



A drill rig operating at a well location in Rocky Mountain House, Alberta, Canada.

SHELL ONSHORE OPERATING PRINCIPLES IN ACTION: INDUCED SEISMICITY FACT SHEET

Shales continue to play an important role in meeting global energy demand. Shell's¹ shales business uses advanced technologies, including hydraulic fracturing, to unlock these resources safely and responsibly.

Today, our shales operations are focused on six assets. We uphold five global principles, the Onshore Operating Principles, which govern the onshore shale (oil and gas) activities where we operate and where hydraulic fracturing is used. The principles cover safety, air quality, water protection and usage, land use and engagement with local communities. We review our Onshore Operating Principles annually and update them as new technologies, opportunities, challenges and regulatory requirements emerge. In 2016, we updated the Principles to include how we manage any potential induced seismic events from our produced water disposal well operations or hydraulic fracturing activities. We are transparent in our activities and actively engage with communities, regulators, industry participants and other stakeholders to bring about improvements in the sector.



Completions operations near Fox Creek, Alberta, Canada.

¹ Royal Dutch Shell plc and its various subsidiaries and affiliates (the "Shell Group") are separate legal entities. In this Fact Sheet the expression "Shell" is sometimes used for convenience where references are made to those entities individually or collectively. Likewise, the words "we", "us" and "our" are also used to refer to companies in the Shell Group in general or those who work for them, and these references do not reflect the operational or corporate structure of, or the relationship between, entities in the Shell Group. Nothing in this Fact Sheet is intended to suggest that any entity in the Shell Group, including Royal Dutch Shell plc, directs or is responsible for the day-to-day operations of any other entity in the Shell Group.

Induced Seismicity

Definition

Induced seismicity refers to earthquakes triggered by human activity.

Magnitude

Earthquakes, alternatively referred to as seismic events, take place when two blocks of the earth suddenly slip past one another. They occur across a vast range of sizes, commonly referred to as their magnitude (M). Seismic events of magnitude $M=1$ may cause weak movement at the surface. Potential for extreme ground motion from earthquakes usually begins at magnitudes of $M>6$. Generally, public concerns related to induced seismicity typically happen within the $2<M<5$ magnitude range as $M<2$ events are rarely felt and $M>5$ events are extremely rare.

Attribution

Induced seismicity has been attributed to a broad range of human activities, including underground injection, oil and gas extraction, impoundment of large reservoirs behind dams, geothermal projects, mining extraction, construction, and underground nuclear tests. Seismicity induced by high-pressure fluid injection has been documented since the 1960s. This fact sheet is focused on induced seismicity linked to hydraulic fracturing and oil and gas related produced water disposal wells (fluid injection) that is felt by people on the surface (or 'felt-level' seismicity). To further understand induced seismicity, a list of additional resources has been provided at the end of this fact sheet.



Shell staff review plans in Groundbirch, British Columbia, Canada.

Impact

Overall, the likelihood of felt-level induced seismicity due to hydraulic fracturing or produced water disposal well operations is relatively low and the impact geographically isolated. However, some areas are geologically predisposed to higher occurrence. To date, felt-level induced seismicity has not been attributed to Shell's onshore shale operations. In the industry, felt-level induced seismicity has been attributed to hydraulic fracturing in very few cases, none of which have resulted in any injuries, property damage or environmental impacts. Reports have linked seismicity associated with produced water disposal wells to property damage in some isolated areas.

SAFETY.

Shell designs, constructs and operates wells and facilities in a safe and responsible way.



Induced Seismicity

Shell Approach

Shell takes concerns around induced seismicity seriously and proactively manages the risk, beyond regulatory requirements. Shell has added induced seismicity to its Onshore Operating Principles and developed internal guidelines, which are applied to our shale assets. The guidelines outline a risk assessment process and provide a framework for risk management. Subsurface and surface conditions vary from basin to basin, which means that management practices need to reflect the risk profile of each basin and provide customized responses to the risks. Meanwhile, we comply with regulatory requirements and are supportive of state and provincial regulations that are fit for purpose and science based.



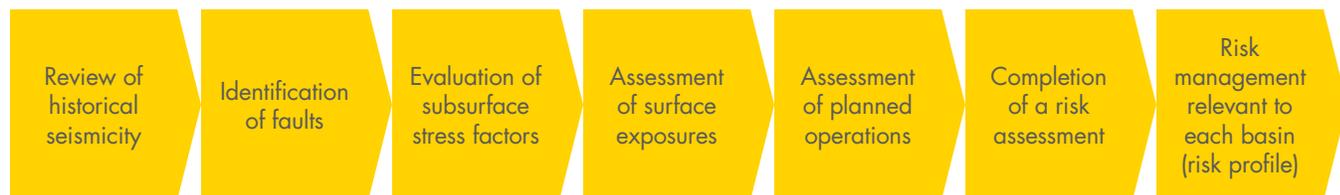
Shell's shale operations in Appalachia, Pennsylvania (USA).

Fast Facts: Difference between Hydraulic Fracturing and Produced Water Disposal in a well

- Hydraulic fracturing involves pumping a fluid that is typically 99% water and sand and around 1% chemical additives into shale formations at high pressure. This causes fissures – widths on the order of the diameter of a human hair – in the rock, creating space into which the hydrocarbons can flow more easily. Meanwhile, produced water disposal in a well involves injecting fluid resulting from oil and gas operations, including flow back water or brine collected from hydraulically fractured wells, into a permeable geologic formation below, and isolated from shallower potentially usable, groundwater aquifers. With respect to induced seismicity, hydraulic fracturing is different from produced water disposal in a well in many ways:
 - Hydraulic fracturing operations are intended to fracture the rock, whereas disposal operations are not intended to fracture the rock.
 - The pumping operation in hydraulic fracturing only lasts for a short period of time and the entire well stimulation typically lasts several days, whereas disposal well operations often last for years.
 - The total volumes injected during hydraulic fracturing are a fraction of what is typically injected during long-term disposal well operations, even when multi-well hydraulic fracturing operations are considered.
 - The fluids in a hydraulic fracturing are largely stored in the (created) fractures and some volume of the fracturing fluids are normally recovered soon after the treatment (during flow back and production), whereas during produced water disposal in a well, fluids are permanently stored in the porous and permeable formation.
 - During hydraulic fracturing, the initially increased pressure associated with the injection of hydraulic fracturing fluids is relieved by the subsequent flow back. Therefore, hydraulic fracturing operations followed by production operations generally result in the eventual lowering of reservoir pressure thereby lowering the likelihood of seismicity.

Induced Seismicity

Shell's Risk Assessment and Management Process



Assessment

Shell assesses the seismicity risk around its hydraulic fracturing and produced water disposal well operations, taking subsurface and surface conditions and planned operations into consideration. The results of our assessments are documented, reviewed and updated regularly.

- Before we start drilling exploration or production wells in a new basin, we conduct a hazard assessment, covering Health, Safety, Security and the Environment (HSSE). We gather and evaluate existing and publicly available geologic and geophysical data to determine historical seismicity. We also identify nearby critical infrastructure as appropriate.
- Before we drill a produced water disposal well, we also conduct a hazard assessment similar to what we do with our exploration and production wells.

Most shale oil and gas resources are not located in naturally seismically active areas. In areas with elevated risk for induced seismicity, we put monitoring, mitigation and response plans in place to manage the risk. Throughout the lifecycle of a project, we continue to gather and evaluate existing and publicly available geologic and geophysical data.

Design and Operations

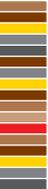
We design and operate our wells based on our understanding of the local surface and subsurface conditions where we operate.

- For exploration and production wells, we follow our Design and Engineering Principles (DEPs). We map geologic faults across our operating areas. We have well design and completion practises in place, which can be deployed to mitigate and respond to induced seismicity. Our third party contractors have an obligation to comply with Shell's drilling and completion standards.

- For produced water disposal wells, we employ a risk-based approach to evaluating and mitigating the induced seismicity risk. We utilize a planning and development tool to assess existing and planned new wells to evaluate and mitigate injection risks that could potentially contribute to induced seismicity. Our underground produced water disposal wells are designed and operated in accordance with local regulatory requirements. While government regulators review our third party contractor wells and issue necessary permits, we also conduct our own risk assessments and risk-based monitoring of our third-party produced water disposal wells.



A contractor monitors drilling operations in Canada.



Induced Seismicity

Monitoring and Mitigation

Where our risk assessment indicates elevated potential for induced seismicity, we put in place monitoring, mitigation and response plans. Each asset has their own plans, which have some key elements but different detailed procedures based on the risk profile of the basin, as well as applicable state and provincial regulatory requirements. These plans may include:

- evaluation of wellbore placement to account for geologic conditions;
- establishment of procedures and preparedness for the possibility of induced seismicity;
- establishment of procedures to monitor for induced seismicity;
- establishment of procedures to mitigate and respond to induced seismicity; and
- communication of these procedures to onsite personnel.

We employ monitoring tools and/or other measurement techniques in line with the risk profile of the basin and as required by regulations. In areas without any regulatory requirements, we either install our own temporary monitoring stations or, where available, participate in consortiums dedicated to monitoring.

For example, in our Rocky Mountain House asset in Alberta (Canada), we have installed our own monitoring arrays near our operations to establish a baseline understanding of any potential for seismicity in the area. Meanwhile, in our Permian asset in West Texas (USA), we monitor seismic activity in real-time via United States Geological Survey (USGS) Earthquake Notification System (ENS).

Response

If we detect seismic activity beyond our seismicity thresholds or regulatory threshold, we will implement our response protocols, investigate and review our operations. Each asset has their own seismicity thresholds and response protocols based on the risk profile of the area and basin, as well as state and provincial regulatory requirements.

For example, we have established real-time, 24-7 seismic monitoring in our Duvernay asset, near Fox Creek, in Alberta (Canada). If seismic events of $M > 2$ are detected

in our completions operations, we employ a range of mitigation tools to reduce any further seismicity. This includes, but is not limited to: reduction of injection pressure, fluid volume and/or pump rate, skipping completions stages, delaying of further pumping until seismicity subsides, redesigning the fracturing program to allow pumping at lower rates and volumes and/or flowing back the well to relieve the pressure.

Collaboration

Shell is collaborating with the oil and gas industry, regulators, academia and subject matter experts to advance the understanding of the complex geologic and geomechanical factors that control the occurrence and severity of induced seismicity due to oil and gas operations. Shell is an active sponsor of the Stanford Centre for Induced and Triggered Seismicity (SCITS) and the University of Texas Bureau of Economic Geology the Center for Induced Seismicity Research (CISR). Shell actively participates in several industry working groups, organized by the American Petroleum Institute (API), the Canadian Association of Petroleum Producers (CAPP) and the Texas Oil and Gas Association (TXOGA) to advance industry collaboration and knowledge sharing.

Induced Seismicity

Additional Resources

- Shell Global/Shell's principles for producing tight/shale oil and gas:
<https://www.shell.com/energy-and-innovation/natural-gas/tight-and-shale-gas/shells-principles-for-producing-tight-shale-oil-and-gas.html>
- Stanford Center for Induced and Triggered Seismicity (SCITS):
<https://scits.stanford.edu/>
- University of Texas Center for Integrated Seismicity Research:
<http://www.beg.utexas.edu/cisr>
- Microseismic Industry Consortium:
<http://www.microseismic-research.ca/>
- TexNet Seismic Monitoring Program:
<http://www.beg.utexas.edu/texnet>
- API: Hydraulic Fracturing:
<https://www.api.org/oil-and-natural-gas/wells-to-consumer/exploration-and-production/hydraulic-fracturing>
- API: Understanding Seismicity Associated with Saltwater Disposal Wells:
<https://www.api.org/oil-and-natural-gas/wells-to-consumer/exploration-and-production/hydraulic-fracturing/understanding-seismicity-saltwater>
- Ground Water Protection Council (GWPC) and Interstate Oil and Gas Compact Commission (IOGCC): StatesFirst Initiative – Induced Seismicity Primer:
<http://www.gwpc.org/states-first-initiative-releases-second-edition-induced-seismicity-primer>
- Rational Middle/Realities of Drilling: Extended and Recut:
<http://rationalmiddle.com/energy/movie/realities-of-drilling-extended-and-recut/>
- Canadian Association of Petroleum Producers:
<https://www.capp.ca/publications-and-statistics/publications/217532>
- British Columbia Oil and Gas Commission:
<https://www.bcogc.ca/public-zone/seismicity/induced-seismicity>
- Alberta Energy Regulator:
<https://www.aer.ca/providing-information/by-topic/seismic-activity>