Comments to Interim Final Rules (IFR) for interstate and intrastate gas storage fields: Inclusion of the earthquake fault displacement hazard and risk management into IFR.

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Recommendations: The IFR needs to specifically recognize and develop guidelines and regulations that address the earthquake fault displacement hazard to gas wells and storage fields in the seismically prone areas of the United States. This addition will further the safe operation of natural gas storage wells and fields. The Pipeline and Hazardous Material Safety Administration's (PHMSA) present plan to adopt the American Petroleum Institute's (API) Recommended Practice 1171 (RP 1171), in its present form, will not provide recognition for such an addition. RP 1171's guidelines are insufficient with regard to seismic hazards, their impacts and risk assessments, and their mitigation and emergency protocols. Gas field operators in seismically prone areas should be compelled to provide risk management plans that include a thorough safety review of the fault displacement hazard and other seismic hazards given their significant potential impacts. Additionally, the IFR should require the states to follow specific guidelines for managing these significant hazards, and require a stringent and transparent review process for the submitted safety reviews of gas storage wells and fields. As with many technical regulations the operator's response, thoroughness, and implementation of safety requirements are nearly as important as the regulations. Cursory, incomplete, and speculative safety plans should not be acceptable. For instance, the State of California and the public will need to judge whether the Southern California Gas Company's (SCGC) recently submitted Storage Risk Management Plan #2 (SRMP #2, 2016) for reopening the Aliso Canyon Gas Storage Field (ACGSF) is sufficient with regard to the fault displacement hazard posed by the Santa Susana fault (GMF, 2017). Similarly PHMSA will need to decide whether SCGC's SRMP #2 provides an acceptable blueprint for other operators to follow for future risk management plans in the seismically prone areas of the United State.

Background: In December 2016 the Pipeline and Hazardous Material Safety Administration (PHMSA) published the Interim Final Rules (IFR) for interstate and intrastate gas storage fields nationwide. The IFR is required by the US PIPES Act, passed in June 2016, in response to the 2015-16 ACGSF leak. The IFR largely follows and makes mandatory, nationwide, the recommendations in the American Petroleum Institute's (API) Recommended Practice 1171 (RP 1171). RP 1171 provides an extensive set of recommendations, guidelines, and protocols for the design, operation, maintenance, hazard and risk assessments, mitigation, and emergency procedures for natural gas wells and storage fields. However, RP 1171 provides only cursory mention of the earthquake fault displacement hazard to natural gas wells and storage fields. Of specific concern to the ACGSF is the Santa Susana fault (SSF) that is intersected by all the storage wells. It should be noted that the ACGSF leak is probably the result of casing corrosion pending on-going investigations and probably not due to movement on the SSF as no other wells crossing the SSF leaked, and there was no nearby earthquake at the initiation of the leak. However, the ACGSF leak demonstrated the serious impacts of a lengthy, uncontrolled gas flow from just one high pressure well adjacent to a large urban area (Harris and Walker, 2016) and the necessity to understand all threats to gas well integrity.

The earthquake fault displacement hazard: Wells at gas storage fields that cross active or potentially active earthquake faults in the subsurface are a specific hazard to well integrity. Sudden fault displacement of 0.3 meters or more across wells will likely cause leaks in the well casings and tubings. Earthquake fault movements of up to 0.25 meters severely damaged numerous oil wells in the subsurface at the Wilmington oil field (Frame, 1952). These shallow earthquakes were in response to oil field subsidence and the earthquakes much smaller than the moderate to large tectonic earthquakes common to southern California that generate much larger fault displacements. The damaged wells were oil wells producing from a low pressure reservoir. In contrast, gas storage fields are under much higher pressures that make leakage to the surface more likely and leakage control more difficult. Natural gas (methane) migrates upward and leakage from a damaged well has the potential of reaching the earth's surface and atmosphere along the exterior of well casings (as occurred during the ACGSF leak), and along established geologic migration pathways such as fault zones and vertical fracture sets. This hazard is especially severe where thrust or normal faults, which dip at a low angle into the subsurface, are intersected by several or more gas wells. Where storage fields are developed across such low angle faults it can be argued that the earthquake fault displacement hazard is a much more significant risk than chronic infrastructure issues such as casing corrosion, especially when the field is adjacent to an urban area. In such a geologic setting fault movement across wells has the potential to simultaneously disrupt the well integrity of numerous wells in a very short period of time. As impact increases so does risk (API, 2015), and while the yearly probability of damaging fault movement is low, the risk is very significant, especially near urbanized areas. Control and mitigation of the impacts would be costly, perhaps impossible, and place an enormous legal and financial burden on the operators. Many of the operators are public utilities and it is possible that the rate payers and tax payers (the public) could end up with these burdens.

RP 1171 and the earthquake fault displacement hazard: PHMSA proposes that RP 1171 be federally mandated for the safer operation of the nation's natural gas storage wells and fields. RP 1171 declares "Depleted hydrocarbon reservoirs are candidates for natural gas storage because the reservoir integrity has been demonstrated over geologic time by hydrocarbon containment at initial pressure conditions." This statement is true except that gas wells have not existed over geologic time. While the intention of the API was to provide general guidance nationwide it is a matter of debate whether RP 1171 sufficiently deals with the earthquake faulting hazard in the seismically prone areas of the US. In the 60-page RP 1171 faulting is mentioned only once, earth movements twice, and active faults never. Contrast this with the United States Nuclear Regulatory Commission's entire publication devoted to earthquake hazards: Seismic and Geologic Siting Criteria for Nuclear Power Plants (NRC). Furthermore, RP 1171's mention of faulting is in regard to compromising reservoir integrity and not the threat posed to wells crossing earthquake faults. RP 1171 provides no discussion and guidance on identification, evaluations, risk assessments, preventive and mitigation programs, or emergency preparedness and response with regard to the earthquake fault displacement hazard to gas storage wells and fields. RP 1171 is insufficient with regard to this significant hazard and its risk.

PHMSA's existing regulations on earthquake faults: Presently PHMSA has regulations and guidelines for gas pipelines crossing potentially active faults at the earth's surface (PHMSA, 2011), but not in the subsurface. This is an odd and dangerous oversight as in general subsurface leaks in gas wells are more difficult to control than leaks in gas pipelines as underscored by the lengthy and costly effort to control the ACGSF leak. There has been some recent progress to close this regulatory gap at the state level. The 2016 Discussion Draft from the California Division of Oil and Gas and Geothermal Resources (DOGGR) requires gas storage field operators to evaluate and mitigate subsurface threats like the SSF (DOGGR, 2016). In addition to the required assessment and mitigation of the SSF hazard at the ACGSF, other gas storage fields in California will require an earthquake fault evaluation. However, the fault threat to storage fields outside of California remains an unappreciated and unstudied national earthquake hazard, and to date the various natural gas storage fields in California remain largely unevaluated for seismic hazards and risks.

The Aliso Canyon Gas Storage Field (ACGSF) and Santa Susana Fault (SSF) example: The ACGSF and the SSF present a case study of the earthquake fault displacement hazard to gas wells and storage fields. The SSF's existence and location within the ACGSF and the prior oil field have been known to geologists since the late 1930s, but prior to the massive methane leak at ACGSF, this hazard and its risk to the storage field have received minimal attention. Consequently, such a low occurrence but very high impact event is poorly appreciated by the communities adjacent to the storage fields, field operators, gas industry organizations, and likewise by state and federal policymakers. There is no public record that the SCGC, over the four decades of its operation at the ACGSF recognized and addressed the hazard and risk posed by the SSF. There is no public record that the state regulators of gas wells and storage fields (DOGGR and the California Public Utilities Commission) recognized this hazard and risk. Similarly, there is no public record that United States Geologic Survey's National Earthquake Hazard Reduction Program (NEHRP) or any other federal agency with the national responsibility for earthquake hazards identification, reduction, and risk analyses recognized the earthquake fault threat to the ACGSF, or at any other gas storage fields located across earthquake faults. Brief recognition of the hazard appears in the Department of Energy's follow-up publication on the ACGSF leak (DOE, 2016, pg. 61) but this document fails to mention the large amount of published research on the earthquake potential and hazard posed by the SSF. Relying heavily on this prior research the Geologic Maps Foundation, Inc. provides the only independent and readily available discussion of this hazard (Davis, 2016 a, b, & c).

Is it possible that an earthquake and movement on the SSF could simultaneously damage numerous wells to produce a massive leak? At this point no one has an answer but here's what is known about the hazard the SSF poses to the ACGSF:

1) The unique geologic setting of the ACGSF presents a hazard where 114 high pressure gas wells (near the end of 2015) crossed the potentially earthquake active SSF at shallow subsurface depths to reach the deeper storage reservoir.
2) To the west the SSF merges with the Oak Ridge and Santa Rosa faults, and to the east the SSF merges with the Sierra Madre fault. The Oak Ridge fault shows evidence along its trace for Holocene and late Quaternary surface rupture, and the Santa Rosa fault shows evidence for Holocene surface rupture (CGS, 2010). A portion of the Sierra Madre fault produced a very damaging earthquake with surface rupture in 1971 (Sylmar, M_W=6.4-6.7) and along other portions the fault shows evidence for Holocene and late Quaternary surface rupture (CGS, 2010). These on strike connections increase the likelihood that the SSF is an active segment of a regional earthquake fault system.
3) The ACGSF is located in one of the most seismically active areas of southern California as shown by the nearby and damaging 1971 Sylmar and 1994 Northridge earthquakes.
4) Numerous published geologic and seismological studies of the SSF conclude that this fault has a high, late Quaternary slip-rate relative to other southern California faults (with the exception of the San Andreas fault). The Third Uniform California Earthquake Rupture Forecast (UCERF3, 2015) shows the SSF's average slip (fault movement) is 2.9 mm/yr. Yeats (2001) states the SSF had 4.9-5.9 km of slip during the last 600,000-700,000 years that yields the exceptionally high slip-rate of 7.0-9.8 mm/yr. This rate is nearly a plate boundary rate and roughly 1/3 to 1/2 the convergence rate of the entire western Transverse Ranges (Namson and Davis, 1988). If this high slip rate is valid it shows the SSF is a much more significant fault rupture hazard than previously thought.

   In general a fault having a high, late Quaternary slip-rate is characterized by a higher frequency of moderate to large earthquakes if the fault lacks aseismic slip. The SSF lacks aseismic slip.
5) The Southern California Earthquake Data Center at CalTech estimates the characteristic earthquake magnitude for the SSF to be from M_W 6.6-7.3. World-wide historic records for this range of magnitudes indicate that from 0.3 to 2.8 meters fault displacement can be expected on the SSF (Wells and Coppersmith, 1994). Such large amounts of nearly instantaneous displacement are probably sufficient to comprise the integrity of many, if not all, the gas wells crossing the SSF (Figure 1). At the Wilmington oil field up to 0.25 meters of earthquake fault movement damaged numerous oil wells (Frame, 1952; see photo at end of this doucment). This movement was in response to small earthquakes with small fault displacements. The moderate to large earthquakes characteristic of the SSF will produce much larger fault displacements. It is instructive to review the photos in Frame (1952) showing the extensive casing damage caused by the small fault displacements at the Wilmington oil field.
6) Shallow intersections of the high pressure gas wells and the SSF make gas migration to the surface more likely. Many of the intersections between the SSF and gas wells at the ACGSF are at shallow depths (less than 800 m below the earth's surface). At ACGSF there are several available migration pathways from the damaged wells to the atmosphere (Figure 1): along the exterior of well casings (as occurred during the ACGSF

leak), and along established geologic migration pathways such as fracture sets and highly permeable fault zones. Vertical and near vertical fracture sets, that favor gas migration to the surface, dominate the geologic strata between the SSF and the earth's surface at the ACGSF. In addition, the potential pathway provided by the SSF zone reaches the surface very near the Porter Ranch community that was severely impacted by the ACGSF leak.

7) The California Geologic Survey recognizes via the Alquist-Priolo Act, that the eastern segment of the SSF is an earthquake and surface rupture hazard based on surface displacement during the 1971 Sylmar earthquake (CGS, 2003). Surface developers wanting to build along the SSF have been required by state and local jurisdictions for over four decades to do geologic studies of the SSF and mitigate for potential fault rupture at the earth's surface. These studies were limited to the construction sites and the adjacent property and probably do not cross the entire width of the SSF zone. They do show that late Quaternary fault rupture has occurred along much of the SSF (CGS, 2003). A rupture hazard at the surface is also a rupture hazard to wells crossing faults in the subsurface. This is because fault rupture propagates upward along the fault surface from the deeper earthquake source to the earth's surface. The regulatory limit to active fault zoning in California's Alquist-Priolo Act, which only applies to occupied structures on the earth's surface, does not diminish or negate the subsurface fault rupture hazard to gas wells. An odd and dangerous regulatory gap exists where it is difficult, if not impossible, to permit construction above the SSF but there is nothing preventing a gas storage field from being located across the SSF.
8) The recurrence time of recent fault movement on the SSF near the ACGSF is presently unclear due to its poor surface exposure, extensive landslide deposits covering much of the fault zone, a wide and complex shear zone with two major splays, and limited fault trenching-all of which constrain surface-based paleoseismic knowledge.
9) Given the shape of the SSF and its splays at depth it is unlikely that new wells can be drilled to avoid crossing the SSF to reach the storage reservoir.

Hazard and risk reviews of the safety of the ACGSF should always keep in mind two distinctive features of the field: 1) It is located very close to a large urban area, and 2) the field is developed across a known earthquake hazard, the Santa Susana fault (SSF).

Summary: Earthquake fault displacement across gas wells and other seismic hazards are threats to the safety of natural storage fields. The potential impacts of these hazards are very significant at local and national levels. RP 1171 is insufficient with regard to seismic hazards, their impacts and risks, and provides little guidance to the mitigation, safe operation, and emergency procedures from these hazards. The nation needs regulations and guidance that will measure the wisdom and safety of siting natural gas storage fields across earthquake faults.

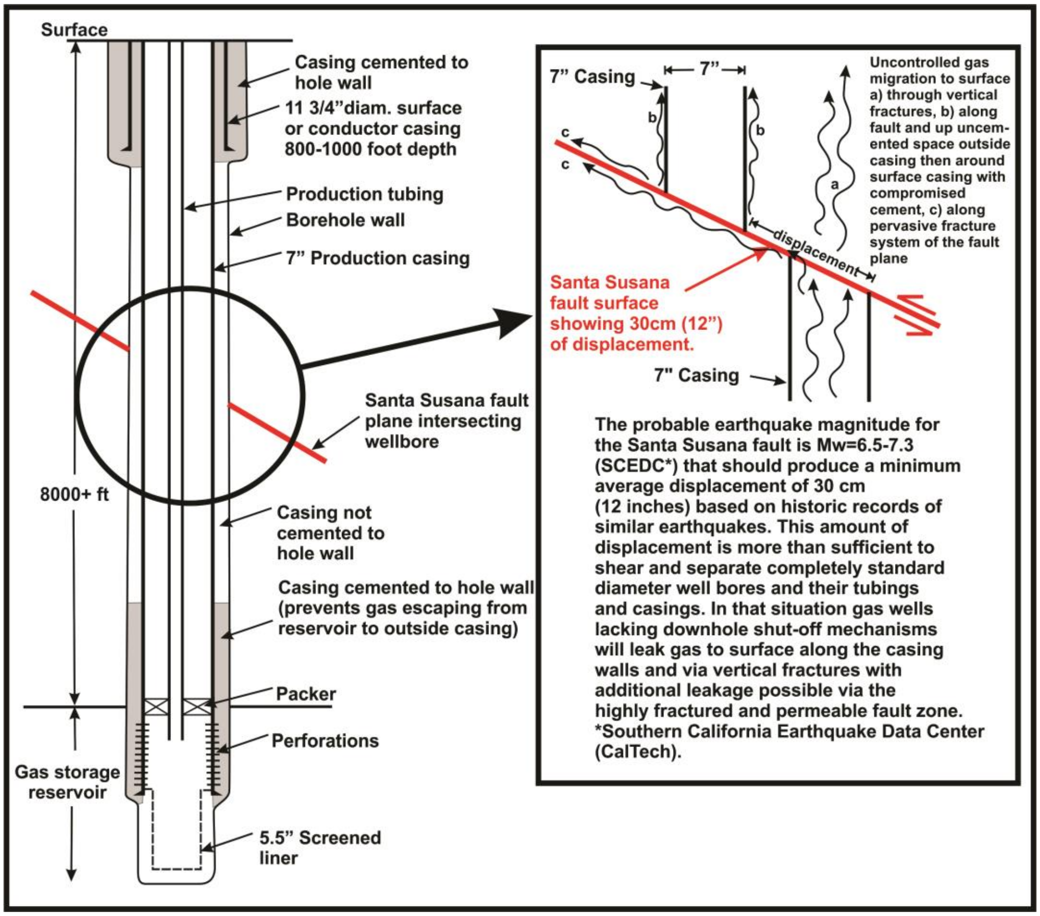

Figure 1. Well schematic showing a gas storage well at the Aliso Canyon Gas Storage Field on the left. Diagram on the right shows a postulated earthquake sourced fault displacement along the Santa Susana fault offsetting the well and postulated methane migration pathways to the atmosphere from the damaged well.

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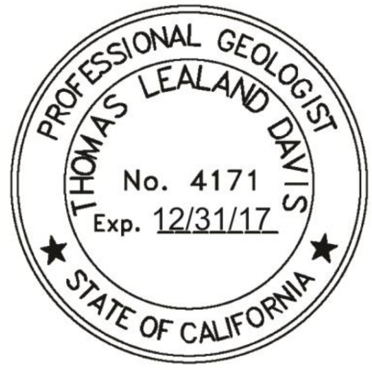

References:

API, 2015, American Petroleum Institute, Functional Integrity of Natural Gas Storage in Depleted Hydrocarbon Reservoirs and Aquifer Reservoirs, API Recommended Practice 1171, First Edition, September, 2015.

CGS, 2003, Fault investigations reports for development sites within Alquist-Priolo earthquake fault zones in southern California, 1974-2003, California Department of Conservation, California Geological Survey (CGS), CD 2003-02.

________, 2010, Fault Activity Map of California: California Geologic Survey, http://maps.conservation.ca.gov/cgs/fam/

Davis, T.L., 2016a, Well integrity and active faulting: presentation at the Workshop on Well Integrity for Natural Gas Storage in Depleted Reservoirs and Aquifers, U.S. DOE National Laboratories, Broomfield, CO, July 12-13, 2016; power point presentation available: http://eesa.lbl.gov/wellintegrity/agendapresentations/ http://geologicmapsfoundation.org/publications.html

________, 2016b, The Santa Susana fault, Aliso Canyon gas storage field, southern California-possible fault rupture hazard, gas well integrity, and regulatory implications (abstract): Joint Annual Meeting of Pacific and Rocky Mountains Sections American Association of Petroleum Geologists (AAPG) Las Vegas, NV, October 2-5, 2016, http://geologicmapsfoundation.org/publications.html

________, 2016c, Fault displacement hazard at natural gas storage fields-a future research and regulatory direction: presentation at the Fault Displacement Hazard Analysis Workshop, December 8 – 9, 2016, USGS Menlo Park, CA, http://geologicmapsfoundation.org/publications.html

DOE (Department of Energy), 2016, Ensuring Safe and Reliable Underground Natural Gas Storage, Final Report of the Interagency Task Force on Natural Gas Storage Safety, October 24, 2016, 83 p.

DOGGR, 2016, Divisison of Oil, Gas, and Geothermal Resources, State of California, Discussion Draft for safe operation of gas storage fields in California following the ACGSF leak: (http://www.conservation.ca.gov/dog/Documents/GasStorage/Public%20Discussion%20Draft%20-Requirements%20for%20Underground%20Gas%20Storage%20Proj.pdf).

Frame, R.G., 1952, Earthquake damage, its cause and prevention in the Wilmington oil field: Summary of Operations, California Division of Oil and Gas, v. 38, p.5-15.

GMF, 2017, Geologic Maps Foundation's comments on Supplement to SoCalGas' Storage Risk Management Plan #2, (10/11/2016), and shown as Attachment B to Letter from Southern California Gas to DOGGR and CPUC, dated November 1, 2016; submitted to DOGGR February 6, 2017.

Harris, K., and Walker, A., 2016, California Division of Oil, Gas, & Geothermal Resources (DOGGR) Response to Aliso Canyon Gas Leak, US DOE National Laboratories Workshop on Well Integrity for Natural Gas Storage in Depleted Reservoirs and Aquifers, Broomfield, CO, July 12-13, 2016.

Namson, J.S. and Davis, T.L., 1988, Structural transect of the western Transverse Ranges, California: implications for lithospheric kinematics and seismic risk evaluation: Geology, v.16, p.675-679.

NRC (United States Nuclear Regulatory Commission), Seismic and Geologic Siting Criteria for Nuclear Power Plants, 10 CFR-Appendix A to Part 100—Reactor Site Criteria, https://www.nrc.gov/reading-rm/doc-collections/cfr/part100/full-text.html.

PHMSA, 2011, Pipeline and Hazardous Material Safety Administration (DOT-Department of Transportation), 49 CFR (Code of Federal Regulations) 192.900 series, Subpart O—Gas Transmission Pipeline Integrity Management, 2011 edition

SMRP #2, 2016, Supplement to SoCalGas' Storage Risk Management Plan #2, Southern California Gas Company, ftp://ftp.consrv.ca.gov/pub/oil/SCG_Attachment/B/4_supplement_socalgas_storage_risk_management_plan2_10-11-2016.pdf

UCERF3, 2015, 3d Uniform California Earthquake Rupture Forecast, Version 3: Working Group on California Earthquake Probabilities (WGCEP), with collaboration of the U.S. Geological Survey, the California Geological Survey, and the Southern California Earthquake Center, Appendix B (PDF, 1.8 MB), Geologic- Slip-Rate Data and Geologic Deformation Model, By Timothy E. Dawson, and Ray J. Weldon, II, Table B1 (XLSX, 185 KB).

Wells, D.L. and Coppersmith, K.J., 1994, New Empirical Relationships among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement, Bulletin of the Seismological Society of America, Vol. 84, No. 4, pp. 974-1002, August 1994.

Yeats, R.S., 2001, Neogene tectonics of the east Ventura and San Fernando basins, California: an overview: in T.L.Wright and R.S.Yeats eds., Geology and tectonics of the San Fernando Valley and east Ventura basin, California, Pacific Section American Association of Petroleum Geologists, Guidebook 77, p. 9-36.

PLATE IV. Union Pacific Railroad Company well No. "Union Pacific" 403, Sec. 3, T. 5 S., R. 13 W., S. B. B. & M. Deformation of 10¾" casing at 1701' ("K_1"). Recovered by washover tool. Date: February 23, 1950.

Oil field casing damage caused by small fault displacement at the Wilmington oil field (Frame, 1952).