formation and determine the instantaneous shut-in pressure. Instantaneous shut-in pressure is the minimum pressure necessary to begin to re-open fractures created during the hydraulic fracturing process. This pressure is significantly lower than the fracture pressure. The Region uses instantaneous shut-in pressure as a basis to establish the injection pressure, thereby preventing the fracturing of the receiving formation, in UIC permits.

In addition to concerns about injection-induced seismicity, there have been questions raised as to the relevance of natural seismicity to injection well permitting. When reviewing permit applications, the Region reviews available USGS information on seismic activity at the location of the well. As described above, knowledge of seismic events that originated in the vicinity of the proposed well can be informative about whether faults exist in that location. However, although earthquakes can be felt miles from their epicenter, earthquakes are not indicative of faults in all the areas where they are registered. Thus earthquakes originating miles away from the proposed well location do not provide information about faults at the location for the proposed well.

Of the hundreds of thousands of injection wells operating in the United States, EPA is not aware of any case where a seismic event, whether naturally occurring or induced, caused an injection well to contaminate an USDW. EPA is also unaware of any studies that have been done specifically to determine whether injection wells have caused contamination of a USDW during a seismic event. There have not been any reports of earthquakes affecting wells in the cases of induced-seismicity in Ohio, Texas, West Virginia or Colorado. The Region consulted with other regional personnel in the Agency and found no example of contamination from injection wells due to an earthquake.

A number of factors help to prevent injection wells from failing as a result of a seismic event and contributing to the contamination of a USDW. Most deep injection wells, those that are classified as Class I or Class II injection wells, are constructed to withstand significant amounts of pressure. They are typically constructed with multiple steel strings of casings that are cemented in place. Deep injection wells are typically designed, using casing and cement standards developed by the American Petroleum Institute (API) and oil field service companies, like Haliburton Services, to withstand significant internal and external pressure. See API website at http://www.api.org/ Halliburton Cementing Tables, Halliburton Services, 1980, for the industry standards in casing and cementing wells. Furthermore, injection well permits require mechanical testing to ensure integrity before they are operated and many are continuously monitored after testing to ensure that mechanical integrity is maintained. Injection wells can be designed to automatically shut in and cease operating if a seismic event occurs that affects the operation and mechanical integrity of the well.

For a more extensive discussion on injection-induced seismicity, see the report by the National Academy of Sciences, *Induced Seismicity Potential in Energy Technologies*, National Academy Press, 2013 , in particular Chapters 2 and 3. See also *A White Paper Summarizing a Special Session on Induced Seismicity*, Ground Water Research & Education Foundation, February 2013; *Preliminary Report on the Northstar1 Class II Injection Well and the Seismic Events in Youngstown, Ohio Area*, Ohio Department of Natural Resources, March 2012; *Final Report and Recommendations*, Workshop on Induced Seismicity Due to Fluid Injection/Production From Energy-Related Applications, Lawrence Berkeley National Laboratory, February 4, 2012; "*Managing the seismic risk posed by wastewater disposal",* Earth, April 17, 2012.