Sammy-Mar, LLC
Statement on Induced Seismicity

The subject of induced seismicity caused by injection of produced water from gas wells has been in the news and concerns were also raised at the Povlik Injection Well Public Hearing conducted by the EPA in Penfield, Pennsylvania on December 12, 2014.

Sammy-Mar, LLC is submitting the EPA's response to the public comments submitted at the public hearing or to written comments received during the comment period as the best answer to these concerns. The pertinent section starts on page six (6) with paragraph eight (8) and concludes on page 13 of the EPA's written responses to the submitted comments.

We are also submitting EPA "Region 3 framework for evaluating seismic potential associated with UIC Class II permits" to further clarify the EPA's seismicity evaluation process.

EPA will review the cementing logs to verify proper cementing without voids between the casing and the well bore that could provide a conduit for fluid movement. Also, the required mechanical integrity test must show that there are no internal failures in the tubing, casing or packer installed within the well before injection operations take place. If new information obtained from the completion report warrants changes to the permit, EPA will modify the permit conditions as appropriate.

7) **The long string casing should be cemented back to the surface. The uncemented annular portion, extending from 1250 feet to about 5030 feet, could allow fluid movement between the formations. In addition, during the cementing process, pressurized gases and fluids from the injection formation could channel upward through the 2000 feet of cement and potentially migrate through the uncemented portion of the casing and into a USDW.**

The permit includes construction requirements for the injection well that include the installation of long string casing to a depth of 7,030 feet and circulation of cement behind the long string casing to approximately 5,030 feet. The cement placed behind the long string casing is designed to seal and isolate the well to prevent fluid movement from the injection formation. Cement logs will confirm the adequacy of the cement job. Sammy-Mar's proposed well construction meets EPA's regulatory requirements for Class II wells in Pennsylvania, found in the UIC regulations at 40 C.F.R. §147.1955(b)(5), which were adopted to prevent endangerment of the USDWs.

During the cementing process, the pressure exerted by the column of cement behind the annulus at the bottom of the long string casing would be approximately 2200 pounds per square inch (psi) based on the density of class A cement. The reservoir pressure in the injection formation reported in the permit application is 25 psi. Therefore, fluids present in the injection formation would not overcome the pressure exerted by the column of cement in the annulus above and could not create channels upward into the cement.

While the UIC regulations do not require pressure monitoring in the annular space behind the uncemented long string casing, the PADEP does require such monitoring at the well head. This pressure is limited by PADEP not to exceed a specific limit based on the depth of the uncemented portion of the long string casing. Such monitoring is intended to prevent the movement of fluids between and into formations.

8) **The proposed injection well is located close to several geologic faults and this could cause fluid migration and seismic activity.**

As explained in the Statement of Basis, although EPA must consider appropriate geological data on the injection and confining zones when permitting Class II wells, the SDWA regulations for Class II wells do not require specific consideration of seismicity, unlike the SDWA regulations for Class I wells used for the injection of hazardous waste. See regulations for Class I hazardous waste injection wells at 40 C.F.R. §§ 146.62(b)(1) and 146.68(f). Nevertheless, EPA evaluated factors relevant to seismic activity such as the existence of any known faults and/or fractures and any history of, or potential for, seismic events in the area of the injection well as discussed below and addressed more fully in *"Region 3 framework for evaluating seismic potential associated with UIC Class II permits, updated September, 2013."*

An EPA report that looks at injection-induced seismicity ("Minimizing and Managing Potential Impacts of Induced-Seismicity from Class II Disposal Wells: A Practical Approach," EPA UIC National Technical Workgroup, February 5, 2015[1]) provides a standard operating procedure for assessing regional and local seismicity when reviewing permit applications. This procedure correlates any area seismicity with past injection practices; evaluates geological information to assess the likelihood of activating any faults; evaluates storage capacity of the formation with consideration of porosity and permeability; includes operational parameters to limit injection rate and volume and to limit operation at below fracture pressure; and requires monitoring of injection pressure and rates.

Induced seismicity background

Under certain conditions, disposal of fluids through injection wells has the potential to trigger seismicity. However, induced seismicity associated with brine injection is uncommon, as conditions necessary to trigger 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 allow movement along the fault line. Induced Seismicity Potential in Energy Technologies, National Academy Press, 2013, at p. 10-11. Although there are approximately 30,000 Class II-D wastewater disposal wells operating in the United States, only a few of these wells have been documented to have triggered earthquakes of significance and none of these earthquakes, which the Region is aware of, has caused injected fluids to flow into or contaminate a USDW.

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. Where a fault is present near an injection site, scientists believe that injection can trigger 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 frictional force that keeps the fault stable. Pore pressure increases with increases in the volume and rate of injected fluid. Thus, the probability of triggering a significant seismic event due to injection, where the injection fluid reaches an active fault, increases with the volume and the rate of fluid injected. In addition, the larger the volume injected over time, 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 result in the formation shifting along the fault line, resulting in a seismic event.

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

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1 The EPA UIC Technical Workgroup finalized this report on February 5, 2015 at EPA Headquarters.

basement rock (deeper geological formations of igneous or metamorphic rock that underlie 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. 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 (secondary permeability). These kinds of rock formations have high transmissivity and low storativity. 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.

Faults near the proposed well

The UIC regulations at 40 C.F.R. § 146.22 require that all new Class II injection wells be sited in such a fashion that they inject into a formation which is separated from any USDW by a confining zone that is free of known open faults or fractures within the AOR. Open faults, or transmissive faults, allow fluid to move along the fault and between formations. Non-transmissive faults, on the other hand, act as a barrier which would prevent movement of fluid along the fault and into another formation across the fault. Because not all faults act as a channel to conduct fluids, but rather as barriers, the UIC Class II requirements focus on ensuring that open faults are not present within the area an injection operation could influence.

The applicant submitted, and EPA reviewed , geological information indicating the probable presence of two faults which appear to be located about one-quarter mile from the injection well site, in the Oriskany/Huntersville Chert receiving formation. Drilling records and geologic cross sections provided in the permit application show displacement of the bedrock. The presence of the fault to the south of the proposed well in the Oriskany/Huntersville Chert receiving formation is confirmed by drilling records included in the permit application. In addition, a seismic survey was submitted by Sammy-Mar which appears to indicate that both faults are localized and non-transmissive. These non-transmissive faults provide the structural confinement which enabled natural gas to be fully contained within, and later produced from this area from the 1950s through the present. Other gas production wells drilled outside the fault zone in which the Sammy-Mar well is located were plugged for lack of production. For example gas production well API# 033-20047 was documented as a dry hole and was actually plugged and abandoned in 1959 shortly after completion. This gas well production history helps to illustrate that the displacement of the Huntersville Chert/Oriskany formation created by the faults established confinement of natural gas and formation fluids within the immediate fault block structure and that fluid flow (natural gas and produced water) along or across the faults is not evident. Because of the non-transmissive nature of the faults, fluid that is injected into the Huntersville Chert/Oriskany formation at the proposed injection well location should be confined within the fault block.

No geologic evidence indicates that these faults extend to the deep Precambrian crystalline basement rock. In this location, Precambrian basement rock is approximately 9,500 feet below the proposed injection zone.

These non-transmissive faults discussed above in the Oriskany/Huntersville Chert formation do not extend to the surface. This can be seen by reviewing the results of a seismic survey submitted with the permit application which does not show displacement caused by these faults extending upward.

The United States Geologic Survey (USGS) tracks, records and maps faults and earthquake epicenters in certain areas throughout the United States. The USGS monitors several active seismometers located in Clearfield County in the vicinity of the proposed well. The USGS as well as the Pennsylvania Department of Conservation and Natural Resources (PA DCNR) which includes the Bureau of Topographic and Geologic Survey, the principal organization that conducts geologic research in Pennsylvania, have not recorded any seismic activity that has originated in Clearfield County.

Although the USGS has recorded seismic events in Clearfield County, such events are extremely rare. Earthquakes that have been recorded, as well as felt in the area, were the result of seismic events that had their origins in other parts of the state or outside of the state's borders. Clearfield County is not located in a seismically active area and although there are a couple sub-surface geologic faults located within one-quarter mile of the injection well site, their presence in the area will not be impacted by the injection operation because they do not penetrate the injection formation. The PA DCNR website http://www.dcnr.state.pa.us/topogeo/hazards/earthquakes/index.htm has an interactive seismicity map and catalog of all recorded seismic events in or near Pennsylvania from 1724 to present.

During an earthquake, energy is radiated away from the hypocenter of the fault in the form of seismic waves. This energy causes the ground to move as the seismic waves travel away from the fault. Seismic events that have been felt in Clearfield County are seismic waves that were transmitted through the bedrock from the hypocenter of a seismic event that originated elsewhere. Seismic events which originate elsewhere do not provide information about the geology of Clearfield County, even if these events were felt there. The distance that the seismic waves travel is not indicative of the extent of the fault where displacement occurred due to the earthquake. Although seismic waves can cause the ground to shake a large distance away from the hypocenter of the earthquake, the fault where displacement occurred does not extend everywhere where the earthquake was felt. For this reason, history of seismicity that originates in areas other than the location of the injection well does not provide information about potential faults or formation pressures at the location of the well. For example, in the case of the Northstar 1 injection well in Youngstown, Ohio, the earthquake is believed to have been generated by injection into Precambrian crystalline bedrock, a deeper receiving formation, with different geology, than what is proposed for the Sammy-Mar well. The seismic waves radiating away from this area were felt in locations at significant distances away from Youngstown, including western Pennsylvania, but they have no relevancy to the geologic setting in Clearfield County or at the Sammy-Mar location.

Factors affecting fluid transmission and pore pressure

Research indicates that continuous very high rates of injection or over-pressurization of a geologic formation can contribute to the possibility of seismic activity. Conditions included in the Sammy-Mar permit were developed to prevent over-pressurization of the injection formation.

The permit limits the surface injection pressure during the injection operations to 2598 psi and the bottom-hole injection pressure to 6194 psi. The surface injection pressure and the bottom-hole injection pressure limits were calculated to ensure that, during operation, the injection will not propagate existing fractures or create new fractures in the formation. Limiting the pressure not only prevents the propagation of fractures that could become potential channels for fluid movement into USDWs but that could also serve as conduits for fluids to travel from the injection zone to known or unknown faults.

The Sammy-Mar permit will also require a yearly pressure fall-off test. During the test, the rate of fluid and volume injected is increased over a predetermined time period, and then the injection is stopped. The top-hole pressure is monitored during active injection and after injection is stopped. The fall-off testing will assist EPA in determining injection reservoir bottom-hole conditions as well as the flow conditions that the injection formation will exhibit during the injection operation. Analyzing flow conditions can help determine whether a preferential flow pattern exists and assist in determining whether that flow could be moving toward or coming into contact with the nearby faults.

A significant volume of gas and brine has already been removed from the proposed injection reservoir during previous gas production operations making the Huntersville Chert/Oriskany formation receptive for the disposal of fluid. The Huntersville Chert/Oriskany formation, the intended injection zone, has been a prolific producer of natural gas in this area since the late 1950s/early 1960s. Literature, as discussed below, documents that the accumulation of gas there is related to the fault system in the Oriskany, because gas migration has not been observed between fault zones. Evidence from gas production records from the PADEP Office of Oil and Gas Management, Oil and Gas Reporting Website[2] indicates that gas production wells located within the Oriskany fault structure, where the injection well is proposed, have produced significantly greater volumes of natural gas and produced water than gas production wells located outside of this fault structure. The removal of both natural gas and brine from the natural pore spaces that exist in a formation lowers the formation's pore pressure (reservoir pressure) and creates available storage capacity making reservoirs with a history of gas and oil production good candidates for the disposal of fluids. The National Academy of Sciences Report entitled Induced Seismicity Potential in Energy Technologies (2013) indicates that where fluids are injected into sites such as depleted oil, gas or geothermal reservoirs, these reservoirs can make excellent disposal zones, because in those cases, pore pressures may not reach their original levels, or in some cases, may not increase at all due to the relatively small volume of fluid injected compared to the volume of fluid extracted.

One commenter states that little brine has been removed from the receiving formation during gas production and that therefore there is not much pore space for the injected fluid. Ultimately, the storage capacity of a receiving formation will be determined by the injection well's operating pressure. This particular injection well is limited by the maximum injection pressure established in the permit for the well. See Part III.B.4 of the permit. Therefore, if pressure buildup occurs quickly during operation, an indication of limited storage capacity, the operation of the injection well will be limited by the established maximum injection pressure.

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[2] The PA DEP Office of Oil and Gas Management, Oil and Gas Reporting Website is a public website located at www.paoilandgasreporting.state.pa.us.

As pore space capacity to assimilate injected fluids decreases, the pressure needed to inject fluids will need to increase. Under the operating parameters of the permit, if such pressure reaches the maximum injection pressure, injection cannot proceed regardless of how long the well has been operating. Therefore, if the storage capacity of the receiving formation is limited, the result will be a reduced operating life of the injection well under the terms of the proposed UIC permit.

The public brought to EPA's attention recent seismic events that have occurred in Ohio, Texas, Oklahoma, West Virginia and Arkansas that were attributed to the underground injection of fluids produced from oil and gas extraction activities. EPA recognizes that there is strong evidence that supports the underground injection of fluids as being the trigger that led to these seismic events. In some cases, these earthquakes occurred in locations where there were no known faults. However, the likely relevant factors behind these seismic events, specifically the geologic setting or the operational history of the injection wells, differ significantly from the proposed Sammy-Mar injection operation as discussed above. Scientific evidence indicates that seismic activity is most likely associated with the depth of a well, the volume and rate of injection, and the injection pressure. In these aspects the Sammy-Mar well contrasts greatly with the wells in the known cases of induced-seismicity.

The "Preliminary Report on the Northstar1 Class II Injection Well and the Seismic Events in Youngstown, Ohio Area, Ohio Department of Natural Resources, March 2012", has indicated that the seismic activity associated with the injection of fluid in the Northstar 1 was likely due to the injected fluid coming into contact with a fault system located in deep Precambrian basement crystalline bedrock. This bedrock is located beneath the sedimentary bedrock structure and has very low permeability. Fluid injected in crystalline basement rocks is essentially transmitted by a network of inter-connected fractures and joints. Because of the high transmissivity (the ability of fluids to move through rock) and minimal ability to store fluids in these kinds of rocks, the potential exists to create flow at considerable distances from the injection well. Once flow reaches a fault, it allows the frictional forces that exist to be reduced thereby allowing the rocks to slip, leading to seismic activity.

In contrast, the injection zone for the Sammy-Mar injection well is the Huntersville Chert/Oriskany formation, a sedimentary rock formation of Lower Devonian age, which has a higher natural porosity and greater interconnection of that pore space throughout the formation than the crystalline bedrock. The Huntersville Chert/Oriskany formation is located at a depth of approximately 7030 feet below land surface at the proposed injection well site. The Precambrian crystalline basement rock in the area of the proposed injection well is located approximately 9,500 feet below the proposed injection formation (Pennsylvania Geologic Survey – General Geology Open File Report 05-01.0). In the Huntersville Chert/Oriskany formation the rock will more readily store injected fluid and the permeability (the available interconnected space between the grains and natural fractures in the rock) within the rock structure will allow a more uniform flow to occur throughout the formation. For these reasons, the geologic setting and reservoir characteristics of the proposed injection well are very different than the circumstances encountered in Ohio. For the proposed Sammy-May well, injection will not occur within, or flow into, the deeper Precambrian crystalline rocks.

Regarding the seismic event in Texas, a study conducted at the University of Texas at

Austin's Institute for Geophysics (Proceedings from National Academy of Sciences, August, 2012), indicates that the seismic activity was likely triggered by the significant volume of fluid that was injected in a relatively short period of time. Approximately 150,000 barrels of fluid per month had been injected down a disposal well since 2006. This equals approximately 75,600,000 gallons of fluid injected yearly for about a five year period. The proposed Sammy-Mar injection well will be limited to a maximum of 30,000 barrels per month, one-fifth the monthly limit of the Texas well. Researchers studying the circumstances that led to the seismic events in both Oklahoma and Arkansas believe that over-pressurization of a nearby fault after years of injection may have led to the seismicity. Similar to what happened in Ohio, injected fluid migrated into Precambrian rocks, which in the case of those wells were found just below the injection zone, and came into contact with a fault ("Science", Volume 335, March 23, 2012). It is believed that the reduction of the frictional stress in the faults led to slippage along the faults (From the journal "Geology", co-authored by researchers with USGS and Oklahoma Geologic Survey, March 3, 2013).

In Braxton, West Virginia, there is no definitive evidence, unlike the evidence produced for Youngstown, Ohio, that concludes injection was responsible for the seismicity in the area. However, information obtained from the West Virginia Department of Environmental Protection seems to indicate that when the injection rate, and later the injection volume, were reduced in the injection well, seismic activity in the area ceased. The geology where this injection well was completed is also different from the geology of the proposed Sammy-Mar injection well. The injection well in West Virginia is drilled into the Marcellus Shale, which has low permeability. The last recorded seismic event in the Braxton, West Virginia area was recorded in January, 2012; the injection well that was suspected of causing the seismicity continues to operate.

Several commenters also mentioned synclinal and anticlinal features in the geology of the area of the proposed well. Synclines and anticlines refer to folds in geological layers similar to surface hills and valleys. These synclines and anticlines also occur in the subsurface but they have no bearing on the faults located in the area of the proposed injection well. The specific syncline in question, the Caledonia Syncline, travels through Indiana County, located directly adjacent to Clearfield County. The synclines and anticlines in the area should not impact injection fluid movement because they are shallow and the injection well will be drilled to a depth of over 7,000 feet, and not in communication with these surface features.

9) Endangerment of USDWs due to earthquakes

Of the hundreds of thousands of injection wells operating in the United States, EPA is not aware of any case where a seismic event caused an injection well to contaminate a USDW. An inquiry through EPA regional offices did not reveal any reports of earthquakes having affected the integrity of injection wells in the cases of induced-seismicity in Ohio, Texas, Oklahoma, West Virginia or Arkansas. A number of factors help to prevent injection wells from failing in a seismic event and contributing to the contamination of a USDW. Most deep injection wells, 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 strings of steel casing that are cemented in place. The casing in these wells is designed to withstand both significant internal and external pressure. The American Petroleum Institute (API) (see www.api.org) and oil and gas service companies such as Halliburton Services (see Halliburton Cementing Tables, 1980), have developed industry standards for casing and cementing wells. Drillers are required to follow these standards.

Similarly, the proposed Sammy-Mar injection well, under the terms of the permit will be constructed with multiple strings of steel casing cemented in place. Furthermore, the proposed Sammy-Mar injection well will be required under the permit to be mechanically tested to ensure integrity before it is operated and will be continuously monitored during operation to ensure that mechanical integrity is maintained. This mechanical integrity testing is required by the UIC regulations for all brine injection wells. If a seismic event were to occur that affected the operation and mechanical integrity of the Sammy-Mar injection well, the well will be designed to automatically detect a failure due to pressure changes in the well annulus between the long string casing and the injection tubing, and this would cause the well to automatically stop injection. See Part II.C.2 of the Permit.

10) Comments questioned where the confining zone(s) were located and the adequacy of the confining zone above the injection zone.

The confining zone is defined as a geologic formation, group of formations or part of a formation that is capable of limiting fluid movement above an injection zone. 40 C.F.R. § 146.3. Formations with low porosity and permeability, limit fluid from passing through it. A series of low permeability shale and limestone formations are located above the receiving formation and separate that formation from the lowermost USDW. The Sammy-Mar application indicates a confining layer immediately above the injection zone, the Onondaga Limestone formation that will serve as an initial confining formation. The Onondaga Limestone formation is approximately 12 feet thick in the area of the injection well according to specific info in the permit application. This thickness, is sufficient to prevent the movement of injected fluid into shallower geologic formations since fracturing is not permitted in the injection formation during injection. In addition, the Hamilton Group and Tully limestone, geologic formation above the Onondaga, will serve as additional confining formations preventing fluid movement upward toward the USDWs. The Hamilton group consisting of medium gray shale directly overlays the Onondaga limestone and has a thickness of approximately 500 feet. Directly above the Hamilton group is the Tully Limestone Formation, a hard, dark limestone approximately 100 feet thick. Cumulatively these formations provide confinement for all injected fluids, as they did for previous natural gas within the Huntersville Chert formation.

The proposed Sammy-Mar injection well 4 ½ inch long string casing will be cemented from the interval beginning above the Tully limestone through the Tully, Hamilton, and Onondaga limestone to the injection formation, preventing fluid movement above those formations.

Several commenters expressed concern that fracturing of the Marcellus gas production wells in the area could have introduced fractures in the confining zone within the area of review. While there are several Marcellus gas production wells completed within a one mile radius of the

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.