An Evaluation of Potential Risk of Induced Seismicity in Pennsylvania From Injection Well Operations

SAFER Technical Briefing

Dale E. Skoff, PG

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Introduction

- Induced seismicity can be caused by various human activities (e.g., dams, mining, injection wells).
- EPA estimates approximately 30,000 UIC Class IID wells (aka “brine disposal wells” and “saltwater disposal wells”) in US.
- Documented correlations between injection and significant seismicity are rare but noticeable seismicity has been related to injection (e.g., Youngstown, OH Northstar #1 well).
- The potential risk of induced seismicity in PA from injection activities will be reviewed considering likely injection intervals, geologic structure, etc.
Injection Wells and Induced Seismicity

Source: GWPC
### Modified Mercalli Scale

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
<th>Richter Magnitude Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Detected only by sensitive instruments</td>
<td>1.5</td>
</tr>
<tr>
<td>II</td>
<td>Felt by few persons at rest, especially on upper floors; delicately suspended objects may swing</td>
<td>2</td>
</tr>
<tr>
<td>III</td>
<td>Felt noticeably indoors, but not always recognized as earthquake; standing autos rock slightly, vibration like passing truck</td>
<td>2.5</td>
</tr>
<tr>
<td>IV</td>
<td>Felt indoors by many, outdoors by few, at night some may awaken; dishes, windows, doors disturbed; autos rock noticeably</td>
<td>3</td>
</tr>
<tr>
<td>V</td>
<td>Felt by most people; some breakage of dishes, windows, and plaster; disturbance of tall objects</td>
<td>3.5</td>
</tr>
<tr>
<td>VI</td>
<td>Felt by all, many frightened and run outdoors; falling plaster and chimneys, damage small</td>
<td>4</td>
</tr>
<tr>
<td>VII</td>
<td>Everybody runs outdoors; damage to buildings varies depending on quality of construction; noticed by drivers of autos</td>
<td>4.5</td>
</tr>
<tr>
<td>VIII</td>
<td>Panel walls thrown out of frames; fall of walls, monuments, chimneys; sand and mud ejected; drivers of autos disturbed</td>
<td>5</td>
</tr>
<tr>
<td>IX</td>
<td>Buildings shifted off foundations, cracked, thrown out of plumb; ground cracked; underground pipes broken</td>
<td>5.5</td>
</tr>
<tr>
<td>X</td>
<td>Most masonry and frame structures destroyed; ground cracked, rails bent, landslides</td>
<td>6</td>
</tr>
<tr>
<td>XI</td>
<td>Few structures remain standing; bridges destroyed, fissures in ground, pipes broken, landslides, rails bent</td>
<td>6.5</td>
</tr>
<tr>
<td>XII</td>
<td>Damage total; waves seen on ground surface, lines of sight and level distorted, objects thrown up in air</td>
<td>7</td>
</tr>
</tbody>
</table>

Scale Source: Missouri Department of Natural Resources
USGS Seismic Hazards Map
Earthquake Epicenters In and Near PA

Source: PA DCNR
Brine Disposal Wells and Marcellus Wells

Source: OH DNR, WVDEP and USEPA Region 3 UIC Class IID well databases.
Of the 30,000 Class IID wells very few disposal well sites have produced seismic events greater than M4.0.

What conditions are necessary for significant injection-induced seismicity?

- Sufficient pressure buildup from disposal activities
- Presence of “Faults of Concern” (i.e., critically stressed region, optimally oriented for movement, sufficient size, etc.)
- Pathway allowing increased pressure to communicate with fault

Greatest risk associated with activating movement along basement faults

A Seismicity Decision Model was developed for use by UIC Directors.
UIC National Technical Workgroup (NTW) Injection-Induced Seismicity Decision Model

**Existing Class II O&G waste disposal well**
- Has seismicity increased (frequency or magnitude) in the area?
- Have operating or site conditions changed since the well was last permitted that would influence seismicity?

**New Class II O&G waste disposal well**
- Is there a history of successful disposal activity in the area of the proposed well?
- Have there been area seismic events?
- Is the disposal zone in or near basement rock?

**Continue UIC regulatory process**

**Have any concerns related to seismicity been identified?**

**Site assessment considerations for evaluating seismicity**
(Based on three key components: stressed fault, pressure buildup from disposal, and pathway between the two)
- What additional areageoscience information is warranted to assess the likelihood of Faults of Concern and seismic events?
- Has the static pressure and potential pressure buildup from disposal operations been determined?
- Are the reservoir pressure distribution pathways characterized?
- Is consultation with external geoscience and engineering experts warranted?
- What is the proximity of the disposal zone to basement rock (directly or through a pathway)?
- Is other information needed?

Source: Minimizing and Managing Potential Impacts of Injection-Induced Seismicity From Class II Disposal Wells: Practical Approaches (USEPA Nov. 2014)
EPA Injection-Induced Seismicity Decision Model

- **Continue UIC regulatory process**
- **Are there any seismicity concerns remaining after evaluating site assessment considerations?**
  - Yes: **Approaches for addressing site assessment considerations**
    - Monitoring
    - Operational
    - Management
  - No: **Conditions not conducive to injection**
- **Can an approach be used to address seismicity concerns?**
  - No: **Conditions not conducive to injection**
  - Yes: **Continue UIC regulatory process with supplemental conditions, as appropriate**

Source: Minimizing and Managing Potential Impacts of Injection-Induced Seismicity From Class II Disposal Wells: Practical Approaches (USEPA Nov. 2014)
Epicenter Distribution Relative to Northstar #1 Injection Well

Source: OH DNR
Range in Magnitude of Youngstown Seismic Events

<table>
<thead>
<tr>
<th>DATE</th>
<th>ORIG. TIME UTC</th>
<th>EPICENTER</th>
<th>MAGNITUDE</th>
<th>FELT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar. 17, 2011</td>
<td>10:42:20.22</td>
<td>41.11, -80.70</td>
<td>2.1</td>
<td>Not Felt</td>
</tr>
<tr>
<td>Mar. 17, 2011</td>
<td>10:53:09.51</td>
<td>41.11, -80.68</td>
<td>2.6</td>
<td>Felt (27 reports)</td>
</tr>
<tr>
<td>Aug. 22, 2011</td>
<td>08:00:31.50</td>
<td>41.12, -80.73</td>
<td>2.2</td>
<td>Not Felt</td>
</tr>
<tr>
<td>Sept. 02, 2011</td>
<td>21:03:26.20</td>
<td>41.12, -80.69</td>
<td>2.2</td>
<td>Felt (few)</td>
</tr>
<tr>
<td>Sept. 26, 2011</td>
<td>01:06:09.82</td>
<td>41.11, -80.69</td>
<td>2.6</td>
<td>Felt</td>
</tr>
<tr>
<td>Sept. 30, 2011</td>
<td>00:52:37.58</td>
<td>41.11, -80.69</td>
<td>2.7</td>
<td>Felt (300 reports)</td>
</tr>
<tr>
<td>Oct. 20, 2011</td>
<td>22:41:09.54</td>
<td>41.11, -80.69</td>
<td>2.3</td>
<td>Not Felt</td>
</tr>
<tr>
<td>Nov. 25, 2011</td>
<td>06:47:26.58</td>
<td>41.10, -80.69</td>
<td>2.2</td>
<td>Not Felt</td>
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<tr>
<td>Dec. 24, 2011</td>
<td>06:24:57.98</td>
<td>41.119, -80.694</td>
<td>2.7</td>
<td>Felt (90 reports)</td>
</tr>
<tr>
<td>Dec. 31, 2011</td>
<td>20:04:59.03</td>
<td>41.118, -80.693</td>
<td>4.0</td>
<td>Felt (more than 4,000)</td>
</tr>
<tr>
<td>Jan. 13, 2012</td>
<td>22:29:33.45</td>
<td>41.11, -80.69</td>
<td>2.1</td>
<td>Not Felt</td>
</tr>
</tbody>
</table>

Source: OH DNR
Well Construction for Northstar #1

Source: OH DNR
OH Injection Well
Into Mt. Simon Sandstone

PA Injection Well
Into Oriskany Sandstone

Base Figure Source: Geology.com
Mt. Simon Sandstone (and Equivalents) Drill Depth

Source: MRCSP
**Existing Injection Formations**

- Upper Devonian Sandstones
- Huntersville Chert
- Oriskany Sandstone
- Medina – Tuscarora Sandstones

**Depth to Precambrian Basement**

- Ranges from approx. 10,000 ft in NW PA to 20,000 ft+. In much of Marcellus Shale Play Area.

**Source:** Stratigraphic Column from PADNR

**Typical extent of faulting in Appalachian Plateau**

**Base of injection interval – D&L Disp. Well _ Youngstown, OH**
Geologic Cross-Section Across Southern PA

Figure 2-3. Generalized Geologic Cross Section
Schematic of Structural Style in Appalachian Plateau

Appalachian Plateau

Precambrian Basement

Devonian Rocks

Salina Salt

Laurel Hill Anticline

Allegheny Front
Why Significant Induced Seismicity is Unlikely in PA

- USGS indicates very low earthquake risk for most of state
- Injection into intervals well above Precambrian basement
- Structural style in Appalachian Plateau – typical fault not extending from injection interval (e.g., Oriskany) to basement
- Preference for injecting into depleted reservoirs which have lower pressures
- Relatively low injection rates (~500 to 2,000 bbls/d)
- USEPA permitted injection pressures below formation breakdown pressure
- No reported incidents to date from operating wells
Summary

• In general, potential for significant induced seismicity from brine disposal well development in PA is very low

• Regardless, site-specific geologic conditions should be carefully evaluated prior to well siting

• Adhering to Maximum Injection Pressure permit limits can help to minimize potential for induced seismicity