08/07/20 Understanding earthquakes caused by hydraulic fracturing
"It has been well known for decades that any injection of fluids in the subsurface has the potential to induce earthquakes. That said, hydraulic fracturing has only been recognized as a source of induced earthquakes very recently.
"In the simplest conceptual model, fluids injected in a subsurface well must be connected to a fault via some permeable pathway. This allows the fluid pressure inside of the fault to increase during stimulation, hydraulically opening the fault. While hydraulically opened, the reduced 'clamping' force on a fault makes it more likely to slip."
https://eos.org/editors-vox/understanding-earthquakes-caused-by-hydraulic-fracturing
Schultz, R. (2020), Understanding earthquakes caused by hydraulic fracturing, *Eos, 101,* https://doi.org/10.1029/2020EO147870. Published on 07 August 2020.

USGS: Does the production of oil and gas from shales cause earthquakes? If so, how are the earthquakes related to these operations?
"**To produce oil and gas from shale formations, it is necessary to increase the interconnectedness of the pore space (permeability) of the shale so that the gas can flow through the rock mass and be extracted through production wells. This is usually done by hydraulic fracturing ("fracking"). Fracking intentionally causes small earthquakes (magnitudes smaller than 1) to enhance permeability, but it has also been linked to larger earthquakes**. The largest earthquake known to be induced by hydraulic fracturing in the United States was a M4 earthquake in Texas."
https://www.usgs.gov/faqs/does-production-oil-and-gas-shales-cause-earthquakes-if-so-how-are-earthquakes-related-these?qt-news_science_products=0#qt-news_science_products

7/22/20 Fracking Factors In OK Quake Likelihood
"In one rock layer examined in the BSSA study, the likelihood that **hydraulic fracturing triggered seismic activity increased from 5 to 50 percent as well operations moved from 1.5 to 5.5 kilometers (0.9 to 3.4 miles) deep, the researchers found**.
"Although the exact mechanisms linking well depth and seismic probability are still being examined, Michael Brudzinski and colleagues suggest the overpressure of fluids trapped inside the rock may be important.
"'The deeper the rock layers are, the more rock that is sitting on top of a well, and that is going to potentially increase the fluid pressures at depth,' said Brudzinski, the study's corresponding author from Miami University in Ohio.
"Oklahoma has been at the center of a dramatic increase in earthquake activity over the past decade, mostly caused by oil and gas companies injecting wastewater produced by drilling back into deeper rock layers. However, a **2018 study identified places in the state where significant amounts of seismic activity were linked to nearly 300 hydraulic fracture wells**.
"'It could be that **volume does still matter, but more so in a cumulative way** than for any given well," he added. "An isolated well with a large volume may not have nearly as much of a [seismic] risk as a large volume well that is in close proximity to other large volume wells.'"
Industrial Safety and Security Source research
https://isssource.com/fracking-factors-in-quake-likelihood-in-ok/

07/27/19 Encana stops hydraulic fracturing on Kingfisher County well after earthquakes Thursday
"According to Oklahoma Geological Survey records, recent stronger earthquakes have affected two areas in Kingfisher County — the area near the Newfield/Encana well west of Kingfisher,

and another about four miles north-northeast of Loyal. **Both appeared to be associated with well completion work."**
https://oklahoman.com/article/5637126/encana-stops-hydraulic-fracturing-on-kingfisher-county-well-after-earthquakes-thursday

2019, Liberty Oilfield Services CEO at North Metro Chamber of Commerce energy breakfast said "We cause earthquakes." Cites Oklahoma
https://youtu.be/mby1XI8s6T4

05/05/19 Damaging Sichuan earthquakes linked to fracking operations
"**Both wastewater disposal and fracking have induced earthquakes** in the south Sichuan basin, say Xinglin Lei of the Geological Survey of Japan and colleagues. In their new study in SRL, the researchers present '**a full chain of evidence' to show that the December and January earthquakes were induced by fracking operations**."
https://m.phys.org/news/2019-04-sichuan-earthquakes-linked-fracking.html
httpsL//m.phys.org/new/2019-04-sichuan-earthquakes-linked-fracking.html

05/02/19 Computer model suggests earthquakes are triggered well beyond fluid injection zones
"Using data from field experiments and modeling of ground faults, researchers at Tufts University have discovered that the practice of subsurface fluid **injection used in 'fracking' and wastewater disposal for oil and gas exploration could cause significant, rapidly spreading earthquake activity** beyond the fluid diffusion zone. Deep fluid injections—greater than one kilometer deep—are known to be associated with enhanced seismic activity—often thought to be limited to the areas of fluid diffusion. Yet the study, published today in the journal *Science*, tests and strongly supports the hypothesis that fluid injections are causing potentially damaging earthquakes further afield by the slow slip of pre-existing fault fracture networks, in domino-like fashion.
"According to the U.S. Geological Survey, the largest earthquake induced by fluid injection and documented in the scientific literature was a magnitude 5.8 earthquake in September 2016 in central Oklahoma. Four other earthquakes greater than 5.0 have occurred in Oklahoma as a result of fluid injection, and earthquakes of magnitude between 4.5 and 5.0 have been induced by fluid injection in Arkansas, Colorado, Kansas and Texas."
https://m.phys.org/news/2019-05-earthquakes-triggered-fluid-zones.html

04/26/19 New research **links fracking to earthquakes** in central, eastern U.S.
In states like Ohio, Pennsylvania and West Virginia, hydraulic fracturing wells are more common than wastewater injections.
https://www.upi.com/Science_News/2019/04/26/New-research-links-fracking-to-earthquakes-in-central-eastern-US/66611556294511

04/25/19, Studies link earthquakes to fracking in Central and East United States
Small earthquakes in Ohio, Pennsylvania, West Virginia, Oklahoma and Texas **can be linked to hydraulic fracturing wells** in those regions, according to researchers speaking at the SSA (Seismological Society of America) 2019 Annual Meeting.
While relatively rare compared to earthquakes caused by wastewater disposal in oil and gas

fields in the central United States, Michael Brudzinski of Miami University in Ohio and his colleagues have identified more than 600 small earthquakes (between magnitude 2.0 and 3.8) in these states.
https://www.seismosoc.org/news/studies-link-earthquakes-to-fracking-in-the-central-and-eastern-united-states/

10/11/18 Induced Seismicity in Western Canada Linked to Tectonic Strain Rate: Implications for Regional Seismic Hazard
'Our results imply that the regional seismic hazard may rise in the short term due to the sharp increase of IIE [Injection-Induced Earthquake, includes hydraulic fracturing, wastewater disposal and enhanced recovery of hydrocarbons]. A likely scenario is that local faults may already be close to failure after a **long period of strain accumulation**. In this case, injections may increase the volume affected by high pore pressure that, in turn, **raises the probability of triggering a fault already loaded with high tectonic strain** (Shapiro et al., 2013) … "
Honn Kao Roy Hyndman Yan Jiang Ryan Visser Brindley Smith Alireza Babaie Mahani Lucinda Leonard Hadi Ghofrani
Jiangheng He First published: 11 October 2018
https://doi.org/10.1029/2018GL079288

12/31/18 Oil and Gas Commission Confirms Fracking Caused Earthquakes Felt by Hundreds
Fort St. John tremors measured magnitude 3, 4 and 4.5, rattling residents.
"Gail Atkinson, one of Canada's top seismic hazard experts, told The Tyee that if the magnitude 4.5 earthquake had occurred in a densely populated area it would have caused property damage."
"In 2017 fracking operations in Sichuan, China, did just that by triggering a similar sized tremor. "**Industry operations induced a magnitude 4.7 earthquake that damaged or destroyed nearly 600 homes**.
"According to a 2017 study published in the science journal *Nature*, China's fracking industry has triggered four magnitude 4.0 quakes or greater in addition to 2,400 smaller scale tremors in the Sichuan Basin, the country's richest natural gas deposit.
"Since 2014, B.C.'s fracking industry has triggered thousands of quakes, including 43 greater than a magnitude of 3.0 and three greater than magnitude of 4.0, according to an Oil and Gas Commission presentation at a Banff scientific conference last October.
"**Hydraulic fracturing and wastewater disposal** in the Montney basin, which will supply B.C.'s proposed liquefied natural industry, **caused the majority of the events**."
https://thetyee.ca/News/2018/12/31/Oil-Gas-Commission-Confirms-Earthquakes/

04/04/18 Colorado seeing earthquakes where they've never happened before.
https://kdvr.com/2018/04/04/colorado-seeing-earthquakes-where-theyve-never-happened-before/amp/

11/18/16 Earthquakes **triggered by fracking, not just wastewater disposal**, study finds
"Hydraulic fracturing drives earthquakes in western Canada, according to research published Thursday in Science. **The results defy the often-touted belief that the disposal of wastewater is the sole source of man-made earthquakes** with fossil fuel extraction

technique."
https://www.pbs.org/newshour/amp/science/earthquakes-triggered-by-fracking

12/15, Insurance Regulators Discuss Earthquake Issues and Challenges
There has been a great deal of scientific research aimed at finding the causation for the large increase in seismic activity over the past several years in the central and eastern U.S. Prior to 2009, the central and eastern U.S. averaged only about 20 earthquakes with a magnitude of 3 (the point at which an earthquake can be felt) or greater per year. For the 2010–2013 periods, this number jumped to an average of more than 100 earthquakes with a magnitude of three or greater.1 The USGS has linked the increase in earthquake activity in these regions to waste water disposal from hydraulic fracturing operations. In a study released in April, the USGS identified 17 areas within eight states in the central and eastern U.S. with increased rates of induced seismic activity. These eight states are: Alabama, Arkansas, Colorado, Kansas, New Mexico, Ohio, Oklahoma and Texas, with Oklahoma showing the sharpest increase in induced seismic activity.
Anne Oberstaedt, Researcher, NAIC Center for Insurance Policy and Research, December 2015
https://www.naic.org/cipr_newsletter_archive/vol17_earthquake.pdf

04/23/15 USGS links wastewater, fracking to rise of earthquakes across the country
By CPR News Staff and The Associated Press
Government scientists say more than a dozen regions in the United States, **including some in Colorado,** have experienced a rise in man-made earthquakes in recent years.
A report released Thursday by the U.S. Geological Survey found that 17 areas in eight states have seen small quakes triggered by oil and gas drilling. They include parts of Alabama, Arkansas, Colorado, Kansas, New Mexico, Ohio, Oklahoma and Texas.
In Colorado, affected areas are the northern Front Range, Western Slope and south of Pueblo. **The earliest incidents in the state date back to the 1960s at Rocky Mountain** Arsenal and as recently as last year in Greeley.
The scientists say most of the shaking is caused by the oil and gas industry injecting wastewater deep underground, which can activate dormant faults. **A few cases stemmed from hydraulic fracturing, or fracking, when water, sand and chemicals are pumped into the ground to free oil and gas**.
https://www.cpr.org/2015/04/23/usgs-links-wastewater-fracking-to-rise-of-earthquakes-across-the-country/#:~:text=USGS%20links%20wastewater%2C%20fracking%20to%20rise%20of%20earthquakes%20across%20the%20country,-By%20CPR%20News&text=A%20report%20released%20Thursday%20by,by%20oil%20and%20gas%20drilling.

Colorado Division of Homeland Security and Emergency Management
"Although many of Colorado's earthquakes occurred in mountainous regions of the state, some have been located in the western valley and plateau region or east of the mountains. The most economically damaging earthquake in Colorado's history occurred on August 9, 1967 in the northeast Denver metropolitan area. **This magnitude 5.3 earthquake, which was centered near Commerce City, caused more than a million dollars damage in Denver and the northern suburbs.**

"This earthquake is believed to have been induced by the deep injection of liquid waste into a borehole at Rocky Mountain Arsenal. It was followed by an earthquake of magnitude 5.2 three months later in November 1967. Although these events cannot be classified as major earthquakes, they should not be discounted as insignificant. They occurred within Colorado's Front Range Urban Corridor, an area where nearly 75% of Colorado residents and many critical facilities are located. Since March 1971, well after the initial flurry of seismic activity, 15 earthquakes of approximate magnitude 2½ or larger have occurred in the vicinity of the northern Denver suburbs."
Summary & Conclusions: Earthquake Subcommittee, Colorado Natural Hazards Mitigation Council
http://www.coemergency.com/2010/01/colorado-earthquake-information.html

The Great Colorado Shake Out 2021
Earthquake Hazards
Most people are surprised to learn that natural earthquakes occur in Colorado!
They are even more surprised to learn that we experienced a magnitude 6.6 earthquake in 1882.
Colorado is most famous in the earthquake literature for the swarm of earthquakes during the 1960s that were triggered by pumping waste fluids down a well at the Rocky Mountain Arsenal.
All of this contributes to a false sense of security concerning the possibility of a damaging earthquake(s) occurring in Colorado.
The Denver [Commerce City] Earthquakes
The most economically damaging earthquake in Colorado's history occurred on August 9, 1967 in the northeast Denver metropolitan area. **This magnitude 5.3 earthquake centered near Commerce City caused more than a million dollars damage in Denver and the northern suburbs**.
This earthquake is believed to have been triggered by the deep injection of liquid waste into a borehole at the Rocky Mountain Arsenal. It was followed by an earthquake of magnitude 5.2 three months later in November 1967.
Although these events cannot be classified as major earthquakes, they should not be discounted as insignificant. They occurred within Colorado's Front Range Urban Corridor, an area where nearly 75% of Colorado residents and many critical facilities are located. Since March 1971, well after the initial injection of fluids ceased, 15 earthquakes of approximate magnitude 2½ or larger have occurred in the vicinity of the northern Denver suburbs. **At least two published articles propose that a magnitude 6.0 earthquake is possible on the fault that passes under the Arsenal**. **Such an earthquake would cause more than $10 billion dollars damage. This would be Colorado's Katrina - the event that we know is possible, but are not necessarily prepared for.**
https://www.shakeout.org/colorado/whyparticipate/

USGS 2017 Colorado Hazard Map (includes hazard from induced seismicity)
https://prd-wret.s3-us-west-2.amazonaws.com/assets/palladium/production/atoms/files/ColoradoMap1.pdf

Colorado Fault Lines
https://my.usgs.gov/eerma/data/index/4f4e496be4b07f02db5a0f59

03/28/16 Colorado Ranks High In USGS Forecast Of Damaging Quakes
By CPR News Staff and The Associated Press
Colorado faces the fourth-highest danger of man-made earthquakes in the country this year, according to a new map from the U.S. Geological Survey.
The USGS says uptick is a byproduct of drilling for oil and gas. The federal agency says earthquakes near Greeley and Trinidad have been linked to oil and gas activity, caused by injecting wastewater deep underground.
https://www.cpr.org/2016/03/28/colorado-ranks-high-in-usgs-forecast-of-damaging-quakes/#:~:text=Colorado%20faces%20the%20fourth%2Dhighest,drilling%20for%20oil%20and%20gas.

05/04/15 As worries grow over man-made quakes, 50-year-old Colorado temblors reverberate
By Grace Hood, CPR
But the U.S. Geological Survey is closely watching seismically active areas across the U.S., including the Arsenal site. For this first time in its history, the agency **is mapping** the hazards associated with man-made earthquakes in 17 zones -- five of which are in Colorado [Rocky Mountain Arsenal, Raton, Greeley, Paradox and Rangeley].
https://www.cpr.org/2015/05/04/as-worries-grow-over-man-made-quakes-50-year-old-colorado-temblors-reverberate/

1981, Earthquake Potential in Colorado: A Preliminary Evaluation
"Colorado has long been considered an area of low seismicity with only a minor potential for future earthquakes. Recent geological and geophysical investigation, however, have discovered **several active faults that are capable of generating future damaging earthquakes and number other faults that are suspected of being potentially active. These investigations suggest Colorado is a moderately active earthquake area and in time larger earthquakes than yet have been experienced can occur.**"
Kirkham, Robert M. and William P. Rogers, "Bulletin 43 – Earthquake Potential in Colorado: A Preliminary Evaluation." Earthquake Bulletin, Denver, CO: Colorado Geological Survey, Department of Natural Resources, 1981
https://coloradogeologicalsurvey.org/publications/earthquake-potential-colorado/

09/27/68 The Denver [Commerce City] Earthquakes: Disposal of waste fluids by injection into deep well has triggered earthquakes near Denver, Colorado
"The implication of the pore pressure mechanism – that the rocks were stressed to their near breaking strength before the injection of fluid – is in accordance with the available data.
"Prior to 1967, the frequency of occurrence of earthquakes of different magnitudes in the Denver area was such that the likelihood of a really destructive earthquake could reasonably considered remote. In the view of the 1967 earthquakes, however, there is no longer any assurance that a destructive earthquake will not occur."
https://earthquake.usgs.gov/static/lfs/research/induced/Healy-et-al-1968-Science-(New-York-NY).pdf

01/01/66 Denver area earthquakes and the Rocky Mountain Arsenal disposal well
"Since the start of fluid injection, **710 Denver-area earthquakes have been recorded.** The majority of these earthquakes had epicenters within a 5-mile radius of the Arsenal well. The

volume of fluid and pressure of fluid injection appear to be directly related to the frequency of earthquakes. Evidence also suggests that rock movement is due to the increase of fluid pressure within the fractured reservoir and that open fractures may exist at depths greater than previously considered possible. (19 refs.)"
https://www.osti.gov/biblio/6805542

1966, The Denver Area Earthquakes and the Rocky Mountain Arsenal Disposal Well
Reprinted 2005 Rocky Mountain Association of Geologists [Evidence of quake activity as injection stops and starts at Rocky Mountain Arsenal]:
DAVID M. EVANS: Consulting Geologist. Denver. Colorado, Rocky Mountain Association of Geologists, The Denver Area Earthquakes and the Rocky Mountain Arsenal Disposal Well
https://scits.stanford.edu/sites/default/files/evans_0.pdf

4/16/19 Rocky Mountain Arsenal continues to leak contaminants into groundwater, Colorado health department lawsuit says; Contaminants include organochlorine pesticides, heavy metals and solvents
The Colorado Department of Public Health and Environment has sued the U.S. Army claiming that dangerous chemicals including pesticides continue to leach into groundwater at Rocky Mountain Arsenal.
The Colorado department's Hazardous Materials and Waste Management Division filed the lawsuit Monday in U.S. District Court in Denver to force the Army to comply with standards set by the federal Comprehensive Environmental Response, Compensation and Liability Act (CERCLA).
https://www.denverpost.com/2019/04/16/rocky-mountain-arsenal-chemicals-groundwater-lawsuit/

2017 6.4 Rocky Mountain Arsenal, Colorado
ITRC (Interstate Technology & Regulatory Council). 2017. *Remediation Management of Complex Sites*. RMCS-1. Washington, D.C.: Interstate Technology & Regulatory Council, Remediation Management of Complex Sites Team.
https://rmcs-1.itrcweb.org/6-4-rocky-mountain-arsenal-colorado/

6/11/1996 EPA Superfund Record of Decision: Rocky Mountain Arsenal (US Army), On-Post Site Operable Unit, Adams County, CO
https://nepis.epa.gov/Exe/ZyNET.exe/10004ZM3.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1995+Thru+1999&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C95thru99%5CTxt%5C00000005%5C10004ZM3.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL

11/30/61 FINAL REPORT ON DRILLING OF PRESSURE INJECTION DISPOSAL WELL ROCKY MOUNTAIN ARSENAL DENVER, COLOR ADO
"Disposal of waste fluids from chemical plants at the Rocky Mountain Arsenal was first recognized as a problem of major consequence when it was found that unsealed evaporation pits permitted leakage into shallow aquifers, contaminating an important water supply near the

surface. In order to meet this emergency the Chemical Corps of the U. S. Army sealed a large earthen pond, designated as Pond F (See Figure I for location) 3 and commenced accumulating waste effluent into it. The rate at which the waste material accumulated exceeded the rate of evaporation to the extent that the capacity of Pond F was expected to be reached in late 1961. Alternative methods for handling these waste fluids on a more permanent basis in the future were considered by the Chemical Corps, and it was decided to drill a deep pressure injection disposal well near Pond F. The design and drilling of this well were assigned to the U. S. Army Corps of Engineers, Omaha District."
E. A. Polumbus, Jr., and Associates, Inc. L C) r Design and Management Engineers - S, - - Denver, Colorado - November 30, 1961
https://apps.dtic.mil./dtic/tr/fulltext/u2/667358.pdf

Brighton Public Water System Order, Colorado Oil and Gas Commission
Rules for oil and gas drilling within Brighton Public Water System
https://cogcc.state.co.us/orders/orders/1/189.html

12/14/20 Compendium of Scientific, Medical, and Media Findings Demonstrating Risks and Harms of Fracking (Unconventional Gas and Oil Extraction), Seventh Edition
Public health harms now linked with drilling, fracking, and associated infrastructure include cancers, asthma, respiratory distress, rashes, heart problems, and mental health problems. Multiple studies of pregnant women living near fracking operations across the nation show impairments to infant health, including birth defects, preterm birth, and low birth weight. North American fracking operations are driving the current surge in global levels of methane, a greenhouse gas 86 times more potent at trapping heat than carbon dioxide over a twenty-year period. Methane escapes into the atmosphere from all parts of the extraction, processing, and distribution system, at significant rates that exceed earlier estimates by a factor of two to three. In sum, the vast body of scientific studies now published on hydraulic fracturing in the peer-reviewed scientific literature confirms that the climate and public health risks from fracking are real and the range of environmental harms wide. **Our examination uncovered no evidence that fracking can be practiced in a manner that does not threaten human health directly and without imperiling climate stability upon which public health depends. The rapidly expanding body of evidence compiled here is massive, troubling, and cries out for decisive action. Across a wide range of parameters, the data continue to reveal a plethora of recurring problems that cannot be sufficiently averted through regulatory frameworks. The risks and harms of fracking are inherent to its operation.** The only method of mitigating its grave threats to public health and the climate is a complete and comprehensive ban on fracking. Indeed, a fracking phase-out is a requirement of any meaningful plan to prevent catastrophic climate change.
Compilation of Studies and Findings p29: Air pollution p60; Water contamination p86; Inherent engineering problems that worsen with time p142; Radioactive releases p149; Occupational health and safety hazards p162; Noise pollution; Public health effects, measured directly p187 light pollution, and stress p216; Earthquakes and seismic activity p 226; Abandoned and active wells as pathways for gas and fluid migration p257; Flood risks p276; Threats to agriculture, soil quality, and forest p284; Threats to the climate system p298; Threats from fracking infrastructure p339: Sand mining and processing p339, Pipelines and compressor stations p347, Gas storage p373, Liquefied natural gas (LNG(facilities p392, Gas-fired power plants p404; Inaccurate jobs claims, increased crime rates, threates to property values and mrtgages and local government burden p412; Inflated estimates of oil and gas reserves and profitability p440; Disclosure of serious risks to investors p451; Medical and scientific calls for

more study, reviews confirming evidence for hamr, and calls for increased transparency and science-based policy p454
https://secureservercdn.net/166.62.112.150/ejr.4eb.myftpupload.com/wp-content/uploads/2021/02/CHPNY-PSR-Fracking-Science-Compendium-7_20210219.pdf
Concerned Health Professionals of New York and Physicians for Social Responsibility
https://concernedhealthny.org/compendium/